Date Palm Pests and Diseases - Integrated Management Guide

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M. El Bouhssini and J.R. Faleiro (Editors)

مركز خدمات المزارعين بأبوظبي
ABU DHABI FARMERS' SERVICES CENTRE

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Science for resilient livelihoods in dry areas

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Foreword

Date palm (*Phoenix dactylifera* L.) is a major fruit crop in the Middle East and North Africa (MENA). The crop's tolerance to high temperature, drought, and salinity makes it suitable to the harsh environment in the MENA region. Date palm is currently cultivated in nearly 30 countries on the Asian, African, American, and Australasian continents. There are over 100 million date palms worldwide, of which 60% are in the MENA region. Dates provide rural livelihood security to millions of farmers in the arid regions of the world and are of significance to human nutrition, due to their high content of essential nutrients. The world production of dates has increased from 1.8 million tons in 1962 to over 8.0 million tons at present.

Climate change due to global warming has impacted the flora and fauna worldwide, especially in arid zones. This has significantly changed the pest and disease complex of date palm, calling for the implementation of climate resilient pest and disease management programs. It is estimated that over 50% of the date palm plantations are young, below the age of 20 years offering an ideal situation for pests like red palm weevil, *Rhynchophorus ferrugineus* Olivier to establish and proliferate. On the other hand, in older plantations, where irrigation may be scarce the long horn beetle, Jebusea hammerschmidti Reich is emerging as a challenge. Bayoud is considered the most serious disease of date palm, especially in Morocco and Algeria, where it has destroyed millions of date palms. Another major disease that is fast emerging is Al Wijam in the Gulf region.

Integrated Pest Management, which has an ecological base, focuses on the use of a wide range of pest control options instead of relying only on the use of pesticides. Developing or implementing an IPM program for a crop involves a systematic application of knowledge about the crop and the pests involved. This guide on date palm IPM is a comprehensive overview on the biology (life cycle, damage, losses, geographical distribution, and host range) and management of major pests and diseases of date palms, besides addressing issues related to farming practices in relation to pest and disease management.

This guide also addresses important topics of date palm IPM programs, including the concept of threshold-based pest management. Furthermore, this publication highlights the guidelines and methodologies for pest surveillance, design and analysis of common IPM experiments, application of geoinformatics in developing distribution and risk maps for the management of pests and diseases.

The IPM program on date palm should be based on real, field-specific situations and feasible solutions. This IPM guide on date palm offers a sustainable and scientific approach to managing date palm pests and diseases. The approach proposed in this guide to control major pests and diseases of date palm is flexible enough to accommodate the changing demands of agriculture, commerce, and society and will be useful to farmers, pest managers and others involved in the date palm sector.

The publication of this guide is a result of the fruitful collaboration on date palm production system for the last decade between the Gulf Cooperation Council (GCC) countries, Abu Dhabi Food Control Authority (ADFCA) and the International Center for Agricultural Research in the Dry Areas (ICARDA). This book also benefited from the results of the IFAD funded project in Iraq on "improved livelihoods of small farmers in Iraq through integrated pest management and organic fertilization".

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Date: November 2018

Preface

Date palm *Phoenix dactylifera* L. production has a significant share in the food security particularly for rural communities in the arid regions of the world, mainly in the Middle East and North Africa. Date production in these regions has witnessed increasing importance as it makes a substantial contribution in enhancing food security, reducing unemployment, and strengthening income generation in rural areas. There are over 100 million date palms with an annual production of nearly 8.0 million tones. The crop also contributes to crop diversification, land reclamation, and control of desertification. Increasing cultivation of date palm in the recent years as a monocrop has resulted in new challenges, including the emergence of pests and diseases, which requires the development of sustainable pest and disease management programs. This guide presents the latest information on date palm Integrated Pest Management (IPM) programs by leading authorities in the field. The topics covered include the basic principles and concepts of IPM, guidelines and methodologies for pest and disease surveillance, design and analysis of common IPM experiments, application of geoinformatics in mapping of pests and diseases, management of key insect pests, mites and diseases, besides addressing the importance of date palm field operations in reducing pest and disease losses. Increasing trade and rapid transportation has resulted in invasive species being detected and reported at a scale like never before. In this context, surveillance and quarantine programs are becoming increasingly important. This field guide on date palm IPM describes the distribution, host range, damage symptoms, economic importance and biology of major insect pests, diseases and mites of date palm. Furthermore, the guide also presents recent innovative and novel pest management techniques in date palm, including population monitoring, cultural control, host plant resistance, biological control, chemical control, role of semiochemicals in date palm IPM and also highlights emerging strategies in combating major diseases and mites of date palm.

We wish to record our deep appreciation for the support provided by the Gulf Cooperation Council (GCC), Abu Dhabi Food Control Authority (ADFCA), and the International Center for Agricultural Research in the Dry Areas (ICARDA) in publishing this guide on date palm IPM.

Editors

Mustapha El Bouhssini

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This publication also benefited from the results of the IFAD funded project in Iraq "improved livelihoods of small farmers in Iraq through integrated pest management and organic fertilization", and this is acknowledged.

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About the Editors

Dr. Mustapha El Bouhssini completed his **B.S. in Plant Protection** (1980) at the National School of Agriculture, Meknes, Morocco. After working for three years at the National Institute of Agricultural Research, he joined **Kansas State University,** Manhattan, USA, where he earned his **M.S.** (1986) and **Ph.D** (1992) degrees. In 1992, he returned to Morocco and worked as an Entomologist until 1996 at the Dryland Agricultural Research Center in Settat, Morocco. In 1996 Mustapha joined the International Center for Agricultural Research in the Dry Areas (ICARDA), where he has been leading integrated pest management (IPM) program in North Africa, West and Central Asia (CWANA). Mustapha also serves as Adjunct Professor at the Entomology Department, Kansas State University, since December 2005. About two decades of dedicated work has yielded significant contributions to the development of IPM options that are now being increasingly used in CWANA. The outcomes from this IPM work have been documented in refereed publications (110), *proceedings* (30), *newsletters and extension publications* (15), *books* (5) and *book chapters* (8), *and voluntary and invited presentations* (150 +) at international and regional meetings worldwide. He also serves as a reviewer for a number of entomology and plant protection journals. He has been heavily involved in human resources development, including giving short-term training courses, mentoring individual trainees, and supervising graduate students work (20 MSc. 16Ph.D). Over 500 junior scientists and technicians benefited from these training courses, either at ICARDA headquarters or in mandate countries. He has also participated in preparing teaching and practical educational materials, including lecture notes, manuals, leaflets, and field guides in English, French and Arabic**.** Based on his scientific achievements in the area of entomology, Mustapha has been recognized with a number of awards, including *Lifetime Achievement Award* in plant resistance to insects from the International Association of Plant Resistance to Insects (2018), Distinguished Scientist Award from the Entomological Society of America-International Branch (2014), Distinguished Alumnus Award from the Entomology Department, Kansas State University (2014), International Plant Protection Award of Distinction from the International Association for the Plant Protection Sciences (2007) and the ICARDA Scientist of the Year (1998).

Dr. Jose Romeno Faleiro obtained his **Ph.D** in Entomology from the Indian Agricultural Research Institute, New Delhi during 1985 and specializes in tropical insect pest management. He began his professional career as Scientist (Entomology) during May, 1985 with the Indian Council of Agricultural Research (ICAR). He is renowned for his work on the Red Palm Weevil (RPW), which goes back over two decades, when he was deputed as a member of the Indian Technical Team on the control of RPW during 1993 for a period of five years by Government of India to the Ministry of Agriculture in Saudi Arabia, where he assisted in planning, implementing and supervising the first area-wide control program against RPW.

Over the years Dr. Faleiro has led Research Projects on IPM/RPW in India (ICAR) and Saudi Arabia (Food and Agriculture Organization of the UN and King Faisal University). He has also widely published his research on diverse aspects of IPM in internationally renowned peer reviewed Journals besides contributing book chapters, and presenting invited talks on RPW in several countries.

Since 2008, he has completed several consultancy assignments for FAO on RPW in different date producing countries of the Near East and North Africa, including Saudi Arabia, UAE, Yemen, Morocco, Libya, Tunisia, Mauritania, and Egypt. In recognition of his work on RPW in the date palm sector, Dr. Faleiro received the prestigious “Khalifa International Date Palm Award” from the Government of the United Arab Emirates during 2015.

Chapter I

Integrated Pest Management: Economic Threshold and Economic Injury Level

Chapter I

Integrated Pest Management: Economic Threshold and Economic Injury Level

Mustapha El-Bouhssini[1] and Abdul Nasser Trissi[2]

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1. Integrated Pest Management

Integrated Pest Management (IPM) is defined as an ecosystem approach to crop production and protection, which combines different management strategies and practices to grow healthy crops and to minimize the use of pesticides (FAOSTAT, 2012). Therefore, IPM employs the best combination of control tactics for a given pest problem, when compared with the crop yield, profit and safety of other alternatives (Kenmore et al., 1985). The United States Environment Protection Agency (2012) defined IPM as an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. Sandler (2010) defined IPM as the intelligent selection and use of pest control actions that ensure positive economic, ecological, and sociological outcomes. Thus, and in the case of date palm, IPM could be a broad-based ecological approach to structural and agricultural control that integrates pesticides into a management system, incorporating a wide range of practices for economic pest control. A successful IPM program requires proper identification of the pest and knowledge of its biology, ecology, sampling and monitoring of its population for developing appropriate actions and identifying thresholds. IPM approaches combine elements of plant resistance, chemical, semiochemical, biological and microbial control. In this context, an assessment of the pest complex and associated biological control agents is essential.

2. Sampling and decision making

2.1. Sampling procedure

Sampling in order to assess the population of arthropods is the cornerstone of IPM. Control decisions should be based on current and accurate information about the pest population, the application cost, and the expected yield and quality loss from pest infestation. Surveillance is defined by the IPPC (International Plant Protection Convention) as 'an official process which collects and records data on pest occurrence or absence by survey, monitoring or other procedures'. According to McMaugh (2005), the survey plan should include the definition of the purpose (e.g. early detection, assurances for pest free areas, information for a commodity pest list) and the specification of the phytosanitary requirements to be met; identification of the target pest(s); identification of scope (e.g. geographical area, production system, season); identification of timing (dates, frequency, duration); in the case of commodity pest lists, the target commodity; indication of the statistical basis, (e.g., level of confidence, number of samples, selection and number of sites, frequency of sampling, assumptions); description of survey methodology and quality management, including an explanation of the sampling procedures (e.g., attractant trapping, whole plant sampling, visual inspection, sample collection and laboratory analysis), the procedure would be determined by the biology of the pest or purpose of the survey, diagnostic procedures and reporting procedures. For example, the red palm weevil (RPW), *Rhynchophorus ferrugineus*, native in South Asia, has over the last two decades invaded several Middle Eastern countries and, from there, it has moved to Africa and Europe, mainly due to the movement of infested planting material (Faleiro, 2006). Pest status and an early detection survey of RPW on palm trees was conducted in Syria in 2012 and was recorded in two coastal provinces (Al Kadour et al., 2014).

2.2. Evaluating control decisions

Sampling provides information on pest densities, but knowledge of current pest densities is not enough to justify control action. Concepts used in this decision process are the economic threshold (ET) and the economic injury level (EIL).

2.2.1. Economic injury level (EIL)

Stern et al. (1959) defined the EIL as the lowest population density that will cause economic damage; where the economic damage (ED) is the amount of injury, which will justify the cost of artificial control measures. Mumford and Norton (1984) defined ED as the density of the pest at which the loss through damage just exceeds the cost of control.

The mathematical formulae for calculating economic injury levels are simple. A general model for a range of pests that has been widely used is that of Pedigo et al. (1986).

The Economic Injury Level EIL = C / V I D K, where:

C = cost of control ($ ha^{-1}), V = market value of product ($ tonne^{-1}), I = injury per insect per production unit (e.g. % defoliation per insect h^{-1}), D = damage per unit injury (tonnes of reduction ha^{-1} = % defoliation), and K = control coefficient (the percentage reduction in pest attack).

The EIL changes if any of the component factors changes. For example, if the control of the cost increases, it will take increased pest infestations and subsequently more loss in yield to justify control action; therefore, the EIL increases. Also, the market value is another factor that causes EIL to change. If the product price declines, more pests and damage can be tolerated before the amount of loss becomes equal to the control costs; thus, the EIL increases.

However, obtaining the above information to incorporate into the formula is not easy. It is especially difficult where natural enemies are involved in population regulation, where numerous applications of insecticide are required during a season or where damage can be caused at different stages of plant growth (Mumford and Norton, 1984).

In addition, the total cost includes only the cost of each management practice previously used. However, more recently, there is a growing appreciation that some management actions also bear an environmental cost. If these environmental costs (e.g. the cost of pollution or of destroying non-target populations with chemical insecticides) can be assessed, then it is possible to include these costs in the variable C. By including these environmental costs in C, the EIL of some pests may be increased. Such additional costs included in the EIL may reduce the frequency of insecticide applications. Alternative methods with lower environmental costs may become economically possible (Pedigo and Higley, 1992).

2.2.2. Economic threshold (ET)

Economic threshold (ET) is defined as the level of pest population density at which the pesticide use is justified (Stern et al., 1959). In other words, it is the pest density at which action should be taken to prevent a pest population from increasing to the EIL. The ET is sometimes called the action threshold. Below this level of pest population, no significant economic loss is caused to the crop, so increasing costs for pesticide use are not justified. Above the threshold, economic losses from pests exceed the incurred pest control costs.

In practice, there are different types of economic thresholds, generally based on how they have been determined (Poston et al., 1983; Morse and Buhler, 1997). According to Morse and Buhler (1997), the deferent types include the subjective ETs (nominal and simple thresholds), which are based on field experience and logic, or calculated by quantifying the pest-host relationship in terms of pest damage potential, crop market value, control costs, and potential crop yield. Objective ETs are another type of economic threshold based on many factors, such as production system, multiple pests, and crop stress effects. The fixed ET is calculated as a fixed percentage of the EIL. The term "fixed" does not mean that these are unchanging; it means only that the percentage of the EIL is fixed and, therefore, changes with the EIL. The objective ETs are flexible over time, whereas the subjective ones are typically derived by experience or estimates. In practice, the subjective ETs are predominant (Pedigo, 1996).

Three important parameters are required to obtain the ET: (1) unit price of the crop output (P), (2) crop yield before (Yo) and after the intervention (Yi), and (3) cost of control application (C). The economic loss due to pest attack may be expressed as: $C = (Yi - Yo) * P$.

The economic losses start occuring when the costs exceed the right-hand side of the above expression. This expression may be outlined in the following form to identify the threshold level of pest attack on a particular crop.

The threshold level is given by:

T = C/PLR,

where P = Unit price of the crop output, L = Loss of crop yield per unit of pest population, R = Reduction in pest attack achieved by the pest control, and T = Level of the pest attack. Only the pest population above T justifies the application of pest controls.

3. Pest control decision

ET and EIL provide an economic basis for making pest control decisions and are rational bases for responsive or curative pest control decisions (Fig. 1). Economic thresholds have been calculated for a number of insect species. For example, the assumed economic threshold of *R. ferrugineus* is 1% of infested palms (Faleiro, 2006). The ET of the Dubas bug was estimated at 11 (first instar) per leaf, 4 (second instar) per leaf, or 1 (third to fifth instar) per leaf (Thacker et al., 2003). Unfortunately, the economic thresholds for most arthropod pests of date palm have not yet determined. Thus, more research in this area needs to be strengthened so that IPM options for key date palm pests are developed and applied by the growers.

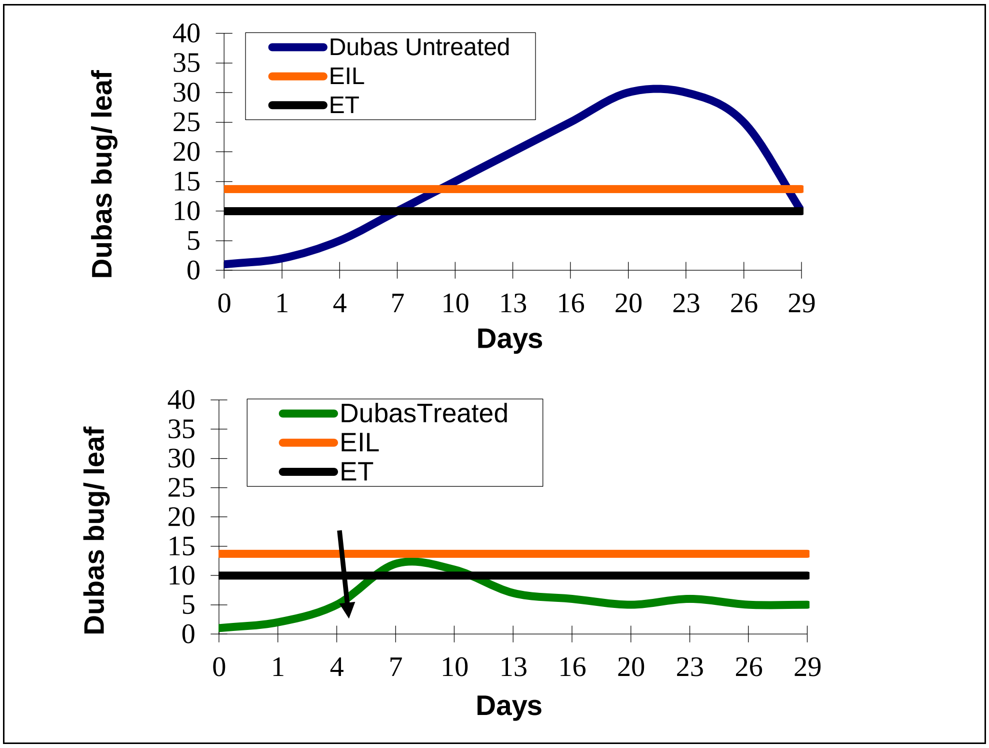

Fig. 1. The relationship between the Economic Threshold (ET) and Economic Injury Level (EIL). The arrow indicates when a pest control action is taken (case study of Dubas bug, number of first instars/leaf).

The main difficulty in establishing the EIL for date palm pests lies in determining the relationship between pest infestation and yield losses. When both EILs and ETs based on research data are lacking, entomologists often develop a nominal ET based on their field experience and limited research data. Unlike scheduling or spraying pesticides at a particular time, nominal ETs may prevent unneeded pesticides use when pest populations are small.

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Chapter II

Statistical Design and Analysis of Date Palm Insect Pest Management Experiments

Chapter II

Statistical Design and Analysis of Date Palm Insect Pest Management Experiments

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1. Introduction

This chapter discusses selected experimental design and data analyses in the context of date palm insect experiments. This chapter illustrates the number of infested fruit, an analysis of repeated measurements, and estimates the number of juvenile nematodes of two species and three sizes found in a date palm species with real data. It presents an analysis of dose-binary response data with an aim to estimate the lethal dose and it provides a World Wide Web link for computation[1]. In a date palm experiment with insect pests, one may be interested in controlling the insect population or the effects on fruit damage by applying a number of newly developed chemical or bio-control insecticides and organic preparations. A detailed and systematic description of establishing date palm in a suitable environment/land is presented by Zaid and Botes (2002) and Zaid et al. (2002). Multiple date palm trees of various varieties with similar planting date are grown such that trees of the same age are available as effective controls of insect pests, including the application of insecticides. One or many insecticides may be applied on infested date palms. Treated palms are observed by recording insect counts or yields over several days within a meaningful period of time. The general objectives in these situations are to estimate and to compare the effects of the insecticides or control measures. Integrated Pest Management (IPM) experiments on date palm may involve a wide range of objectives. Some examples include the study of the following factors: effect of pesticides on insect mortality rates and yield on a date palm variety, surveys to identify the locations with high prevalence of various date palm insect pests, associations between the pest infestation and clustering of locations for similar pest incidences, estimation of the peak period for infestation of date palm pests, modeling infested plants in order to study the spatial and temporal distribution of infestation rates.

We discuss the data analysis of the following three experiments.

Study 1: Consider a date palm experiment with a view to control the effect of *Batrachedra amydraula* Meyrick on fruit infestation using 5 insecticides on the branches. The

[1] http://geoagro.icarda.org/bss/shinyapps/ld50

experimental design was a completely randomized design with 6 treatments (including water as a control) each with six trees as replications. Thus, the insecticides were randomly applied to the trees. Fruits on three branches on each tree were examined for infested and healthy (un-infested) fruits. The observations were taken on a weekly basis. The objective was to examine and to compare the effectiveness of the insecticides in controlling the fruit infestation.

Study 2: In another study on entomopathogenic nematodes, *Steinernema feltiae* and *Heterorhabditis bacteriophora* were counted on date palms over a period of time. The nematodes of each species varied in weight (or size) and were grouped as small, medium, or large. Each species and each size group of nematodes were counted, for juveniles, on each of the five randomly chosen trees for 4 – 37 days with an interval of 3-4 days. The objective was to examine any association (interaction) between species and size of the nematodes for the infective juvenile numbers as well as their dynamics over time.

Study 3: Dose – response relationship to control small grain storage insects. Fifteen samples of seed and grains from wheat and barley infested with *Rhizopertha dominica* (Fabricius) were collected from storage facilities in the North of Syria. Three-week-old populations of *R. dominica* were reared from the samples collected and exposed to variable doses of Phosphine (PH_3), including a discriminating dose for this insect species, which is 0.03 mg/l PH_3 for 20 hrs. At the end of this fixed exposure time (20 hrs), the insects were incubated under optimal environmental growing and reproduction conditions for *R. dominica* at 70% RH and 25 ˚C for 14 days. The insect populations were then sorted into two categories: responded (killed) and non-responded (survived).

2. Experimental designs

Some basic concepts and commonly used experimental designs in date palm pest experiments are described below.

2.1. Elements of experimental designs

Treatments refer to the different factors or procedures intended to create variation in a response (responses) in an experiment, e.g., insecticides.

An experimental unit is the smallest size of the experimental material to which the treatment is applied, such that any two units may receive different treatments. For example, a palm tree is an experimental unit to which an insecticide is applied while a neighboring palm tree may be applied a different insecticide. If instead of one palm tree, one has sets of 5 trees grown together and the same treatment is applied to the set of 5 trees, then the set of 5 trees is an experimental unit, provided any such sets may receive different treatments.

Experimental Material is the collection of all experimental units for the chosen experiment. For example, all the palm trees used for the experiment.

An experimental design is used to estimate and to compare treatment effects on a response variable (e.g., fruit yield, number of infested fruits) with a high degree of precision. Even if the same treatment has been applied on a number of homogeneous experimental units, a variation in a response is observed and may have arisen due to uncontrolled causes. This is called experimental error variation and is essential to obtain the precision of an estimate of the effect or difference of means. It is desirable to have a good experimental design which estimates treatment effects/comparisons from any systematic variation in the experimental material, high precision, valid comparisons with measurable uncertainty and generalizable over a wide range of conditions or environments.

2.2. Fisher's principles of experimentation

$$r = \frac{\theta^2 t^2}{\varepsilon^2}$$

Where

θ = coefficient of variation ($\frac{\sigma}{\mu}$),

t= critical value of t- distribution (r-1 df) and approximated at 2 for 5% level of significance,

ε= maximum error set, $\left|\frac{\bar{x}-\mu}{\mu}\right|$, where $\bar{x}$ is sample mean expected from r replications, and μ is the population mean (unknown).

Some standard texts on basics of experimental designs and analysis include Cochran and Cox (1957), Gomez and Gomez (1984), Hinkelmann and Kempthorne (2005), and a review by Singh and El-Shamaa (2015).

When designing an experiment for IPM on date palm, the following situations may arise:

Situation 1: the experimental material is fully homogeneous.

If the experimental material is homogeneous, e.g., all palm trees are of same genotype, same age, and grown and cared in the same environment, one may randomly apply the experimental treatments with the same or a variable number of replications. Such a design is called Completely Randomized Design (CRD). In this situation, the total variability is partitioned through a mechanism called analysis of variance (ANOVA) into the sources of variation due to treatment and experimental error.

Situation 2: The experimental material is partly homogeneous.

If the experimental material is partly homogeneous, Local Control or Reduction of Error is done by accounting for any systematic variation in the experimental material at either the design stage or at the analysis stage or both. One example of control is practiced by forming homogeneous blocks or groups of experimental units. Such an experimental design is called a randomized complete block design (RCBD). The treatments are randomly allotted to the units within each block. The sources of variation to account for the total variation are blocks, treatments, and experimental error. Examples of blocking may be age of the trees, location of the trees, etc. After block variation has been accounted for, RCBD reduces the experimental error relative to CRD.

3. Analysis of data from designed experiments

The standard analysis of data from a design is based on expressing the response as a linear model in terms of effects of various factors, such as blocks and treatment, and an uncontrolled (experimental) error. The analysis of variance (ANOVA) is a method which partitions the total variation in the response into the components (sources of variation) in the above model. The following assumptions are validated before drawing inferences on the treatments: additivity of factors effects, constancy of error variance, normality of experimental errors, and independence of experimental errors A statistical software is used to carry out the computations. We here consider two specific cases of data analysis.

3.1. Analysis of data with repeated measures

In the context of Study 1 and in order to evaluate the effects of the five insecticides and a control on fruit damage, a completely randomized design with 6 treatments (including water as a control), each with six trees as replications, is implemented. Over 5 weeks, the numbers of infested fruits were observed for three individual branches in each tree:

Treatment	Tree	Branch	InfFruits0	InfFruits1	InfFruits2	InfFruits3	InfFruits4
Control	1	1	7	2	18	36	1
Control	1	2	4	4	5	18	5
Control	1	3	3	13	11	7	3
Control	2	1	6	6	7	7	1
Control	2	2	6	5	6	10	2
.							
.							
.							
Insecticide A	2	1	8	2	2	6	8
Insecticide A	2	2	8	7	13	16	7
Insecticide A	2	3	8	3	8	4	1
Insecticide A	3	1	12	0	1	5	7
Insecticide A	3	2	1	2	1	7	6
Insecticide A	3	3	2	2	2	9	6
Insecticide A	4	1	13	0	0	8	3
Insecticide A	4	2	17	0	0	4	5
Insecticide A	4	3	13	0	4	1	10
Insecticide A	5	1	0	1	2	0	0
Insecticide A	5	2	3	1	4	1	3

The observations on the same branch over the weeks are correlated. Furthermore, the number of fruits in the observed range may require square-root transformation before analysis using repeated measures method to test significance of insecticide and week interaction and estimate their effects. The following Genstat directives were used in the analysis:

```
AREPMEASURES [PRINT=epsilon, test; APRINT=aovtable,
information,mean,%cv; TREATMENT=Treatment;\
BLOCK=Tree.Treatment/Branch; FPROB=yes; PSE=diff, lsd,
means; LSDLEVEL=5;\
TIMEPOINTS=!(0,1,2,3,4); FACT=9]SqrtInfFruits0, \
SqrtInfFruits1,SqrtInfFruits2,SqrtInfFruits3,SqrtInfFru
its4
```

where Tree, Branch, Treatment and Week are factors standing for the date palm tree (1-6), branch (1-3), insecticides (A-D, Control) and weeks (0-4). The square-root transformed values of the number of infected fruits during weeks 0 to 4 are SqrtInfFruits0, SqrtInfFruits1, SqrtInfFruits2, SqrtInfFruits3, SqrtInfFruits4, respectively.

Partial output:

```
Box's tests for symmetry of the covariance matrix
Chi-square 24.06 on 13 degrees of freedom:        probability 0.031
F-test 1.85 on 13 and 59480 degrees of freedom:  probability 0.031
Greenhouse-Geisser epsilon
 Epsilon: 0.9346
Analysis of variance
 Variate: SqrtInfFruits0,SqrtInfFruits1,SqrtInfFruits2,SqrtInfFruits3,SqrtInfFruits4
 Source of variation        d.f.         s.s.          m.s.    v.r.    F pr.
 Tree.Treatment stratum
Treatment                   5        251.6054       50.3211  12.59   <.001
Residual                   30        119.9434        3.9981   4.26
 Tree.Treatment.Branch stratum
                           72         67.6233        0.9392   1.17
 Tree.Treatment.Branch.Time stratum
d.f. correction factor 0.9346
Time                        4        102.7442       25.6861          31.95   <.001
Treatment.Time             20        118.0055        5.9003           7.34   <.001
Residual                  408        327.9775        0.8039
Total                     539        987.8993
 (d.f. are multiplied by the correction factors before calculating F probabilities)
Tables of means
Variate: SqrtInfFruits0,SqrtInfFruits1,SqrtInfFruits2,SqrtInfFruits3,SqrtInfFruits4
Grand mean  1.781
```

Treatment

Control	Insciticide_A	Insecticide_B	Insecticide_C	Insecticide_D	Insecticide_E
2.299	2.058	0.762	2.717	1.800	1.049

Time	0	1	2	3	4
	2.450	1.281	1.632	2.111	1.430

Time	0	1	2	3	4
Treatment					
Control	2.234	1.721	2.464	3.352	1.723
Insciticide_A	2.902	1.314	1.722	2.303	2.046
Insecticide_B	1.920	0.780	0.596	0.458	0.056
Insecticide_C	2.328	1.960	3.350	3.430	2.516
Insecticide_D	2.752	0.994	1.105	2.405	1.746
Insecticide_E	2.563	0.918	0.556	0.715	0.490

Standard errors of means

Table	Treatment	Time	Treatment Time
rep.	90	108	18
e.s.e.	0.2108	0.0863	0.2831
d.f.	30	381.32	92.93

Except when comparing means with the same level(s) of

Treatment	0.2113
d.f.	381.32

Correction factors have been applied to residual d.f.(see analysis-of-variance table for details)

Least significant differences of means (5% level)

Table	Treatment	Time	Treatment Time
rep.	90	108	18
l.s.d.	0.6087	0.2428	0.8045
d.f.	30	381.32	92.93

Except when comparing means with the same level(s) of

Treatment	0.5947
d.f.	381.32

Correction factors have been applied to residual d.f.(see analysis-of-variance table for details)

In the above ANOVA table,

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	251.6054	50.3211	12.59	<.001
and					
Treatment.Time	20	118.0055	5.9003	7.34	<.001

Interactions between the treatments (insecticides and control) and week are statistically significant. Further, significant differences in overall means (main effects) of the treatments are observed as p-values (F-probability) and are very low, $P < 0.001$. Using back-transformation to the original scale of number of fruits, we need to square the means based on square-roots. However, the standard errors associated with these squared values will be different for different means. In order to compare treatments for the means, we keep the SqrtInfFruits0-4 variable means with their common standard errors.

The significant interaction indicates the choice for selecting the insecticide, which would be more effective in a desired week. Furthermore, we notice considerable variability in the means under week 0, particularly for insecticides A and B. Insecticide B controls the fruit damage significantly, ($P < 0.05$) most effectively (i.e., in relation to the control) during weeks 1, 3 and 4.

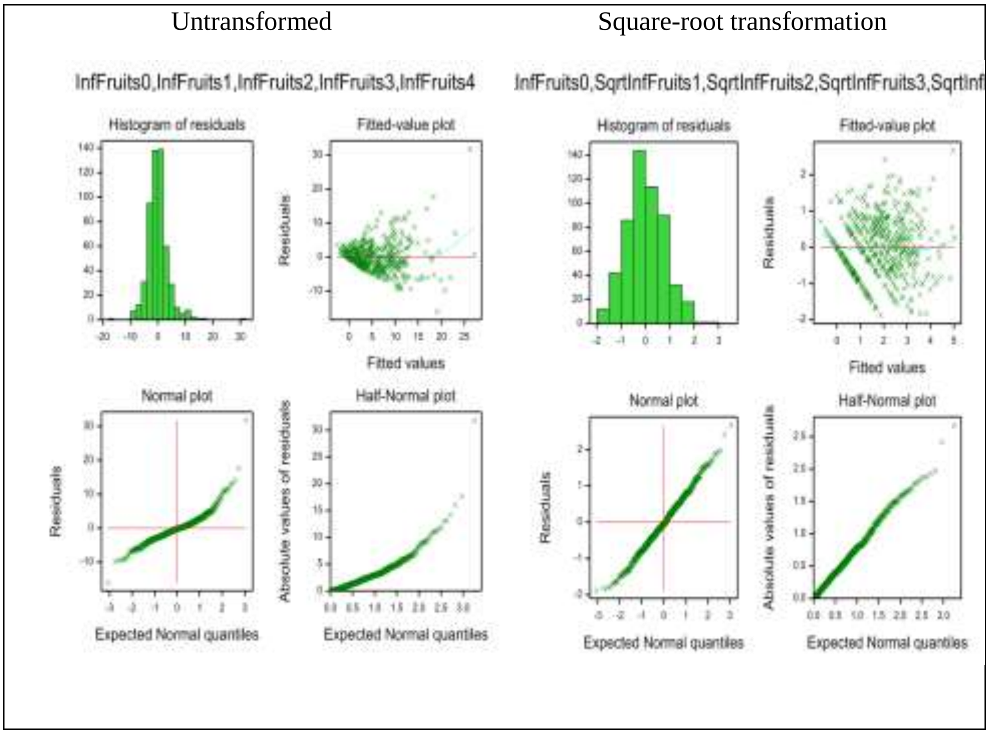

Fig.1. Residual plots for infested fruit number (left panel) and its square-root (right panel): Histogram of residuals (left upper row), residual versus fitted values (right upper row), quantile plots of residuals (left lower row) and quantile plot of absolute values of residuals (right lower row).

Study 2: In the study on nematodes of two species and different sizes, the number of infective juveniles found on a species of date palm was observed. A subset of data on the number of counts over a period of 37 days is shown below:

Nematode	Galleria Weight	Replicate	Infective Juveniles
S.feltiae	Small	1	75032
S.feltiae	Small	2	180615
S.feltiae	Small	3	51900
S.feltiae	Small	4	160500
S.feltiae	Small	5	137100
S.feltiae	Small	6	7392
S.feltiae	Small	7	94206
S.feltiae	Small	8	15428
S.feltiae	Small	9	90400
S.feltiae	Small	10	75851
S.feltiae	Medium	1	140200
S.feltiae	Medium	2	64384
S.feltiae	Medium	3	262100
S.feltiae	Medium	4	129500
S.feltiae	Medium	5	127600
S.feltiae	Medium	6	69858
S.feltiae	Medium	7	57165

The association of the average number of infective juveniles and the species and sizes can be examined using an analysis of variance. However, we also need to adjust for the heterogeneity of variances that may arise with species and size. These numbers were log-transformed and their means and variances are as follows:

Nematode	Weight	N	Mean(IJs)	Var(IJs)	Mean(LogIJs)	Var(LogIJs)
H.bacterip	Large	10	436202	2.43E+10	12.86	0.4293
H.bacterip	Medium	10	350104	5.34E+09	12.74	0.0499
H.bacterip	Small	10	244756	4.72E+09	12.37	0.0864
S.feltiae	Large	10	147778	1.02E+09	11.88	0.0427
S.feltiae	Medium	10	115029	3.53E+09	11.55	0.205
S.feltiae	Small	10	88842	3.3E+09	11.07	1.0613
p-value for homogeneity of variances				P < 0.001		P < 0.001

The resulting boxplots were as follows:

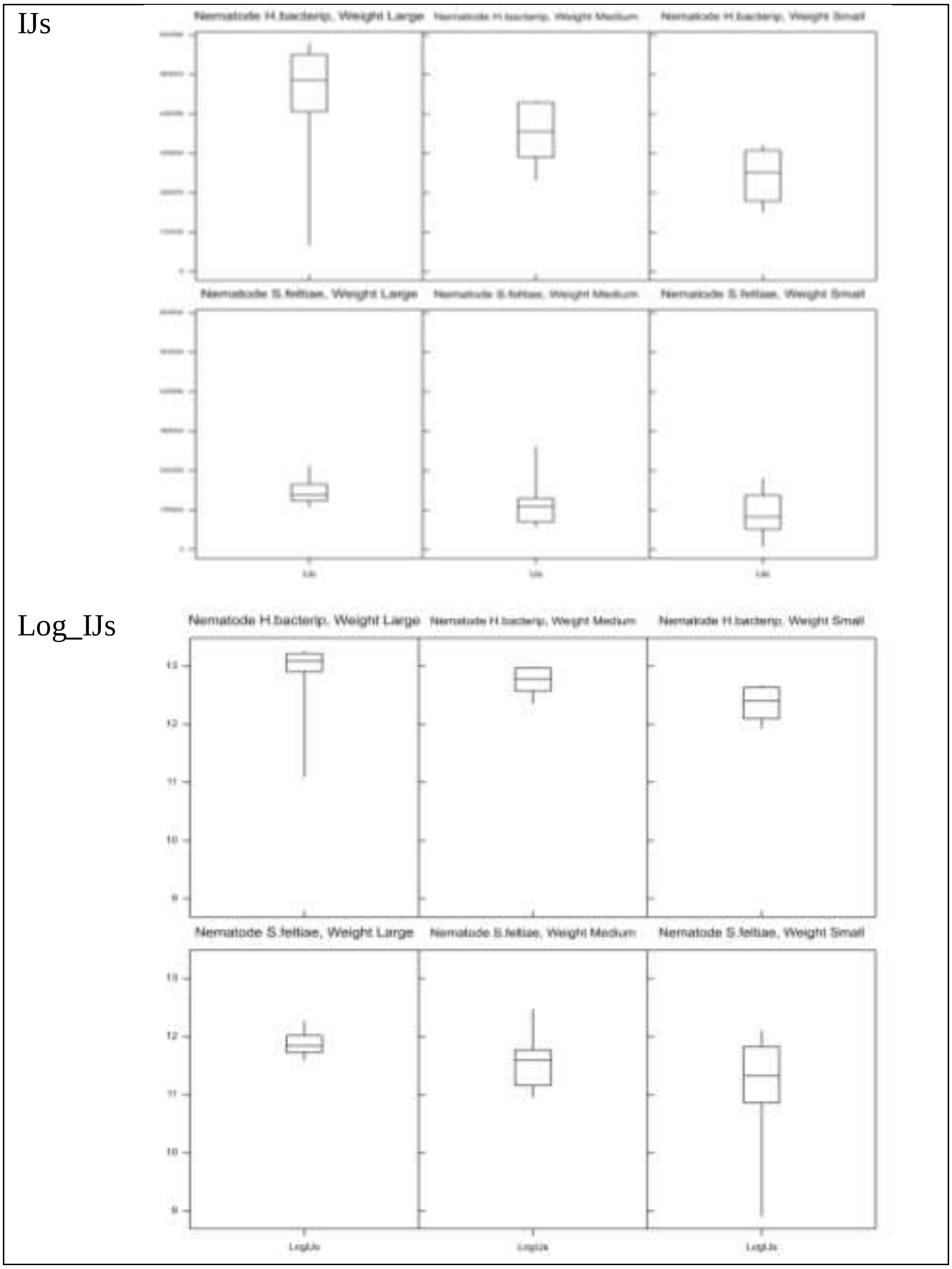

Fig.2. Boxplots of the number of infective juveniles (left panel) and its logarithmic transformation (right panel) for the two species (rows) and three sizes (columns) of the nematodes.

Ignoring the variance heterogeneity, the ANOVA gives an assessment of the association of the mean number of infective juveniles with species and size, but no interaction, at the log-transformed values. We also need to note that the means here are per replicate basis.

```
CALCULATE LogIJs=log(IJs)
BLOCK "No Blocking"
TREATMENTS Nematode*Weight
COVARIATE "No Covariate"
ANOVA [PRINT=aovtable,information,means; FACT=32;
CONTRASTS=7; PCONTRASTS=7; FPROB=yes;   PSE=diff,lsd,means;
LSDLEVEL=5] LogIJs
Analysis of variance
```

Variate: LogIJs

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Nematode	1	20.0852	20.0852	64.28	<.001
Weight	2	4.4231	2.2115	7.08	0.002
Nematode.Weight	2	0.2779	0.1389	0.44	0.643
Residual	54	16.8726	0.3125		
Total	59	41.6587			

Tables of means
Variate: LogIJs
Grand mean 12.080

Nematode	H.bacterip	S.feltiae
	12.658	11.501

Weight	Large	Medium	Small
	12.372	12.149	11.718

Nematode Weight	Large	Medium	Small
H.bacterip	12.860	12.745	12.370
S.feltiae	11.884	11.554	11.066

Standard errors of means

Table	Nematode	Weight	Nematode Weight
rep.	30	20	10
d.f.	54	54	54
e.s.e.	0.1021	0.1250	0.1768

Least significant differences of means (5% level)

Table	Nematode	Weight	Nematode Weight
rep.	30	20	10
d.f.	54	54	54
l.s.d.	0.2894	0.3544	0.5012

```
 DELETE [REDEFINE=yes] _mean, _rep, _var, _resid, _rdf,
_scode
AKEEP [FACTORIAL=9] Nematode.Weight; MEAN=_mean; REP=_rep;
VARIANCE=_var; RTERM=_resid;   STATUS=_scode
 AKEEP [FACTORIAL=9] #_resid; DF=_rdf
 AMCOMPARISON [PRINT=letter; METHOD=bonferroni;
DIRECTION=descending; PROB=0.05; FACTORIAL=9]
Nematode.Weight
```

Bonferroni test
Nematode.Weight
Comparison-wise error rate = 0.0033

		Mean
H.bacterip	Large	12.86 a
H.bacterip	Medium	12.74 a
H.bacterip	Small	12.37 ab
S.feltiae	Large	11.88 bc
S.feltiae	Medium	11.55 cd
S.feltiae	Small	11.07 d

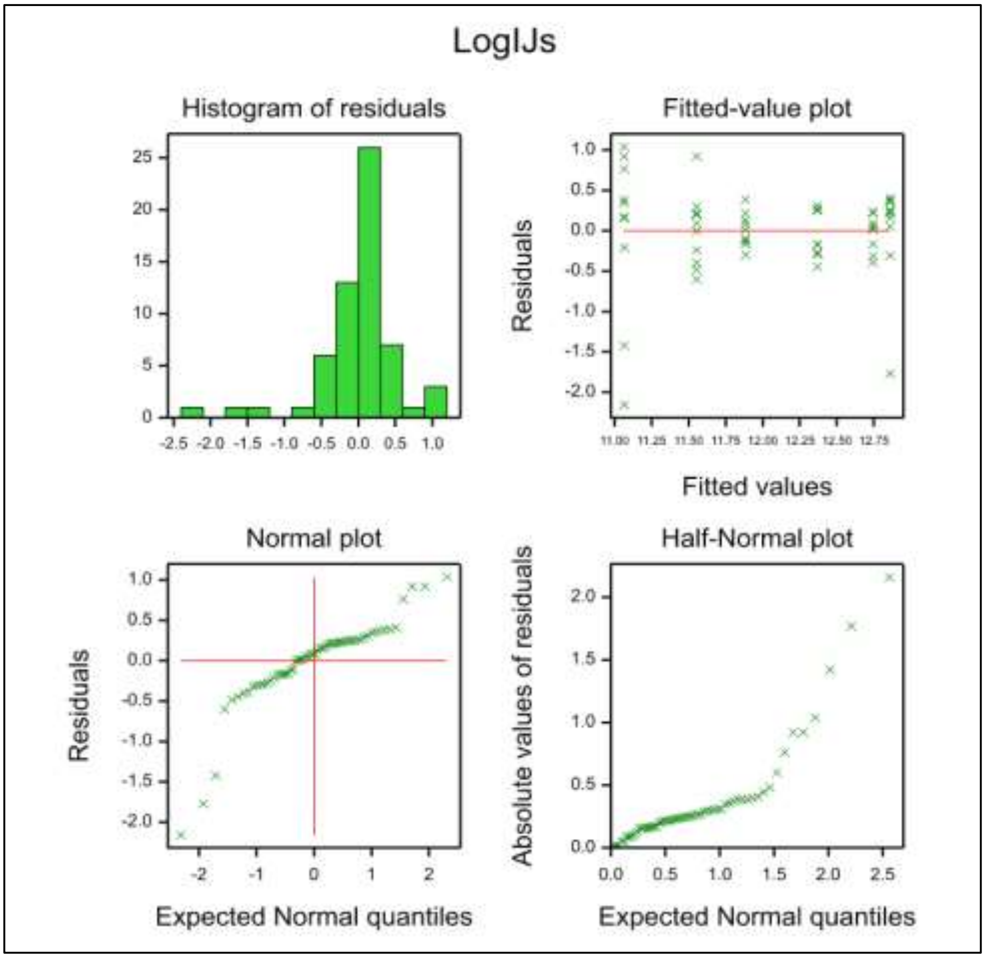

Fig.3. Residual plots of the logarithm of the number of infective juveniles: Histogram of residuals (left upper row), residual versus fitted values (right upper row), quantile plots of residuals (left lower row) and quantile plot of absolute values of residuals (right lower row)

Heterogeneity in the variances can be accounted using a weight vector Wet= (number of observation/variance) for the mean for combinations of species and size of the nematodes. In this case, we can use the residual maximum likelihood (REML). In the following output, the symbols Nematode0, Weight0, and yMn are factors for species, size, and variate for mean of logarithms of number of IJs, respectively. The vector Wet is the inverse of the variances of the means. These all are of length 6.

```
104 VComp[Fixed=Nematode0 + Weight0]
105 Reml[Weight=Wet] yMn
REML variance components analysis
Response variate: yMn
Fixed model:      Constant + Nematode0 + Weight0
Number of units:  6
Weights variate:  Wet

Residual term has been added to model
Sparse algorithm with AI optimisation
 Residual variance model
 Term      Model (order)  Parameter      Estimate  s.e.
Residual  Identity       Sigma2         0.452    0.4517

Tests for fixed effects
Sequentially adding terms to fixed model
Fixed term    Wald statistic   n.d.f.   F statistic   d.d.f.   F pr
Nematode0     235.26           1        235.26        2.0      0.004
Weight0       45.23            2        22.61         2.0      0.042

Dropping individual terms from full fixed model
Fixed term    Wald statistic   n.d.f.   F statistic   d.d.f.   F pr
Nematode0     198.60           1        198.60        2.0      0.005
Weight0       45.23            2        22.61         2.0      0.042

Table of predicted means for Nematode0
         Nematode0    H.bacterip    S.feltiae
                        12.70 11.56
Standard errors
Average:        0.04956
Maximum:        0.05658
Minimum:        0.04254

Table of predicted means for Weight0
         Weight0      Large      Medium     Small
                      12.44      12.16      11.79
Standard errors
 Average:       0.05725
Maximum:        0.06920
Minimum:        0.04917
```

Note that the p-values accounting for the heterogeneity of variances have changed from the respective values in the ANOVA table based on homogeneous variances. However, under both analysis scenarios, significant differences were observed between the species and the weight sizes. The number of IJ can be obtained using back-transformation. Using the REML analysis, the IJ for H.bacterip is 327748 [=exp(12.7)] and the IJ for S.feltiae is 104820. The IJs for the three body sizes, Large, Medium and Small, are 252711,190995, and 131927, respectively.

3.2. Estimation of doses for binary responses

Here, we present a more specific IPM situation, controlling the insect pests which cause damage to the fruits. Studying the relationship between dose and dichotomous (dead/alive, germinated/dormant, diseased/healthy) response is helpful in estimating the minimum lethal doses that will cause a desired response, for example, the dose which kills 50% of the insects.

To further our understanding by modeling the dose-response relationship, consider that a number of units (n) are exposed to a given dose (x) and suppose that m units responded. The response rate $p = m/n$ is expressed in terms of dose x . Several models could be used for the underlying mechanism of the response. One such model is cumulative and a sigmoid curve could be used to model a cumulative response rate.

Cumulative probability of response:

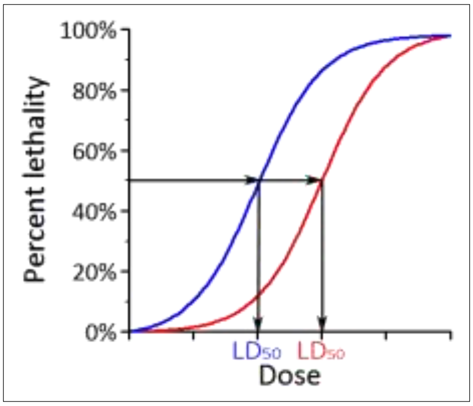

Fig. 4. A hypothetical model for mortality rate and dose relationship

Thus, a model needs to be found to satisfactorily describe the dose-response relationship. We discuss two such models.

<u>Probit analysis:</u>

The binary response is not a normal random variable. A normal random variable often forms the basis of many statistical analyses. However, one way is to contemplate the existence of a tolerance variable, say with value denoted by ς at dose x . Such a variable is latent and might be (or is assumed to be) normally distributed with unknown mean μ and variance σ^2. In this case, one can model the m responses out of n at dose x as

Probability (response at dose x) = $m/n = p$ = Cumulative normal(ζ ; μ , σ^2)= $\Pr(Tolerance \le \zeta)$ = $\Phi((\zeta-\mu)/\sigma)$.

Inverting the above equation to write in terms of normal deviate:

$$\Phi^{-1}(p) = (\zeta - \mu)/\sigma$$

Or, the tolerance $\zeta = \mu + \sigma\Phi^{-1}(p)$ is assumed linear in dose x. Or, $\mu + \sigma\Phi^{-1}(p) = \alpha + \beta x$

Thus, we have the model in observed cumulative probability

$$\Phi^{-1}(p) = [(\alpha - \mu)/\sigma] + [\beta/\sigma]x \quad \text{Or,} \quad \Phi^{-1}(p) = \alpha^* + \beta^* x$$

which is a linear function of dose x. In probit analysis, we fit this function. Once $\alpha^*\, and\, \beta^*$ are estimated, we can estimate x for a given response rate, say 50%. Such a dose is called the lethal dose LD50%, where if response stands for dead (out of total alive).

$$\Phi(\alpha^* + \beta^* x) = p = 0.5 \text{. Or, } \alpha^* + \beta^* x = \Phi^{-1}(p) = \Phi^{-1}(0.5) = 0$$

Thus, $LD(50\%) = x = -\alpha^*/\beta^*$

A detailed discussion of probit analysis is available in Finney (1952).

Logit model:

Cumulative probability can also be modeled as a logit function:

A logit function of p (0< p <1), described as "log of odds ratio", is defined as

Logit(p)=log($p/(1-p)$. It arises from a logistic function in x given as follows:

$p = 1/[1 + e^{-(\alpha+\beta x)}]$, or, $p/(1-p) = 1/e^{-(\alpha+\beta x)}$, or, $\ln(p/(1-p)) = \alpha + \beta x$, a linear function.

Using Generalized Linear model fitting programs (VSN International 2015), we can estimate α and β as well as the dose x at a given response, e.g.. 50%.

Study 3: Laboratory fumigation tests were conducted to determine the toxicity of different Phosphine dosages on storage pests (*Rhizopertha dominica*) using Probit analysis. The experimental design was a completely randomized design with three replicates of 50 insects, each exposed to seven dosages, 0.0, 2.4, 4.0, 8.0, 17.0, 21.0 and 30.0 mcg/l PH_3, covering the anticipated full range of mortality including a control.

Dose	Replicate	Insects tested	Insects killed
0.0	1	51	0
0.0	2	49	2
0.0	3	49	2
2.4	1	52	2
2.4	2	50	1
2.4	3	50	2
4.0	1	51	8
4.0	2	51	7
4.0	3	52	7
8.0	1	50	14
8.0	2	50	45

Dose	Replicate	Insects tested	Insects killed
8.0	3	49	40
17.0	1	50	48
17.0	2	52	48
17.0	3	53	48
21.0	1	50	48
21.0	2	49	42
21.0	3	50	46
30.0	1	51	50
30.0	2	50	48
30.0	3	52	50

An Analysis Tool: In order to estimate the lethal dose for a specified mortality rate (e.g., 50%), one may use the following online tool: http://geoagro.icarda.org/bss/shinyapps/ld50 (El-Shamaa, 2017). This online tool was built using the R language and the Shiny framework for web applications; it fits a Generalized Linear Model (GLM) assuming that the error distribution is binomial; and it can apply three different link functions for probability transformations (Probit, Logit, and Complementary log-log). The user can define the effective (or lethal) dose/concentration and the level of confidence interval using interactive sliders in the left bar. The above web application URL can be accessed using your favorite browser. No statistical software is needed on your computer, simply upload your data and start work on your analysis online.

For this web application, data should be in the Excel file format, listed in the first sheet using column wise style starting from the A1 cell, where the first row contains the column labels. Required inputs include three columns:

- Number of subjects (e.g. total number of insects),
- Responded number (e.g. insects got killed), and
- Explanatory variate (e.g. dose).

An extra optional column refers to a grouping factor whose levels/labels may denote, for example, different pesticides.

Clicking the “Browse” button opens a normal file pop-up window. Select your Excel data file and then click “Open”. It will take a few moments (depending on your file size and your Internet speed) until the “Upload complete” message appears at the progress bar just below the “Browse” button. The data will now be listed in the main body of the “Input Data” tab (see Fig LD50Shiny-1.png).

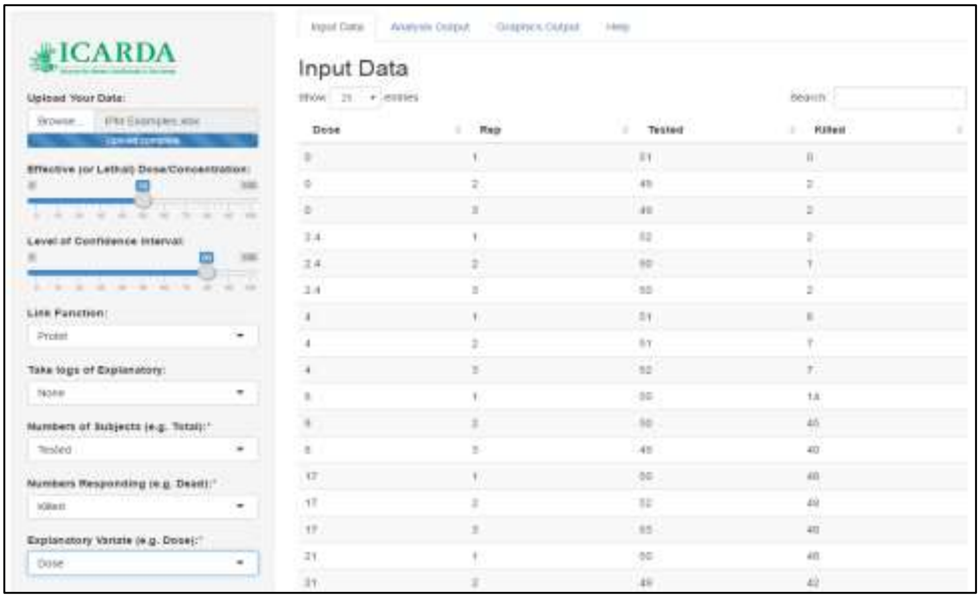

Fig. 5. A screen shot from an online tool at ICARDA: LD50Shiny-1

Analysis parameters include:

Effective (or lethal) dose/concentration (default is 50% and accepted value is in the range [0 – 100]).

Level of confidence interval (default is 80% and accepted value is in the range [0 – 100]).

Link function (default is “Probit” and available options includes also “Logit” and “Complementary log-log”).

Take logs of explanatory (default is “None” and available transformations includes log base 10 and log base e).

Once the data is uploaded, assign the required input columns to the subjects, responded, and explanatory. The web application provides a combo box for each input listing all the columns in your Excel data file in order to select the one associated with each input.

Switch to the “Analysis Output” tab to find out estimates of LDs. If there is a grouping factor, e.g., different types of pesticides, the analysis will be performed for each grouping level separately and provide standard errors, fitted model parameters, and summary statistics (see Fig LD50Shiny-2.png).

Further output can be obtained from the “Graphics Output” tab, which draws a graph of the fitted model showing the relationship of the response with the explanatory variable, including the confidence interval and LD cutting line for selected effective dose/concentration (see Fig. LD50Shiny-3). The user can download the resulting graph in high resolution (e.g., for publications) by clicking on the related button at the top of the graph. The contents of both “Analysis Output” and “Graphics Output” tabs are dynamic; in other words, if you change any of the analysis parameters in the left bar the results will affect and update instantly.

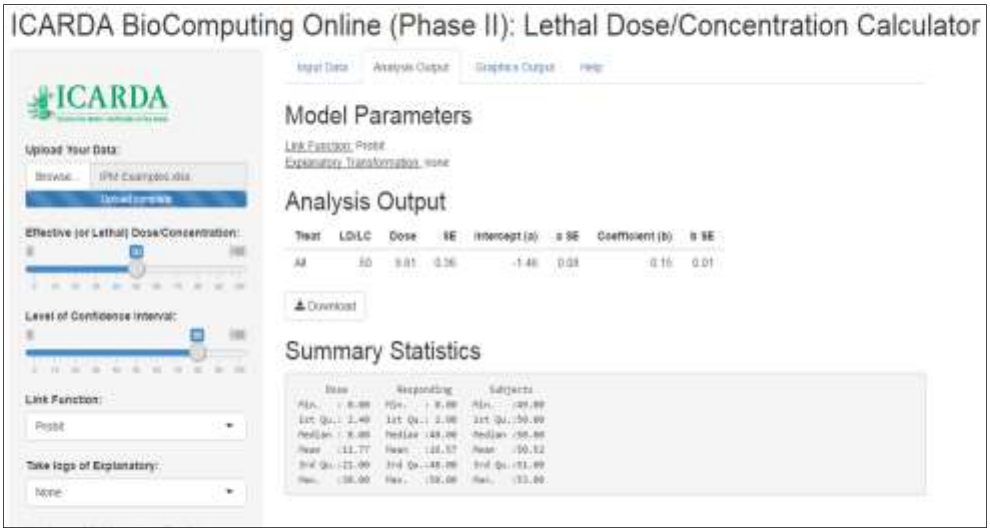

Fig.6. A screen shot from an online tool at ICARDA: LD50Shiny-2

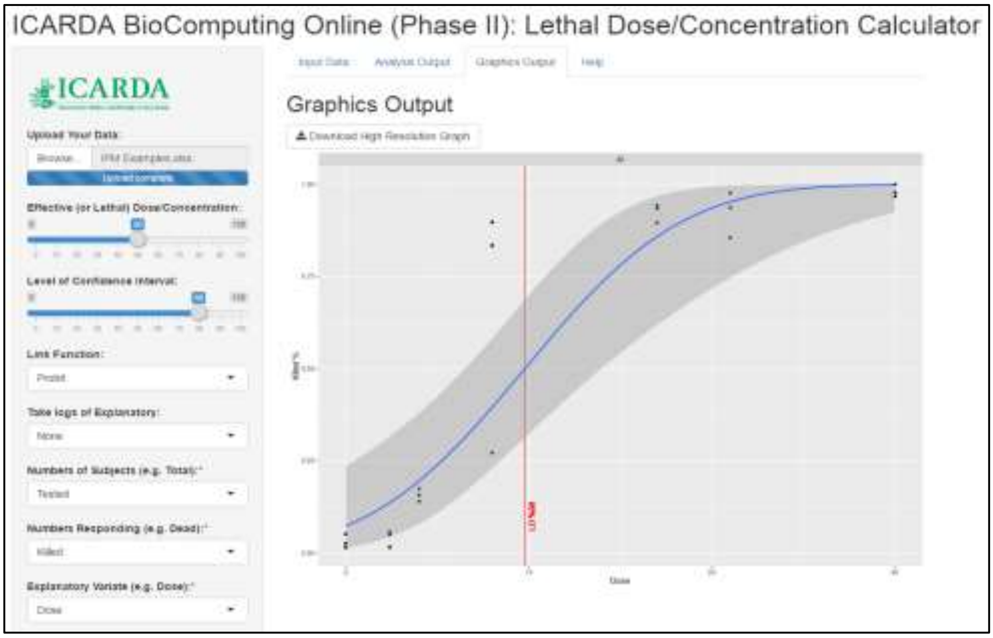

Fig.7. A screen shot from an online tool at ICARDA: LD50Shiny-3

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Chapter III

Geoinformatic Applications in Management of Pests and Diseases

Chapter III

Geoinformatic Applications in Management of Pests and Diseases

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1. Introduction

Global climate variability and change (and framing system) pose a serious threat to food and to nutritional security, with increased concerns of agricultural risks and vulnerability to pests and diseases. The nature and magnitude of the risks and threats to the vulnerability of crops to insect pests and diseases are not yet well-defined and uncertain in terms of spatio-temporal distributions under ever changing bio-physical and plant physiological conditions. This hinders the effective implementation of the pest management strategies and planning of integrated pest management (IPM). One of the foremost preventive measures is to map the vulnerability of crops to specific pests and diseases. The spatial and temporal hotspots are used to curb and to mitigate the risks in advance and/or to take action on already prevailing outbreaks in order to prevent further spread. At the larger scales, fundamental ecological concepts that address factors governing species distribution were often the foundation for the

development of pest risk and vulnerability maps at regional and global scales (Biradar et al., 2014). However, at local scales, such as farm level management of pests, the use of the regular and in-situ monitoring protocols is required to better understand the risks for the proper management at field scales. The spatial model combined geo-spatial climate data, crop and host phenology, persistence of pests and similarity conditions in conjunction with in-situ observations. This type of risk analysis helps to measure the persistence of the pests at a given time and location and the potential risks, vulnerability, and subsequent epidemic outbreaks in a given location.

Geoinformatics tools and technology (GIS, RS, GPS, modeling, web apps) can be used to collect, archive, analyze, and visualize pests and diseases efficiently and economically for the integrated pest and disease management practices. In this chapter, we outline the geoinformatics technology and its potential application in mapping, monitoring, and management of the pest risks to help with the effective implementation of the IPM. Managers/decision makers at farm level need to understand the variability of the risks at spatio-temporal scales and decide when and where to use IPM practices and relevant control measures to reduce the risk and economic damages.

2. Geoinformatics

Geospatial science, technology, and applications have become indispensable tools for modern day research, especially in studies on natural resources and sustainable agro-ecosystems. The recent proliferation of spatial data in agricultural research is due to: a) recent advances in satellite sensor technology, b) guaranteed availability of quality time-series data, c) open (free) access to high quality satellite sensor images, d) advances in processing and handling of large amounts of data, e) rapid increases in computational power, processing chain, and storage/archiving mechanisms, f) decreases in cost of proprietary software, and g) ease and increasing expertise in handling these complex datasets.

Over the last five years, there has also been an increase in the releases of high quality datasets into the public domain, resulting in greater use of spatial data and the development of machine learning algorithms for thematic research. This trend is likely to increase in the coming years and has ushered in a new era of 'open access.'

2.1. Increased resolution

The recent development of advanced sensor technology (e.g., specific bands, red-edge, yellow bands), platforms (e.g., spaceborne, airborne, UAVs), satellite constellation, (e.g., increased orbital speed (WorldView2), multiple-clone satellites (RapidEye)), onboard capacity and grounding stations, etc. has opened a new era of remote sensing applications. Just three years ago, it was a dream to get detailed high-resolution images on a daily basis. Today, one can get satellite imagery on a near-real time basis at sub-meter level (<60cm) each day for any given location. The quality and details of the imagery and therefore of the inherent information has increased dramatically (Biradar et al., 2013). Simultaneously, software companies and open-access platforms are developing the necessary calibration and processing tools to make such information easily available to a range of end users.

2.2. Improved processing

Armed with increased computational power for faster image processing, better GIS infrastructure, and a host of tools, including new algorithms for modeling, the geoinformatics community can now study and characterize agricultural production systems at scales ranging from the field to global levels. One of the primary objectives of the system research is to develop detailed, baseline databases for different "action sites" in order to characterize and understand the current status and the extent of different production systems, in terms of land use and land cover types, as well as various processes such as land degradation, water use, etc. These databases will allow researchers and stakeholders to track the progress and assess the impact of various program interventions. For example, the capability to identify different land management units or production systems through their associated spectral properties is a major step forward in our ability to classify and monitor dryland systems.

Ameliorated computational storage, processing power, and automated machine learning algorithms have been playing a greater role in enhancing pixel-based image analysis of high resolution data acquired over complex and highly variable agro-ecosystems. Of course, there are still certain limitations associated with time-variant identical spectral characteristics among different land use and land cover types. However, the combined use of higher spatial, spectral, and temporal resolution images has enabled us to produce better thematic maps with higher classification accuracy.

Fig. 1. Schematic representation of the geoinformatic application in pest management (Biradar et al., 2017).

2.3. Decreased cost of operations

In the past, the operational cost of Geoinformatics was one of the major bottle necks in adopting the technology for a wide array of applications. A major portion of the cost used to be associated with the acquisition of satellite images, followed by the cyber infrastructure for processing and handling the satellite data, and the high prices of major software packages and expertise. However, such overhead costs have been declining in the last few years due to increased open access to data, open source programs and algorithms, decreasing costs of mass storage and increased computational efficiency.

This drastic reduction in the operational costs has led researchers to use geoinformatics tools and technology across wide areas of applications in agricultural research, starting from molecular level research to landscape level assessments, ensuring food and environmental security.

3. Approaches

There are several ways and approaches to map and monitor pest risk at field to landscape and regional level (Low et al., 2016). Here, we discuss geoinformatic approaches to mapping pest risks and associated parameters in order to better manage insect pests and diseases.

Farm managers, extension workers, and often farmers need to know the precise locations of insect pests or disease infestation/infection in their fields, how abundant they are, their direction and magnitude over time, etc. in order to make good timely decisions about control measures, use of chemicals, and deployment of the work force. Without timely and localized treatment, the insect populations can grow and cause substantial yield reduction and economic damage. Alternatively, if an excessive amount of chemicals and/or IPM practices is needlessly applied to areas that pose little to no threat of insect damage, then unnecessary spray costs and other disruptions can occur and, vice versa, failing to locate real risks in the control application. This could happen without knowledge of the location of the pests on the spatio-temporal scales. Taking these points into consideration, as well as size of the farm holdings, crop types, management network, and extension systems in place, one has to select a monitoring tool, which is cost effective and easy to use from data collection to visualization and decision making.

Evaluating the risk of a particular pest or disease can be done using the source of the information (point-based) or modelling of the ecological niche for a broader scale. The information intensive hotspot approach is one of the best and accurate methods to track and to quantify the risk hotspot at spatio-temporal scales. The following assumptions were used to identify these hotspots:

Risk is directly proportional to the presence of the vulnerable host (e.g., crop, date plam);

Risk associated with the presence of the virulent agent or pests (e.g., insects, viruses);

Risk is associated with climate and biophysical conditions (temperature and precipitation patterns) being similar to the area in which the pest/disease has been epidemic.

3.1. Ground truthing

Geo-tagging field data is essential for the risk assessment of several associated variables. The simple approach is to identify areas at higher risk than others. Certain factors need to be taken into consideration for risk analysis and management. One of the easy and economical options is to use smart phones or tablets, with GPS sensors, and/or to use a smart extension diary enabled with Google APIs. Google Earth high-resolution images as background images with GPS-enabled devices can be used to mark individual trees with decent position accuracy. Another approach is to use existing or already collected field survey data and to geo-tag those data with farm coordinates to GIS field boundary to assess at farm level.

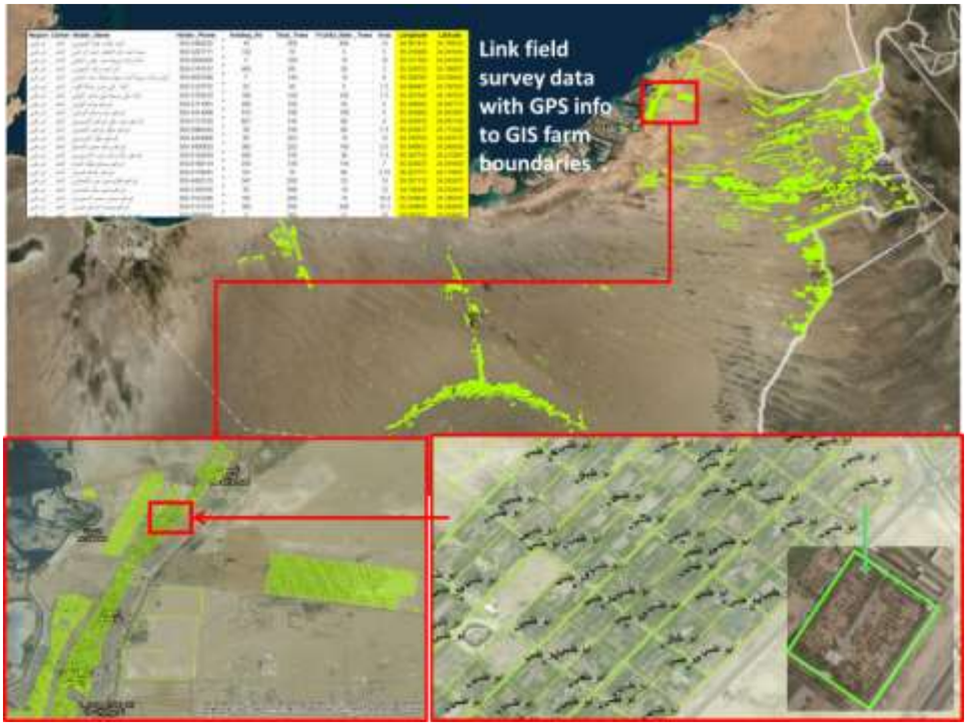

Fig. 2. Geotagging of the field data to GIS field boundary.

Fig.3. Geo-tagging individual trees using mobile devices and apps.

3.2. Spatial modeling

3.2.1. In-situ Observations and Geo-tagging

A lack of geo-referenced information (GPS readings) in field surveys is one of the major limitations for developing risk models and potential risk analysis at spatio-temporal scales. In many instances, the conventionally collected field data will not have GPS coordinates. Sometimes, even if they are collected, they are collected as separate information with no common fields to be able to link to the main database. Furthermore, the collected data could have missing information or some error while enterring the data in the field or after the survey, such as data entry errors, wrong GPS coordinates or format which lead to several errors such displaced points, missing points, double entries, etc. Secondly null values are entered as zeros, which results in misleading information, such as either a particular field is visited or visited but with no records, or records are entered as zeros as parameters with no incident, etc.

Such errors affect the result of spatial statistics and data analysis. Thus, these errors should be detected and eliminated before further analysis in the GIS platform. Preventing such errors can be done by using developed applications and apps on smart phone and tablets with general or tailor-made survey forms or questionnaires to minimize the errors and also data collection efforts, which often saves over 80% of the data collection and post survey curation and analysis.

When all field observations either at point level (tree level) or farm level are tied to their location, their actual position on the ground with the help of GPS coordinates or auto-geotaggging can bring a 3rd dimension to the data. This additional position info will help understand the spatial and temporal patterns and arrangements of the data. These geo-tagged data will help in developing GIS layers for spatial matrix analysis using various geo-statistical methods, the use of spatial-based methods allows us to consider issues of spatial error, relative location and proximity in the data, which may give us an insight into the problems and needs of investigation.

<u>Measure of distribution</u>

The simplest measure of the center of a distribution is the mean to the center, which is the direct spatial equivalent of the mean. The calculation of the mean center is similar to the calculation of the mean and involves estimating the average position of the data points with their positional information (geographic coordinates). The resulting means are the coordinates of the mean center of the distribution. In certain cases, there may be a need to consider more than just the average distribution of the data points. We might also want to take the other relative observation made at that location into account. For example, if we want to know the mean center of the infested date palm trees with a specific pest, we can use the weighted mean center of the given pest or all pests. The weighted mean center is where we weigh the calculation of the mean center using the observation at each point.

Basically, the x and y coordinates are weighted by the observations at each point. Such analysis will help in deploying appropriate IPM practices at the right place and time. For example, questions, such as where to place the pheromone traps and how many units are required etc., can be addressed by mapping hotpots of concentration (mean of the distribution) to place the traps.

Measuring dispersion

Another important measure is data dispersion, which measures how the data points in the datasets are spread around the center. Standard distance is a convenient measure of point dispersion. However, the spread about the mean center may vary in different directions. Thus, a standard deviational ellipse could be used to investigate whether there is an uneven spread in the data. This measure uses an ellipse to characterize the spread in the data, rather than the circle used in standard distance, so that it can account better for uneven directional variation. The ellipse used is centered on the mean center and is orientated such that its long axis is in the maximum direction of dispersal and the short axis (which is orthogonal to the long axis) is orientated in the minimum direction of dispersal. This parametric analysis will help to identify if there is a temporal pattern in the pest distribution. This temporal pattern will help design better IPM management practices in response to several environmental factors.

3.2.2. Hotspot analysis and risk mapping

Field data points or field boundary polygons create a map of statistically significant hotspots using GIS based hotspot matric using Getis Gi statistics (ArcGIS; ESRI 2016). It evaluates the characteristics of the input feature class to produce optimal results. The analysis generates a spatial matrix using parameters derived from characteristics of field survey and input data. The optimized hotspot analysis in the GIS domain interrogates the data to obtain the settings that will yield optimal hotspot maps. Using the distribution of the weighted features, the tool will identify an appropriate scale of analysis.

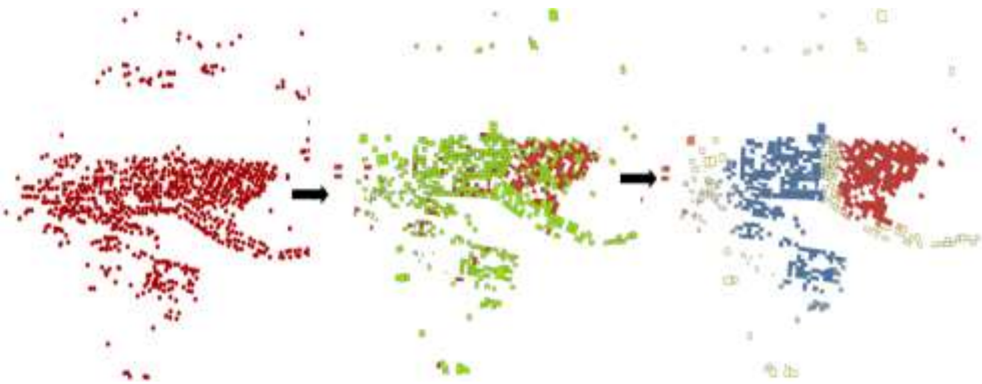

Fig. 4. Hotspot spatial analysis in GIS domain

The corrected shapefile of the date palm data needs to be projected to any metric coordinate systems, such as transverse mercator or polyconic. This is because chordal distances are based on a sphere rather than the true oblate ellipsoid shape of the earth. Given any two points on the earth's surface, the chordal distance between them is the length of a line, passing through the three dimensional earth, to connect those two points. Then, the spatial analysis is run to identify statistically significant spatial clusters of high values (more risk) and low values (low risk). It automatically aggregates incident data, identifies an appropriate scale of analysis, and corrects for both multiple testing and spatial dependence. This tool interrogates your data in order to determine settings that will produce optimal hot spot analysis results.

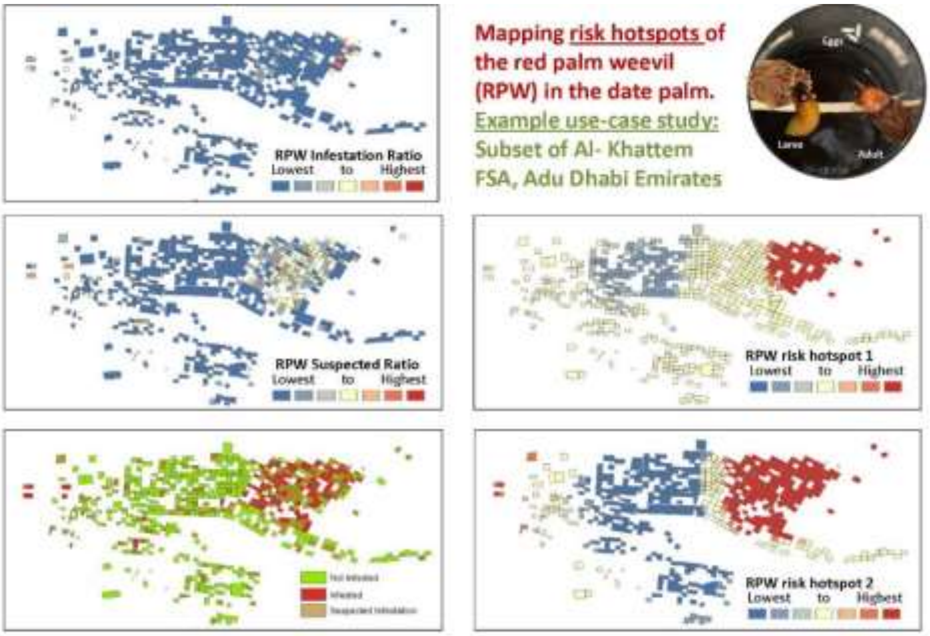

Fig. 5. Pilot case study of the Al Khattem Farmers Service Center area, Abu Dhabi showing the maps of the infested, suspected and hotspot risk maps of the red palm weevil

4. Conclusion

Recent advances in geoinformatics tools with improved processing power and algorithms have opened a new era for mapping and managing agricultural production systems and associated resources. Today, it is possible to map and characterize the date palm production systems more precisely through enhanced availability of high resolution remotely sensed data, increased use of the location analytics, GPS, mobile gadgets with institutional adoption of open-access data policies, and improved big-data analytics and web-GIS tools. These will allow better access to the knowledge needed by researchers, policy makers, and other stakeholders at the right time for a better integration of the several management practices and IPM packages. These tools will enrich an enormous amount of the field data collected over the years for designing better management practices while minimizing economic losses and ecological damages (ICARDA, 2017). The mapping of the potential risks, current and future trends and patterns will help to draw a quantitative description of the various components needed to improve overall system sustainability and productivity. It will also lead to the development and monitoring of the key indicators across a range of cross-cutting activities needed for improved pest and diseasemanagement, agronomic, and cultural practices. The resulting outcomes will lead to improved and more efficient production systems.

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Chapter IV

Management of Key Insect Pests of Date Palm

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1. IPM of Red Palm Weevil

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1.1. Scientific name

Rhynchophorus ferrugineus (Olivier); Coleoptera: Curculionidae

1.2. Description

R. ferrugineus (Olivier) is a key pest of date palm *Phoenix dactylifera* L. Worldwide, the crop is cultivated on an estimated 1 million ha with over 100 million date palms, of which 60% grow in the Arab world, mostly in the Middle East and North Africa (FAO stat, 2013). This lethal pest of palmswas first described on the coconut palm in 1906 (Lefroy, 1906) and on the date palm in 1917 (Brand, 1917). Cultural practices associated with date palm farming, such as in-groove humidity, frond and offshoot removal, crop and field sanitation, etc. influence the extent of incidence and subsequent infestation by *R. ferrugineus*. During the last three decades (since the mid-1980s), the pest has rapidly spread throughout the world through infested planting material transported for farming and ornamental gardening.This emphasizes the need to implement strict quarantine regimes to ensure the movement of pest-free planting material. *R. ferrugineus* is a hidden and lethal tissue borer of the date palm. The detection of infested palms is carried out through regular visual inspections of young date palms and it is currently managed in the date palm and other palm agro-ecosystems using a pheromone-based (ferrugineol) Integrated Pest Management (IPM) strategy.

Fig. 1. Young date palms less than 20 years of age are prone to attack by *R. ferrugineus* (Source: J R Faleiro)

1.3. Distribution

Globally, weevils constitute the most serious group of Coleopteran insect pests, attacking a diverse range of palm species (Faleiro et al., 2016). Among the *Rhynchophorus* species, the red palm weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) is the only weevil that has significantly expanded its geographical range from its original home in south and southeast Asia (Wattanpongsiri, 1966) to almost the entire world. Indeed, it has now been reported in several countries on every continent (Giblin-Davis et al., 2013). *R. ferrugineus*is has currently been reported in 45 countries (Table 1) and ecological niche modeling predicts that this pest can expand its range still further (Fiaboe et al., 2012). *R. ferrugineus* and *R. vulneratus* constitute the Asian Palm Weevils and *R.vulneratus* and *R.schach* are synonyms (Boheman, 1845; Hallett et al., 2004). *R. ferrugineus* spreads rapidly and causes widespread damage to palms, whereas *R.vulneratus* is restricted in its spread. The 2010 palm weevil report (CDFA, 2010) from Laguna Beach, California, USA indeed confirmed it to be *R. vulneratus* (red stripe palm weevil) and not *R. ferrugineus* (Rugman-Jones et al., 2013).

The global spread of *R. ferrugineus* has been rapid after it gained a foothold in date palm during the mid-1980s in the Gulf region of the Middle East. *R. ferrugineus* was discovered in UAE in 1985 (Zaid, 2002) and was subsequently reported in several date-producing countries in the region. It spread further mainly through infested planting material transported for ornamental gardening and farming (Faleiro et al., 2012; Al-Shawaf et al., 2013).

Table 1. Occurrence of Red Palm Weevil in Different Countries

Asia-Oceana			Africa	Europe	Americas
South and South East		Middle East			
India	Thailand	UAE	Egypt	Spain	Curacao Islands (Caribbean)
Pakistan	Cambodia	Qatar	Morocco	Turkey	
Sri Lanka	Vietnam	Saudi Arabia	Libya	Italy	
Myanmar	China	Kuwait	Tunisia	Greece	
	Taiwan	Oman	Mauritania	France	
	Philippines	Bahrain		Portugal	
	Malaysia	Israel		Cyprus	
	Indonesia	Palestine		Malta	
	Timor	Jordan		Georgia	
		Iran		Croatia	
		Iraq			
		Lebanon			
		Yemen			

1.4. Host range

After the mid-1980s, the host range of *R. ferrugineus* has significantly increased, from only four palm species in the mid-1950s Nirula (1956) to 40 palm species being currently reported (Anonymous, 2013 ; http://www.savealgarvepalms.com/en/weevil-facts/host-palm-trees),including *Areca catechu*, *Arenga saccharifera*, *A. engleri*, *A. pinnata*, *Bismarckia nobilis*, *Borassus flabellifer*, *B*. sp., *Brahea armata*, *B*. *edulis*, *Butia capitata*, *Calamus merrillii*, *Caryota cumingii*, *C. maxima*, *Cocos nucifera*, *Corypha utan*, (= *C*. *gebanga*, *C*. *elata*), *C*. *umbraculifera*, *Chamæerops humilis*, *Elæis guineensis*, *Livistona australis*, *L*. *decipiens*, *L*. *chinensis*, *L*. *saribus* (= *L*. *cochinchinensis*), *L*. *subglobosa*, *Metroxylon sagu*, *Oncosperma horrida*, *O*. *tigillarium*, *Phoenix canariensis*, *P*. *dactylifera*, *P*. *roebelinii,P*. *sylvestris*, *P*. *theophrastii*, *Pritchardia pacifica*, *P*. *hillebrandii*, *Ravenea rivularis*, *Roystonea regia*, *Sabal umbraculifera*, *Trachycarpus fortune*, *Washingtonia filifera*, *W*. *robusta*, *Syagrus romanzoffiana*. Among these palm species, the canary island date palm, *Phoenix canariensis*, date palm, *P. dactylifera* and coconut palm, *Cocos nucifera* are the most widely preferred hosts (Faleiro et al., 2014).

1.5. Damage and symptoms

Understanding the symptoms of damage is vital to detect palms in the early stage of attack and is key to the success of *R. ferrugineus*-IPM programmes. In the absence of any reliable *R. ferrugineus* infestation detection device, infested date palms are difficult to detect due to the hidden nature of the pest, where larval feeding results in tunnel formation and is known to cause extensive tissue damage. Therefore, the periodic visual inspection of palms using a screw driver probe is the only way to detect infested palms in the susceptible age group, before the pest completes its life cycle within the palm and adults emerge. Usually, date palms below the age of 20 are most affected, with most of the infestation being restricted to the trunk within 1m off the ground. However, in male date palms, infestation occurs in the crown, even in old palms. Infestation begins when gravid female weevils lay eggs in the palm tissue, before the damage-inflicting larvae hatch. The damage symptoms in date palm as reported by Abraham et al., 1998; *viz.*are as follows: i) oozing of brownish fluid together with frass (palm tissue excreted by feeding grubs), which has a typical fermented odor, ii) drying of infested offshoots, iii) tunneling of palm tissue by grubs, iv) presence of adults and pupae at the base of fronds, v) pupae on the ground around an infested palm, vi) drying of outer leaves and fruit bunches, and vii) toppling of the trunk in the case of very severe and extensive tissue damage. Sometimes, the ooze (brownish fluid) of a slimy liquid due to infestation by the long horn stem borer *Jebusea hammerschmidti* Reich (Coleoptera: Cerambycidae) can be mistaken for an infestation of *R. ferrugineus*. While the brownish fluid due to *R. ferrugineus*has a typical fermented odor, the secretion associated with an infestation by *J. hammerschmidti* is devoid of any fermented odor.

On-going research on detecting *R. ferrugineus* infested palms is currently centered on bioacoustic detection, chemical detection, thermal and spectral imaging (Soroker et al., 2013). Using trained sniffer dogs to detect infested palms is a possibility once an efficient training protocol has been established and a dedicated team with specially trained dogs is maintained (Nakash and Kehat, 2000; Soroker et al., 2013).

Fig.2. Training a dog to detect R. ferrugineus infested date palms at M/s Yousef Bin Abdul Latif & Sons Agriculture Co. Ltd. date plantation in Al-Qassim , Saudi Arabia (Source: J R Faleiro)

Fig. 3. Excess offshoots around the mother palm makes inspection to detect infestation difficult (Source: J. R. Faleiro)

A B

Neglected plantation (A) and flood irrigation (B) offer an ideal micro-climate for *R. ferrugineus*

A B

Frond shaving (A) and offshoot removal (B) attract female weevils for oviposition

A B

Beheaded palms (A) and closed gardens (B) are potential breeding sites for R. ferrugineus

Fig. 4. Factors that predispose date palms to *R. ferrugineus* attack (Source : J. R. Faleiro, Abdul Moneim Al-Shawaf and Sami Al-Saroj)

1.6. Economic importance

R. ferrugineus is a lethal pest of palms. Indeed, if the pest is not detected and treated in the early stage of attack, infested palms will die. If no control measures are taken to combat the pest, its spread is known to be rapid and the entire date palm groove is lost to the *R. ferrugineus* attack within 2-3 years.Infested palms exhibit extensive tissue damage in overlapping generations and multiple life stages of the pest.

Due to the lethal nature of the pest and difficulties in detecting of *R. ferrugineus*, action thresholds to initiate control measures are low and have been assigned to just 1% of infested palms in *R. ferrugineus* control programmes and only one infested palm in small date palm grooves (Faleiro, 2006; Faleiro et al., 2010)

R. ferrugineus has been designated as a category1 pest on date palm in the Middle-East by FAO and has been the most destructive insect pest of palm plantations throughout the world (Anonymous, 2004; Bertone et al., 2010). In the Gulf region of the Middle-East, the annual loss, due to eradication of severely infested palms by R. ferrugineus, has been estimated to range from US$5.18 to 25.92 million at 1 and 5% infestation, respectively (El-Sabea et al., 2009).

Fig.5. Visual symptoms of damage due to *R. ferrugineus* infestation in date palm (Source: J.R.Faleiro and Abdul Monein Al-Shawaf)

1.7. Biology and Seasonality

Female weevilsof *R. ferrugineus*lay about 250-350 creamy-white eggs (2.6 mm in length and 1.1 mm of width) inside the palm tissue, usually in cracks and crevices on the palm trunk. Egg laying is characterized by the female weevil first puncturing the palm tissue with its snout, followed by a 180^{o} turn for depositing the egg inside the puncture using its ovipositor. Palm tissue volatilesemitted from fresh injuries, due to frond and offshoot removal, attract gravid female weevils for egg laying usually to young date palms, less than 20 years old (Abraham et al., 1998). Eggs hatch after 2 to 6 days into damage inflicting grubs that tunnel the palm moving inwards towards the centre of the trunk. The larval stage lasts for 1 to 3 months with a varying number of larval instars. Subsequently, a fully-grown larva forms a cocoon and goes into pupation. The pupal stage lasts for 15-30 days after which reddish-brown adults (35 mm long and 12 mm wide) emerge, characterized by a snout, black spots on the thorax, and can live on average for up to 3 months. Adult male weevils have a tuff of bristles on the dorsal tip of the snout (Wattanapongsiri, 1966; Avand Faghih 1996; Abraham et al., 2001; Aldryhim and AlAyedh, 2015; Al-Dosary et al., 2016).

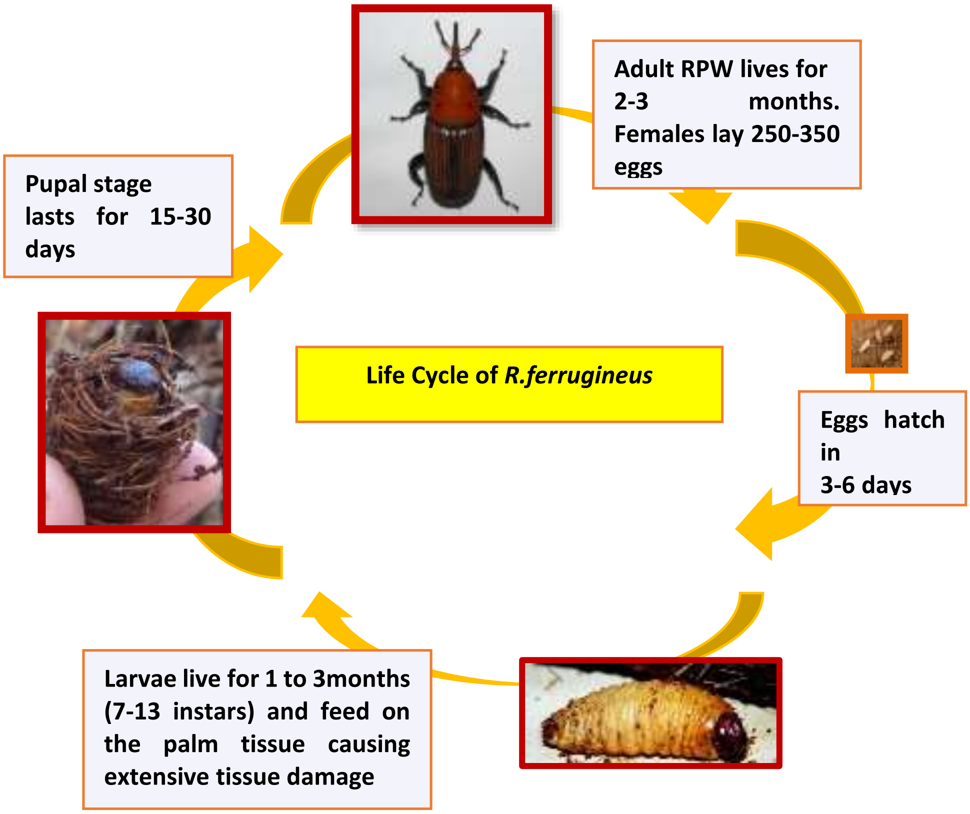

Fig. 6. Life cycle of *R. ferrugineus*

In date palm plantations of the Middle East, adult weevils are most active between March to May and again during October to November (Abraham et al., 1998; Vidyasagar et al., 2000; Soroker et al., 2005). Eggs laid during the second peak are mostly caught in the winter, resulting in fewer infestations compared to oviposition occurring during the first peak between March to May (Faleiro, 2006).

1.8. Management

Area-wide IPM of *R. ferrugineus* in date palm comprises several tactics, but revolves mainly around "trapping adult weevils using pheromone traps, regular inspection of palms to detect infestations, preventive and curative insecticide treatments and eradication (removal) of severely infested date palms". The other components of the IPM strategy for *R. ferrugineus*are crop and field sanitation, implementing strict quarantine protocols, identifying and eliminating hidden breeding sites, periodic validation of the control strategy based on weevil captures in traps and infestation reports, training of farmers and other stakeholders on the latest best IPM practices, besides adopting of *R. ferrugineus* mitigating date palm farming practices related to palm density, irrigation, and frond and offshoot removal.

1.8.1. Population monitoring

Monitoring the*R. ferrugineus* population is essential in order to locate infested palms and to initiate control measures as early as possible. Effective surveillance programmes in vast stretches of date palm plantations are possible by setting food-baited pheromone traps along roads, with one trap for every kilometer within the date palm oasis. The question pest managers often ask is 'if surveillance trapping programmes need also to be carried out in areas where the pest does not exist'. This would depend on the confidence in the control programme, including the enforcement of quarantine regulations in areas where the pest exists. However, in order to detect the presence of the pest early, it would be advisable to implement a pheromone trap based monitoring programme at least once a year during peak weevil activity (March to May or October to November) in areas where the pest does not exist. This needs to be coupled with intensive extension programmes to educate farmers and other stake holders about the symptoms of damage in date palm due to *R. ferrugineus* besides implementing strict quarantine regulations to ensure movement of pest free planting material.

1.8.2. Cultural control

Crop and field sanitation is vital to curb the build-up of the population and to sustain the levels of success where the pest is controlled (Abraham et al., 1998; Faleiro et al., 2016). Date palm farming practices influence the incidence and subsequent buildup of *R. ferrugineus* (Sallam et al., 2012). Enhanced soil moisture and flood irrigation provides temporary harborage to adults and increases the possibility of *R. ferrugineus* infestation in date palm (Aldryhim and Khalil 2003; Aldryhim and Bukiri 2003; Sallam et al., 2012).Close spacing of palms at planting and open flood irrigation enhances in-groove humidity, consequently favoring attack by *R. ferrugineus*.

Sallam et al., 2012 reported more infestations in date palms without any off shoots, indicating that by removing offshoots the palm is exposed to attack by *R. ferrugineus,* especially when the fronds are pruned and the offshoots are removed.This highlights the need to protect fresh injuries on the palm by applying insecticide as proposed by Abraham et al., 1998. At the same time, it is imperative to maintain crop sanitation by annual frond and offshoot removal, which is necessary to carry out periodic inspection of palms (at least once every 60 days) to detect infestations. Any wound to the palm tissue due to frond and offshoot removal should be immediately treated with insecticide (chlorpyriphos) to prevent female weevils from getting attracted to the site (fresh wound) for oviposition. Regular inspection of palms to detect infestations is becoming increasingly important and is now known to be the most essential component of the IPM strategy against*R. ferrugineus*.

Furthermore, finding and treating hidden breeding sites, such as cut palms (Abraham *et al*., 1998) particularly in closed gardens and other areas that are difficult to access can significantly contribute towards the control of this pest.

1.8.3. Host plant resistance

Host plant resistance, though constituting the first line of defense, is still in its infancy with regard to *R. ferrugineus* and, therefore, it is not exploited for the control of this lethal pest of palms. The currently cultivated date palm varieties are well established and a change of varieties is not readily accepted by farmers. Date palm varieties with high sugar content are known to enhance the growth and development, while cultivars with high calcium content with hard tissue inhibit the growth and development of *R. ferrugineus* (Farazmand 2002; Faleiro 2006; Al-Ayedh 2008). Varying degrees of oviposition antixenosis (non-preference) by *R. ferrugineus* has been reported in date palm cultivars (Al-Bagshi et al., 2013; Faleiro et al., 2014). However, factors governing this mechanism are yet to be fully established. Gene silencing or RNA interference (RNAi) shows great potential to control insect pests of date palm, including *R. ferrugineus,* and provides an entirely new and unique path to developing resistant plant varieties (Niblett and Bailey, 2012). Recently, Al-Ayedh et al., 2016 reported insecticidal potency of RNAi-based catalase knockdown against *R. ferrugineus* where dsRNA can cause broad-scale gene knockdown within the body of *R. ferrugineus*.

1.8.4. Biological control

Mazza et al., 2014 reported more than 50 natural enemies, including viruses, bacteria, fungi, nematodes, yeast, mites, insects and vertebrates to attack the *Rhynchophorus* weevils, noteworthy among which were fungi for inclusion in *R. ferrugineus*- IPM programs. Laboratory and semi-field cage studies showed the possibility of infecting R. *ferrugineus* adults with *Beauveria bassiana* using pheromone traps (Hajjar, 2015). The literature also suggests that Entomo-pathogenic fungi (EPF) and Entomo-pathogenic nematodes (EPN) are promising biological control agents against *R. ferrugineus* (Hanounik, 1998; Salama and

Abd-Elgawad, 2001; Abbas et al., 2001; Llácer et al., 2009; Gindin et al., 2006; Dembilio et al., 2010; Manachini et al., 2013). However, in date palm, deployment of these agents in the field has not been encouraging, probably due to the extreme climatic conditions prevailing in the arid regions of the world, where date palm is cultivated. The hidden nature of the pest also makes it difficult for EPFs and EPNs to survive the harsh climatic conditions and to reach the pest life stages deep within the palm (Al-Dosary et al., 2016).

1.8.5. Semiochemical control

Food baited pheromone (ferrugineol: Hallett et al., 1993) traps are widely used to monitor and mass trap adult *R. ferrugineus* in date palm, where most weevil captures are females, usually twice as many as male weevils (Hallett et al., 1999; Faleiro, 2006). Since pheromone trapped female weevils are known to be young, gravid, and fertile (Abraham et al., 2001), mass trappings of the pest help to curtail the build up of the*R. ferrugineus* population in the field. However, for adequate control of the pest, pheromone trapping has to be combined with other RPW-IPM techniques (El-Shafie and Faleiro, 2017). Furthermore, it is essential to adopt the best trapping practices in order to ensure efficient trapping of the pest. The following trapping protocols are to be practiced while using *R. ferrugineus* -food baited pheromone traps.

Trap Component / Character	Best Practice	Reference
Trap design	Four-window bucket trap (5-10L capacity) with no openings on the lid to prevent entry of rain water. Secure the lid of the trap to the bucket with a piece of wire. Black coloured dome shaped traps (Picusan™) capture more weevils as compared to the bucket traps.	Hallett et al., 1999; Faleiro, 2006 ; Vacas et al., 2013
Trap colour	Black	Abuagla and Al-Deeb, 2012; Al-Saoud, 2013
Trap surface	Rough outer surface	Faleiro, 2006
Food bait	Dates (200g/trap)	Faleiro and Satarkar, 2005
Ethyl Acetate	Ethyl acetate dispensers enhance captures in *R. ferrugineus* pheromone traps, but could significantly increase the cost of an area-wide control program	Oehlschlager, 1998; Al-Shagag et al., 2008; Al-Saoud, 2013; Vacas et al., 2013
Water in trap	1-2 L / trap	Faleiro, 2006; Vacas et al., 2013

Trap Component / Character	Best Practice	Reference
Trap servicing (renewal of food bait &water)	7-15 days	Faleiro, 2006
Lure	Several commercial lures are available on the market. Use most attractive and long-lasting pheromone lures. Hang the lure to the inner side of the bucket lid. Do not discard old lures in the field. These are to be brought back to the operations unit and incarnated or buried deep in the ground.	Faleiro, 2006 Faleiro, et al., 1999
Trap placement	Preferably on the ground with around half of the bucket trap inserted into the soil. Do not place traps on young palms.	Faleiro, 2006
Trap density	Monitoring: 1 trap for every Km. Mass Trapping: 1-4 traps / ha. Use service-less trapping options (Attract and Kill; Dry trap) when trap density has to be enhanced beyond 1trap/ha.	Oehlschlager, 1998; Faleiro et al., 2011; ; El-Shafie et al., 2011;Al-Saroj et al., 2017
Data collection and decision making	Record weevil captures every 7-15 days during trap servicing and develop plans to inspect palms to detect infestation around traps recording high weevil captures. Recently, smart traps have been designed to automatically record weevil captures in trapson a 24x7 basis and could significantly assist in the performance analysis of area-wide *R. ferrugineus* control programmes. However, this technology is still in the experimental stage. Weevil captures in pheromone traps and infestation reports could be used to assess the spatial and temporal spread of *R. ferrugineus* using Geographic Information System (GIS).	Faleiro, 2006; Faleiro et al., 2010; Massoud et al., 2012; Potamitis and Rigakis, 2015; Aldryhim and Al-Ayedh, 2015

Recently, trials carried out at the Centre for Date Palm and Dates, Al Hassa, Saudi Arabia to assess the efficacy of *R. ferrugineus* trapping techniques, not involving trap servicing, found ‘Attract and Kill’ (El-Shafie et al., 2011; Faleiro et al., 2016) or the use of the Electrap^{TM}(Al-Saroj et al., 2017) to be efficient in capturing adult *R. ferrugineus* and could be incorporated into the control strategy where additional pheromone traps need to be deployed, maintaining a minimum of 1trap / ha with the traditional food baited pheromone trap. In the case of Attract and Kill use 1-2 dollops (3g) per palm or 200-400 dollops / ha, while in the case of the Electrap™, a trap density of up to 4 traps/ha could be maintained. Attract and Kill formulations against *R. ferrugineus* are currently manufactured by ISCA Technologies, USA [Hook-RPW™] and Chem Tica International, Costa Rica [Smart Ferrolure™].

Fig.7. *R. ferrugineus* pheromone lures (Source: J. R. Faleiro)

Fig. 8. Do not discard old pheromone lures in the field (Source: J. R. Faleiro)

Fig. 9. Dome shaped Picusan trap ™ for *R. ferrugineus* (Source : J.R.Faleiro)

Fig.10. ElectrapTM for R. ferrugineus that is used without food bait (Source: J.R.Faleiro)

A B

Fig.11. Attract and Kill technology using Hook-RPWTM (A) [ISCA Technologies, USA] and Smart Ferrolure ™ (B) [Chem Tica International, Costa Rica] (Source: J.R.Faleiro)

1.8.6. Chemical control

Preventive and curative insecticide applications are used to control *R. ferrugineus* in date palms (Abraham et al., 1998; Faleiro, 2006). However, preventive insecticide applications through regular spray schedules are often excessive and unnecessary. Besides, the drawbacks associated with such applications are well documented in the literature. In plantations with high weevil activity as gauged by eradication (removal) of severely infested palms and/or more than three weevils/trap/week, a single preventive spray application is justified.

In theCanary Island RPW eradication program, Fajardo et al. (2017) priortized preventive treatments by treating palms around 25% of the traps recording the highest weevil captures and also by spraying palms around each newly infested palm. Intensifying periodic inspections of date palms to detect infestations after 1-2 rounds of initial preventive sprays in and around severly infested plantations followed by two monthly inspections of palms to detect infestations, instead of only continuous periodic prophylactic sprays can also successfully control the pest. During the fruiting season (April-September), nopreventive chemical treatment should be applied.

A B

Fig.12. Slanting holes drilled around the infestation (A) and insecticide injected (B) into the drilled holes (diffusion technique) [Source: J.R. Faleiro]

A curative treatment for *R. ferrugineus* infested palms is essential as this treatment (stem injection), if administered in the early stage of attack, could prevent the palm from dying. Excessive tissue removal around the infested portion of the palm prior to stem injection should be avoided. Currently, several pressure-injecting systems are available. However, the long-term impact of injecting insecticide solution into the palm under pressure is not known and should be carried out only under supervision of trained personnel. Instead, allowing insecticide solution to diffuse through 4-5 slanting holes (20cm deep) drilled around the infestation kills the feeding larvae and should be practiced to treat palms in the early stage of attack. Drenching the infested palm with insecticide is essential to kill adults hiding in the frond axils. In order to ensure success of the treatment, repeat the stem injection two weeks later if the symptoms (presence of ooze and frass) persist. Curative insecticide treatments of palms in the early stage of attack through stem injection technique are known to cure such palms. Although various organophosphates (chlorpyriphos, fenitrothion), carbamates (carbaryl) and pyrethroids (cypermethrin) have been used in prophylactic and curative treatments against *R. ferrugineus* (Abraham et al., 1975; Kurian and Mathen, 1971; Faleiro, 2006; Al-Shawaf et al., 2010), neonicotinoids (imidacloprid) and phenylpyrazoles (fipronil) are also being used (Kaakeh, 2006; Al-Shawaf et al., 2010). Imidacloprid has been reported to cause more than 90% mortality in young grubs for more than 2 months after treatment (stem injection) as compared to abamectin which resulted in 50-90% mortality of young larvae and persisted one month after treatment (Dembilio et al., 2015; Dembilio and Jaques, 2015). Date palms in the late stage of attack exhibiting severe tissue damage (>30%) should be eradicated (removed).

1.8.7. Eradication and Quarantine

Date palms in the advanced stage of attack by *R. ferrugineus* have to be eradicated. This operation is laborious and time consuming. Palms to be eradicated are cut into small logs which are then transported in a closed vehicle to a central palm shredding facility. The section of the stem in the field that is cut at ground level with a chain saw and cannot be removed and transported to the shredder should be thoroughly drenched with insecticide in order to prevent it from becoming a site for oviposition. Severely infested palms could also be eradicated in-situ by cutting them into small pieces (20/10 cm) and drenching the cut pieces with insecticides. Burning of large palm logs doesn't ensure mortality of hidden stages of the pest.

During the last three decades, *R. ferrugineus* has spread rapidly due to the local, regional, and international shipments of palms for ornamental landscape gardening and farming (Faleiro et al., 2012; Faleiro et al., 2016). To ensure movement of pest free material, there is a need to develop and build on the concept of 'certified plant nurseries', which would meet the need of palms and offshoots for ornamental gardening and date palm farming. While it has been recommended to dip date palm offshoots in 0.004% Fipronil for 30 minutes before transportation (Al-Shawaf et al., 2013), there is no reliable protocol that ensures larger palms, transported for ornamental gardening, are free of *R. ferrugineus*.

Fig. 13. Eradication of date palms severely infested by *R. ferrugineus* using a shredding machine (Source : J. R. Faleiro)

Fig. 14. Trade of ornamental palms and palm shipments for landscape gardening contribute to the spread of *R. ferrugineus* (Source: J. R. Faleiro)

Fig.15. Dip date palm offshoots in 0.004% Fipronil for 30 minutes before transportation (Source: J. R. Faleiro)

1.8.8. Data collection, performance analyses, and capacity building

In any area-wide pest management operation, large amounts of data are generated. This data is vital to gauge the situation (performance analysis), to inform decision-making in order to strengthen the operation and judiciously use men and material. In *R. ferrugineus*-IPM programmes, data on weevil captures in pheromone traps and infestation reports could assist pest managers to know where the pest is most active and reinforce the IPM strategy around the core tactics pertaining to trapping, inspection of palms to detect infestation, chemical treatments and eradication of severely infest palms (Al-Shawaf et al., 2012; Hoddle et al., 2013). In this context, GIS aided maps based on weevil captures and infestation reports could also be periodically developed to assess the temporal and spatial spread of *R. ferrugineus* (Massoud et al., 2011; Massoud et al., 2012). Data collection from the field could be accelerated by using smart traps that record and transmit data on weevil captures continuously on a 24x7 basis (Potamitis and Rigakis, 2015; Aldryhim and Al-Ayedh, 2015) or by developing suitable applications on mobile smart phones that could assist in instantly collecting and transmitting weevil captures during trap servicing and also in recording data on infestation from the field without having to manually enter data first in the field (hard copy) and then on the computer in the data collection unit.

Furthermore, continuous building of capacity through targeted training programmes of all stakeholders, including date palm farmers, farm labor, agriculture officers, plant quarantine implementing agencies, policy makers and administrators with the latest knowledge on *R. ferrugineus*-IPM, is necessary to control *R. ferrugineus* in date palm. The *R. ferrugineus*- IPM programme could receive a major boost if farmerswould participate in the programme. However, despite the programme being entirely supported by the states in almost the entire date palm growing region of the Middle-East, particularly in the GCC countries, there is hardly any participation by the farmers.

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2. IPM of Date Palm Borers

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2.1. Scientific names

Date palm is attacked by many palm borers, including the frond borer, *Phonapate frontalis* (Fähraeus) (Coleoptera: Bostrichidae), longhorn date palm stem (Trunk) borer, *Jebusaea hammerschmidtii* (Reiche) (Coleoptera: Cerambycidae) and two main species of dynastid or rhinoceros beetle (Coleoptera: Scarabaeidae: Dynastinae): *Oryctes elegans*, and subspecies of *Oryctes agamemnon* in several countries.

2.2. Description

2.2.1. Frond borer, *Phonapate frontalis*

The mature adult is a small beetle (15–22 mm), dark brown to black in color (Fig. .1). Its body is rectangular in shape and the first segment of the thorax covers the head. The anterior dorsal part of the first thoracic segment is serrated, while the posterior dorsal part is smooth and glossy. The larva is creamy white in color, legless, and more or less C-shaped (about 20 mm).

Fig. 1. Adult of *Phonapate frontalis* (Source: M. Zaidan Khalaf)

2.2.2. Longhorn date palm stem borer, *Jebusaea hammerschmidtii*

Larvae of the longhorn date palm borer are about 45 mm long, legless, and are creamy to white in color. Usually, there is one larva per tunnel. The first two segments of the thorax are broader than the rest of the body, which tapers towards the tail end. This is a major difference between this pest and other legless larvae, like that of the red palm weevil, which is stouter and more spindle-shaped. Pupae are exarate and vary from 36 to 45 mm in length.

The adult female is bigger than the male. The female is 27.36 mm in length, while the male is 21-24 mm, both have compound eyes and antennae longer than the body. The body is light-to-dark brown in color and the antennae are as long as the length of the body (Fig.2).

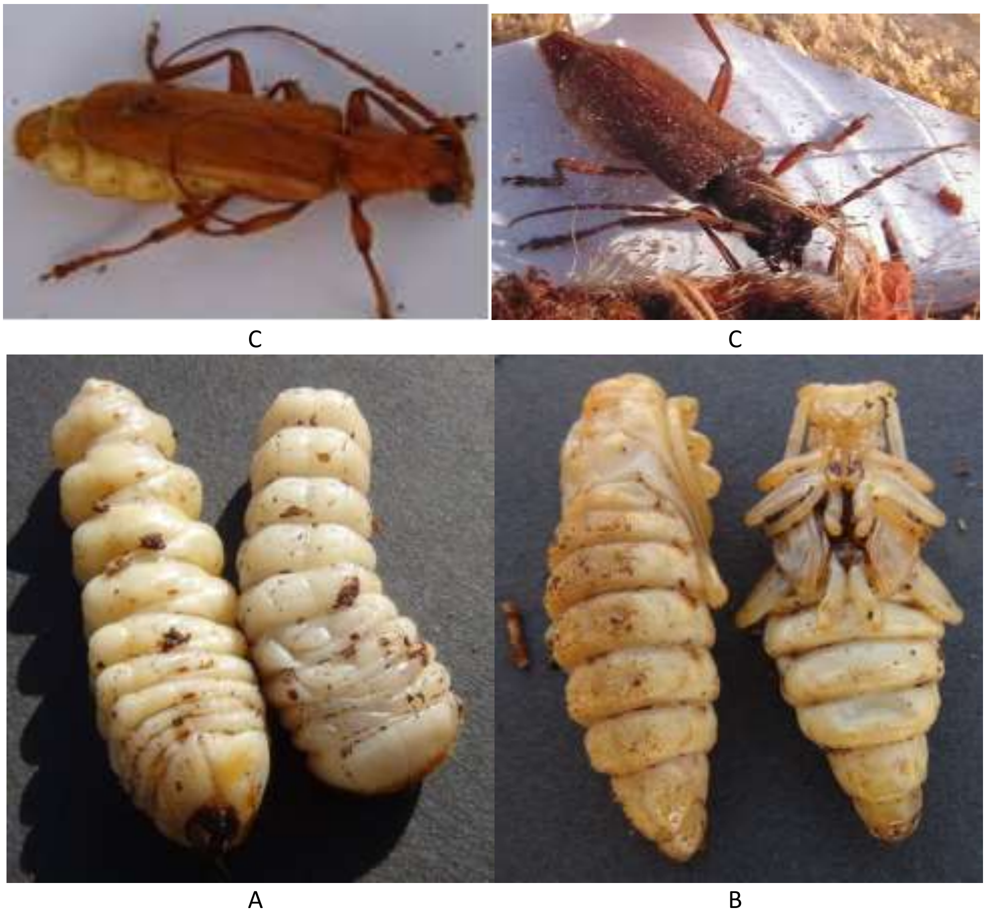

Fig. 2. ***Jebusaea hammerschmidtii*****; larvae (a), pupae (b), adults (c) (Source: M. Zaidan Khalaf)**

2.2.3. *Oryctes spp.*

The eggs of *Oryctes agamemnon arabicus* are oval in shape, white in color, 2.9 mm in length, and 2.15 mm in width (Fig.3a). The larvae of *Oryctes* spp are C-shaped and creamy white in color. The head has strong mandibles capable of chewing the base of the fronds within hours. The larvae have three pairs of legs of different length. The first pair is 6mm, the second pair is 7mm, and the third pair is 9mm long. The lateral side of the larvae has nine pairs of circular spots light brown in color, with a pair on the prothorax and the remaining eight pairs are on the abdominal segments. The feces of the larvae are black and laid in masses, roughly the size of wheat grains. The length of fully developed larvae is 76.8mm, while its width at the middle of the body is 16.1mm and its weight is 7.80g (Fig. 3-b). Pupae develop inside the larval wall and are capable of making T-shape grooves for eclosion (Fig. 4c). The pupae are obtect, white in color for the first few hours before turning brown. Pupal length is 39.2mm and its width at the middle of its body is 27.4mm. Its weight on the first and second days after pupation is 3.2g (Fig. 4d,e). After an adult emerged from the pupa, its color is red and changes to black the first day after eclosion (Fig. 5f). The abdomen is 39.4 and 33.6mm long, 16.4 and 13.4mm wide, while its weight is 2.79 and 2.00g for male and female, respectively. The male differs from the female by the presence of a long horn starting from the center of the head, whereas the female has a very short horn. (Fig. 5g, h). The adult has a concave prothorax characterized by two projections in the male and one in the female. The wings of the male are larger than those of the female (Fig. 5).

A B

Fig. 3. Arabian rhinoceros beetle, *Oryctes agamemnon arabicus*: eggs (a), larva (b) (Source: M. Zaidan Khalaf)

2.3. Distribution

2.3.1. Frond borer, *Phonapate frontalis*

Phonapate frontalis is not a major economic pest of the date palm. It has been reported to occur in Iraq, Saudi Arabia, Egypt, Bahrain, Yemen, Libya, Tunisia, Algeria, and Oman.

2.3.2. Longhorn date palm stem borer, *Jebusaea hammerschmidtii*

The geographic distribution of *Jebusaea hammerschmidtii* (Reiche) (Coleoptera: Cerambycidae), is not as large as that of the red palm weevil *Rhynchophorus ferrugineus* (Olivier). However, the situation is worrying in certain infested areas. This pest has been reported in Iraq, Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, UAE, Egypt, Algeria, Jordan, Iran, and India. In Iraq, the distribution of this pest varies from one region to another, sometimes overlapping with other borers, such as *Oryctes* spp.

C

D

E

Fig. 4. Arabian rhinoceros beetle, *Oryctes agamemnon arabicus*:pupa after eclosion (c), pupa (d, e) (Source: M. Zaidan Khalaf)

F

G

H

Fig. 5. Arabian rhinoceros beetle, *Oryctes agamemnon* arabicus: emerging adult (f), adult male (g), adult female (h) (Source: M. Zaidan Khalaf)

2.3.3. *Oryctes spp.*

Borers belonging to genus *Oryctes* infest date palm on the Arabian Peninsula and in neighboring countries. *Oryctes elegans* is endemic in Iran, Iraq, Northern Pakistan, Saudi Arabia, UAE, Bahrain, and Qatar. Various subspecies of *O. agamemnon*are have also been reported to attack date palm. *O. agamemnon arabicus* Fairmaire is endemic in certain areas, on the Arabian Peninsula, i.e., Saudi Arabia, Oman, UAE, and in Tunisia.

2.4. Host range

2.4.1. Frond borer, *Phonapate frontalis*

The frond borer has been reported to infest pomegranate and grapes trees besides date palms.

2.4.2. Longhorn date palm stem borer, *Jebusaea hammerschmidtii*

The date palm tree is the major host of *J. hammerschmidtii* and is spread by the movement of trees or offshoots infested with its larvae. Also, the adults are strong fliers and thus can easily infest new areas.

2.4.3. *Oryctes* spp.

Different varieties of date palm have varying levels of susceptibility to *Oryctes* attack. In Iran, *O. elegans* damage is more prominent in young date palms (10–20 years) and on short varieties (Mozafati) than in old plantations and tall varieties (Halili, Krout and Mordarsang). No other plant species are reported as hosts. In Iraq, the date varieties Brem and Ustaomran (Umrani) were the most susceptible to attack and infestation by *O. agamemnon arabicus*. Around 9 - 10 larvae per tree were found in the parts exposed during the annual frond pruning of palms. Varieties having fragile textured fronds are preferred by *Oryctes*, compared to the varieties with solid and hard textured fronds.

2.5. Damage and Symptoms

2.5.1. Frond borer, *Phonapate frontalis*

Both the larvae and adults of *P. frontalis* cause damage by feeding on green fronds. Larvae usually feed inside tunnels, resulting in the excretion of sticky material at the entrance holes (Fig. 6). Infestation due to this pest either results in breaking of the frond or gradual drying of the frond. The infestation by this pest results in the frond becoming powdery. Also, this pest is capable to borrow inside fruit stalks, causing dryness and rendering fruit unsuitable for consumption.

The main characteristic of infestation due to this pest is the appearance of sticky points at entry/exit holes.

Fig. 6. Damage by *Phonapate frontalis* (Source: M. Zaidan Khalaf)

2.5.2. Longhorn date palm stem borer, *Jebusaea hammerschmidtii*

The main damage by this borer is the larval ability to burrow at the base of the fronds at the top of date palm trees. The main symptom of damage due to this borer is the appearance of brown sticky materials at the holes made by this borer at different parts of the trunk. During our survey in some areas of Iraq, we recorded 265 holes per meter in date palm tree (Fig. 7, 8). The *J. hammerschmidtii* infestation shortens tree longevity and reduces yield. It also decreases the market value of the dates.

Fig. 7. Damages and symptoms by *Jebusaea hammerschmidtii* (Source: M. Zaidan Khalaf)

Fig. 8. Pupa of *Jebusaea hammerschmidtii* inside the hole (Source: M. Zaidan Khalaf)

2.5.3. *Oryctes spp*.

The adults usually burrow tunnels through the trunk (stem) (Fig. 9), green fronds, and even stalks of the fruit. As a result of strong wind, the trunk and fronds then often break, especially if several adults attack a palm. Recently, we noticed that larvae and adults could transfer fungal and bacterial diseases to the palm that resulted in death of the infected palms. The larvae are always found either inside the trunk, under the base of the fronds, or even in the crown of the tree (Fig. 10). The presence of several larvae in one place of the trunk for feeding causes a large hole inside the trunk (Fig. 9) and could result in the breaking of the trunk. The larvae prefer the wet part of date palm and young trees (offshoots). Date palm varieties differ in their sensitivity to this borer. Trees aged over 30 years suffered the highest level of infestation in comparison with middle age and young trees. The infestation shortens palm longevity and reduces yield. It also decreases the market value of dates. The trunks of heavily infested palms break especially during strong winds and storms (Fig. 11).

2.6. Biology

2.6.1. Frond borer, *Phonapate frontalis*

Both the larva and the adult live inside the tunnels, which they make in the fronds. The seasonal activity of *P. frontalis* varies according to the regional and environmental conditions. A field study conducted in three orchards in Iraq during 2010 showed that the highest flight activity of *P. frontalis* occurred during the months of May, June, and July. In Saudi Arabia, the adult activity started in March.

Fig.9. Damages by Oryctes spp., holes in trunk (Source: M. Zaidan Khalaf)

Fig. 10. Larvae of *Oryctes agamemnon* detected in their tunnels in frond bases (Source: M. Zaidan Khalaf)

Fig. 11. Breakdown of trunks due to highest infestation by *Oryctes agamemnonarabicus* (Source: M. Zaidan Khalaf)

2.6.2. Longhorn date palm stem borer, *Jebusaea hammerschmidtii*

This insect pest passes winter as larvae inside the trunk of the date palm trees. Later, when the temperature increases during spring, the larvae burrow a hole at the end of the tunnel and pupate. The duration of the pupal stage takes about three weeks. The emerging adults find their way out by making circular exit holes. The adults are mostly noticed in early May when mating occurs and the females lay their eggs singly at the base of the fronds. The eggs hatch within two weeks and the larvae start borrowing the trunk. The duration of the larval stage is about three months.

2.6.3. Oryctes spp.

2.6.3.1. *Oryctes elegans*

Males produce an aggregation pheromone which attracts both sexes. This is 4-methyloctanoic acid and its attractiveness is strongly enhanced by the presence of odor from fresh date palm tissue. The laboratory protocol for the synthesis of this pheromone is standarised and reported. The larvae are found in the axils of fronds and at the junction of dead and living tissue in crowns and may tunnel toward the growing point. Groups of larvae may tunnel in moist tissues inside dying or newly dead palm trunks, forming a large hole, which can topple the palm. In laboratory studies, the larvae were reared on a food mixture of decayed wood or compost and cow dung at 28–30 °C. The average duration of the development stages were: egg, 10 days; larva, 91 days (three instars); prepupa, 7 days and pupa, 31 days. Larvae were also able to feed on living palm tissue. In another laboratory study at 27 °C, slightly longer development times were observed. The adult life span was about 4 months, and egg-laying began 2–3 weeks after individuals were brought together as couples, with an average of 60 eggs laid by a single female per life cycle.

2.6.3.2. Arabian Rhinoceros Beetle (ARB), *Oryctes agamemnon arabicus*

The incubation periof of *Oryctes agamemnon arabicus* eggs is about 13.2 days. The larvae pass through three larval instars, which last for 196 days. After the larvae complete development, they rest in a nest for pupation, which lasts 29 days.

2.7. Management

2.7.1. Population monitoring

Light trapping techniques have been used for monitoring populations of *O. elegans* and *O. agamemnon* in Iran, *O. agamemnon arabicus* in Iraq, *J hammerschmdtii* and *Oryctes* spp. in UAE, Oman, *O. elegans* in Saudi Arabia, and *O. rhinoceros* in Yemen. In Iraqi date palm orchards, solar light traps (Magna Trap with lamp of 320–420 nm wavelength, Russell IPM Limited, UK) are used for monitoring and controlling *Oryctes* spp (Fig. 12).

A

B

C

C

D E

Fig. 12. Solar light trap (Magna Trap with lamp of 320–420 nm wavelength, Russell IPM Limited, UK) used for monitoring and controlling *Oryctes* spp. in date palm orchards in Iraq, External shape (a), Another solar light trap produced by Directorate Technology of Renewable Energy, ministry of Science & Technology,Iraq (b), Internal design (c), lamp at night (d), *Oryctes* spp. and *J. hammerschmidtii* adults capture by light trap (e)

2.7.2. Cultural control

Cultural and physical control are very important in managing palm borers in all date growing regions. Old and almost dried frond bases are pruned and removed from the palm trunk in an annual servicing (Fig.13) at a downward sloping 45° angle (Fig.16), the cut ends allow the farmers to climb the tree (Fig.14). Layers of fiber between fronds, frond thorns, and old dried bunch stalks are also removed (Fig.15). This eliminates sites for beetles to hide and oviposit, and for larvae to develop, and allows hand picking of any larvae (Fig.17). Pruned palm harbors significantly fewer beetles than unpruned palms. Pruning also reduces humidity around the trunk and frond bases thereby discouraging oviposition.

Fig. 13. Tools used in annual servicing of date palm trees (Source: M. Zaidan Khalaf)

Fig. 14. A climbing harness being used in annual servicing of a middle-age date palm (Source: M. Zaidan Khalaf)

Fig. 15. Young date palm showing a stage in annual servicing (Source: M. Zaidan Khalaf)

2.7.3. Host plant resistance

Date palm varieties exibit varying levels of susceptibility to *Oryctes* attack. In Iraq, the date varieties Brem and Ustaomran (Umrani) were the most susceptible to attack by *O. agamemnon arabicus.* Date palm varieties show differences in their morphological characters, length and orientation of leaves, type of growth, and shape of frond etc. In Iraq, a study on the characteristics of the dried base of fronds for different commercial date palm varieties in relation to borer infestation showed that varieties having fragile textured fronds are preferred by *Oryctes*, compared to varieties with solid and hard textured fronds.

Fig. 16. Previously pruned trunk showing frond bases cut off at the recommended 45° angle (Source: M. Zaidan Khalaf)

Fig. 17. Hand collection larvae of *Oryctes agamemnon* detected in their tunnels in frond bases during important annual servicing in Iraq (Source: M. Zaidan Khalaf)

2.7.4. Biological control

The entomopatogenic nematodes (EPN), *Rhabdits blumi*, and the entomopatogenic fungi (EPF), *Beauveria bassiana* and *Metarhizium anisopliae* have been tried as biocontrol agents against date palm tree borers, *Oryctes* spp. (Coleoptera: Scarabaidae: Dynastinae) (Fig. 18). Field experiments showed that an injection of 50 ml per palm tree at a concentration of 1000 IJs/ml of *R. blumi* resulted in about 42% mortality in ARB larvae. Meanwhile, an injection of 50 ml of 1×10^{9} conidia/ml^{-1} of *B. bassiana* caused 50% mortality in larvae (Fig. 19). Spraying of spore suspensions against larvae or the use of light traps to capture and infect adults followed by their release may have the potential for incorporating the fungus into future IPM programmes against *Oryctes* spp. (Khalaf et al. 2016). In the UAE and Iraq, *O.elegans* and *Oryctes agamemnon* adults often carry a large load of the phoretic mites *Sancassania* sp. and *Hypoaspis rhinocerotis* Oudemans on their body and under the elytra (Fig. 20).

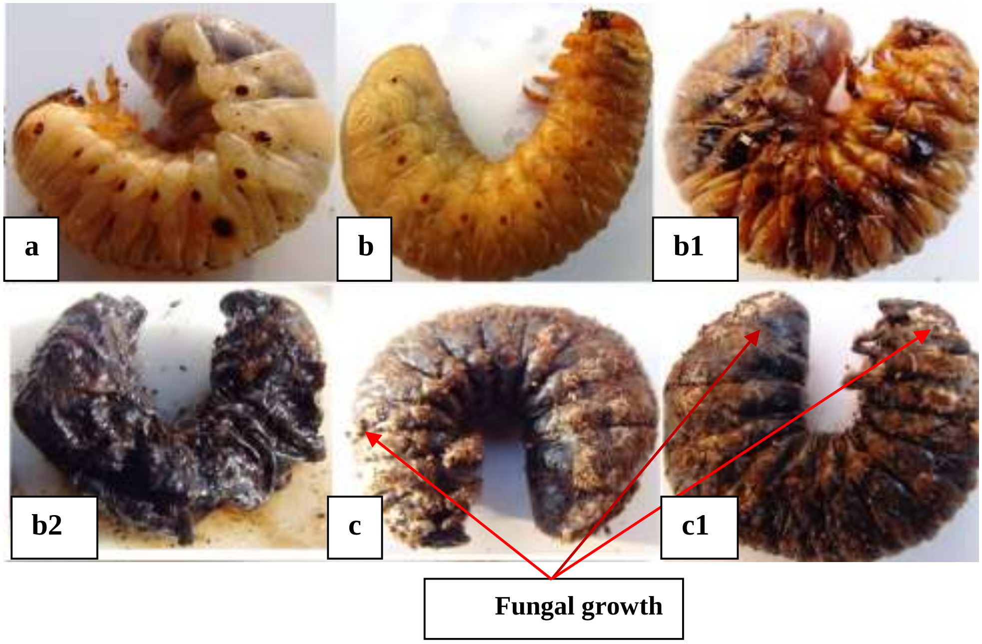

Fig. 18. Larvae of *Oryctes agamemnon arabicus*: healthy (a), infected by EPN *Rhbditis blumi* (b after 6 day, b1 after 8 day, b2 after 12 day) , infected by EPF *Beauveria bassiana*(c after 21 day, c1 after 28 day) (Source: M. Zaidan Khalaf)

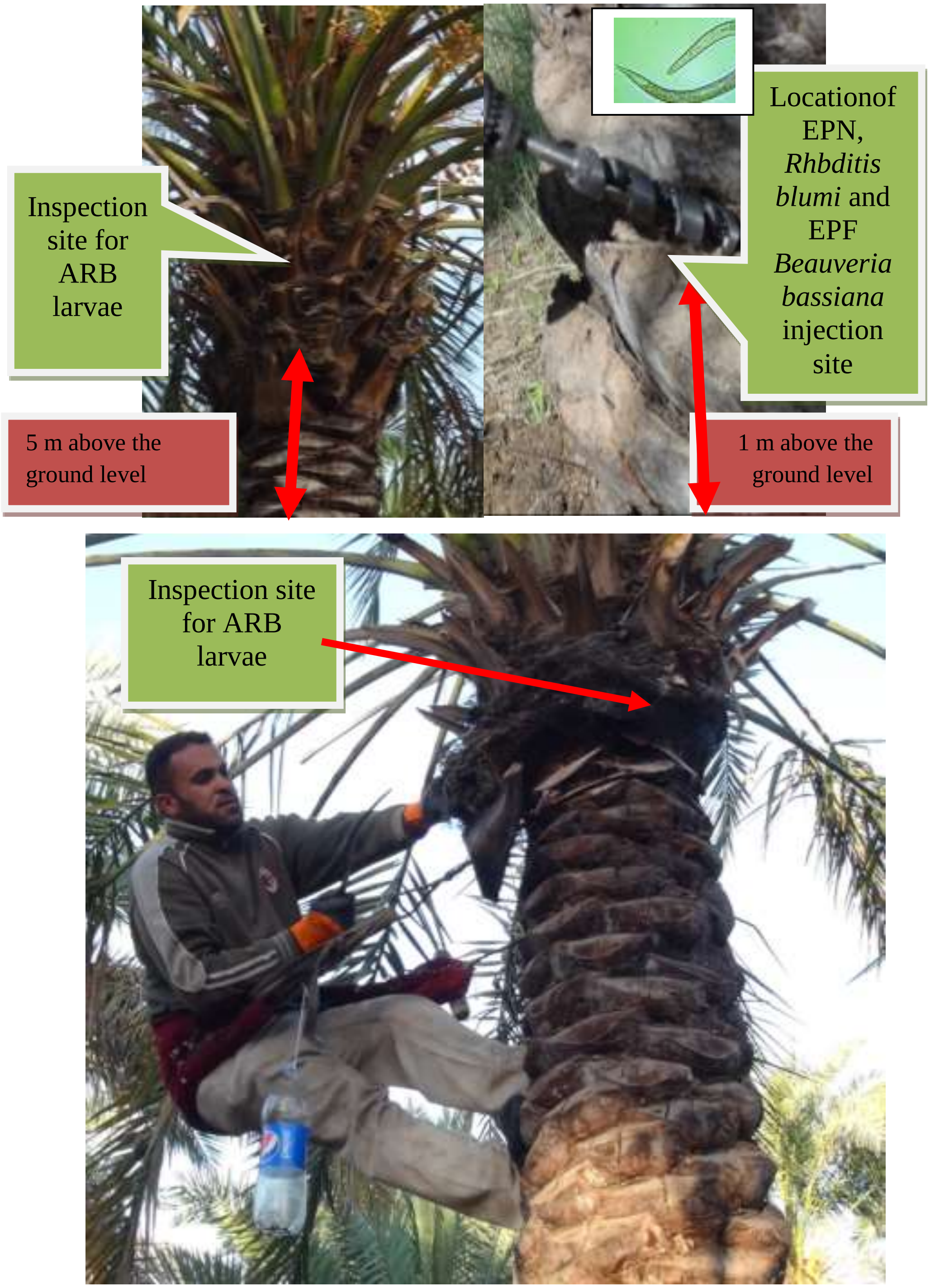

Fig. 19. Injection of bioagents and Inspection of palm tree crown for collecting ARB larvae (Source: M. Zaidan Khalaf)

Fig. 20. Mites, *Hypoaspis* sp on *Oryctes agamemnon* adult (Source: M. Zaidan Khalaf)

2.7.5. Semiochemical control

Pheromone traps are widely used to monitor *Oryctes* activity in date palm plantations in the Middle East during April to September.

2.7.6. Chemical control

Chemical control of date palm borers is carried using systemic insecticides, either as injection or through irrigation water after harvest to target the larval stage. In Iraq, field experiments showed that injection of Imidacloprid (10ml per liter water) @40ml per palm caused about 85.8% mortality of *O. agamemnon arabicus* larvae compared to 100% using Thiamethoxam (5 ml/liter water) at the rate of 10ml per palm(Fig.21-a). Furthermore, irrigating a palm with 25 suspension, containing 25ml Imidacloprid or 5ml Thiamethoxam resulted 75% and 80% mortality of larvae, respectively (Khalaf and Alrubaei, 2016). These insecticides had no effects on the pests when used as direct sprays (Fig. 21-b).

A B

C C

Fig. 21. Control methods of date palm trees: (a) trunk injection, (b) direct spray and (c) collecting dead and live larvae of ARB, *Oryctes agamemnon arabicus* in date palm orchards (Source: M. Zaidan Khalaf)

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3. IPM of Dubas Bug

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3.1. Scientific name

The Old World date bug that is commonly known as the Dubas bug, *Ommatissus lybicus* de Bergevin (Hemiptera: Tropiduchidae) (Talhouk, 1977).

3.2. Description

The Dubas bug is a hemimetabolous insect that includes three distinct stages: egg, nymph, and adult stage. Adults are yellowish brown and varying to green. The female is 5-6 mm long, with pairs of up to 10 dark or black spots based on the head and on the 7th and 8th abdominal segments. The wings are clear, with venation concentrated at the apices. The male is 3-3.5 mm long; the wing length is greater in proportion to the body length, has a more tapered abdomen without pairs of spots on the abdomen. The male’s wings extend further beyond its abdomen when compared to the female (Al-Abbasi, 1988; Hussain, 1963; Asche and Wilson, 1989).

Dubas bug nymphs pass through 5 instars to reach the adult stage and are distinguished by the number of clusters of waxy caudal filaments they bear (Hussain, 1963; Howard and Wilson, 2001) as follows:

1st instar: is basically pale gray, 0.8-1.25 mm long with distinct dark patches on each side of the thorax and abdominal segments, with no lines on the dorsal surface of the thorax and abdomen.

2nd instar: is 1.3-2.25 mm long with dark brown dots beginning to appear in two lines on the dorsal surface of the abdomen.

3rd instar: is 1.6-2.68 mm long with two longitudinal lines on the dorsal surface of the abdomen and thorax.

4th instar: is 2.18-4 mm long with three lines on each side of the thorax.

5th instar: is yellowish brown, 2.5-3.64 mm long with first wing bud covering the second wing bud and the third abdomen segment.

The adults can jump distances of about 12 times their body length and can fly for a short distance when disturbed, whereas nymphs can only jump a short distance (Howard and Wilson, 2001).

The egg is ovoid and markedly elongated in shape, 1.0-0.5 mm long and 0.29-0.10 mm at its greatest diameter, bright green when first laid, changing to yellowish white and then to bright yellow just before hatching (Hussain, 1963; Mjeni and Mokhtar, 1983).

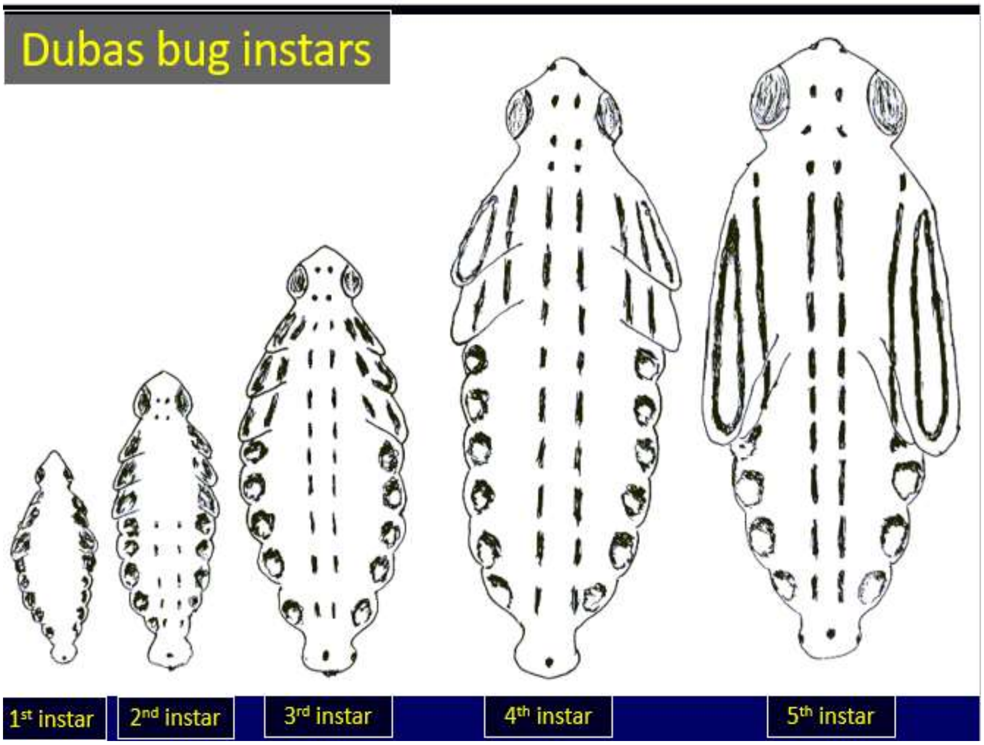

Fig.1. Dubas bug instars (Source: Abd-Allah et al., 1998)

3.3. Geographical distribution

The Dubas bug has been reported as a major pest of date palm in the Middle East and North Africa in Iraq, Iran (Talhouk, 1977), Oman (El-Haidari and El-Tijani, 1977; El-Haidari and Al-Hafidh, 1986), Pakistan (Shah, 2009), United Arab Emirates (El-Haidari and Al-Hafidh, 1986), and Yemen (Hubaishan et al., 2005). Its presence is recorded in Algeria (El-Haidari and Al-Hafidh, 1986), Bahrain (El-Haidari, 1979), Egypt (de Bergevin, 1930; Talhouk, 1977; Asche and Wilson, 1989), Jordan (Kinawy et al., 2010), Kuwait (El-Haidari and Al-Hafidh, 1986), Libya (El-Haidari and Al-Hafidh, 1986), Palestine (Asche and Wilson, 1989), Saudi Arabia (Talhouk, 1977; El-Haidari and Al-Hafidh, 1986), Sudan (El-Haidari and Al-Hafidh, 1986) and Tunisia (Zouba and Raeesi, 2010).

3.4. Host range

The Dubas bug is an oligophagous insect that is known to complete its life cycle on date palms and causes significant direct damage to palms through feeding, honeydew production, or damage associated with oviposition (Howard and Wilson, 2001).

3.5. Symptoms and Economic Importance

The Dubas bug attacks the leaves of date palm trees, sucking the nutrient fluid sap which results in direct damage. As a result of feeding by nymphs and adults, honeydew accumulates on the palm surface and with time leads to the growth of a black sooty mould, which affects the photosynthesis process. In addition, the presence of a large amount of honeydew on the leaflets and the accumulation of dust on the honeydew leads to light green or yellowish green leaflets (Mokhtar and Al Mjeni, 1999). Moreover, females oviposit eggs into any green or soft date palm tissues, which include the fruit bunch except the fruits. It leaves necrotic scars symptoms on the leaf tissue, where the female lays its eggs. It was reported that extremely heavy populations may lead to the death of some palms. The economic losses were recorded as up to 50% in Iraq on date palms (Talhouk, 1977) whereas it was estimated as 28% in crop losses in Oman due to the infestation of *O. lybicus* (Khan et al., 1983).

Fig.2.Feeding symptoms of Dubas bug on leaves of date palm (Source: S. Al-Khatri)

3.6. Biology

Biological studies revealed variations in the lifespans between male and female and between spring and autumn generations based on temperature. During the spring generation, the range is 21-102 days for the male and 17-95 days for the female. The male lifespan during the autumn generation is 19-133 days, whereas that of the female is 14-117 days.

During the spring generation, the females oviposit 17-205 eggs. They have a pre-oviposition, an oviposition, and a post-oviposition period of 5-18, 5-69 and 1-18 days, respectively. On the other hand, during the autumn generation, the females oviposit 11-216 eggs and have a pre-oviposition, an oviposition, and a post-oviposition duration of 7-19, 3-97 and 2-18 days (Table 1).

Dubas bug eggs hatch after 39 days at 27.5°C and after 99 and 81 days at 35°C and 20°C, respectively (Table 2). However, during winter seasons, the incubation period may reach 140-170 days. After hatching, the nymphs pass through five instars to reach the adult stage. The nymphal development takes 34 to 95 days at 32.5 and 20°C, respectively, where each instar takes about 7, 6, 6, 7 and 9 days at 32.5°C and about 21, 14, 14, 21 and 24 days at 20°C for the 1st, 2nd, 3rd, 4th and 5th *O. lybicus* instars, respectively (Table 2). The development duration from egg to adult takes 84 days at 27.5 to 100 and 175 days at 35°C and 20°C, respectively (Table 2).

O. lybicus is a bivoltine insect with two generation per year (spring and autumn generation). Spring generation is during February to May and autumn generation is during August to November (Hussain, 1963 ; Talhouk, 1977; Mjeni and Mokhtar, 1983; El-Haidari and Al-Hafidh, 1986; MAF, 1997; Abd-Allah et al., 1998; Elwan and Al-Tamimi, 1999). During the spring generation, eggs start hatching from February to April. After hatching, the nymphal stage passes through 5 instars to become adults in about 7 weeks. The adult lives for about 6 weeks from the middle of April until the end of May. The eggs of the spring generation aestivate until the autumn generation when they start hatching from the last week of August until the last week of October. The young nymphs last about 6 weeks after which they develop into adults; the adults then live for about 12 weeks (Mjeni and Mokhtar, 1983; MAF, 1997; Abd-Allah et al., 1994; Elwan and Al-Tamimi, 1999; Kinawy, 2005). In general, the female lays more eggs in the autumn generation than in the spring generation. The sex ratio in both generations was reported to be 1:1 (Hussain, 1963; Al-Shamsi, 2003).

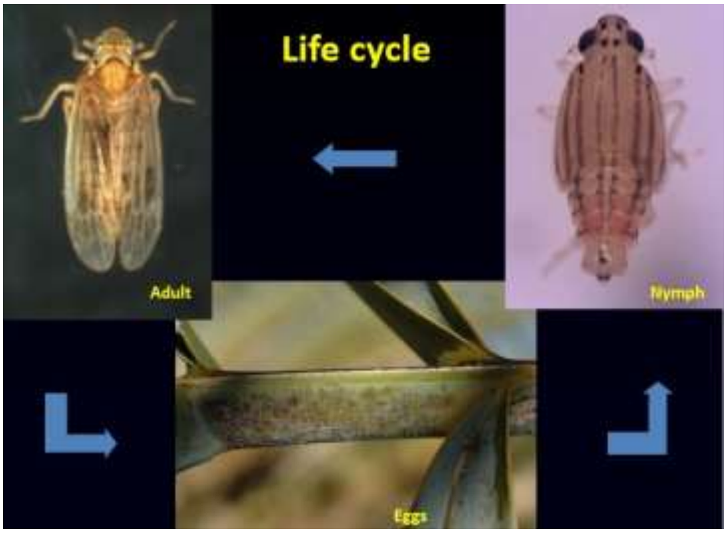

Fig 3. Life cycle of Dubas bug (Source: S. Al-Khatri)

Table 1. Duration of *O. lybicus* adult stage (days) during spring and autumn generation (Mean (Range).

		Pre-oviposition	Oviposition	Post oviposition	Fecundity (eggs/female)	Longevity Female	Longevity Male
Abd-Allah *et al.*, 1994							
Oman (Spring 1994)	Field	**9.0** (8-9)	**32.3** (15-44)	**7.9** (4-10)	**106.8** (45-176)	**47.7** (25-60)	**45.7** (21-59)
	Lab.	**12.0** (8-14)	**50.8** (37-69)	**4.8** (3-6)	**143.6** (100-196)	**72.7** (66-91)	**82** (74-96)
Elwan and Al-Tamimi, 1999							
Oman (1995-1996)	Spring	**12.0** (7-16)	**30.0** (3-62)	**5.1** (1-18)	**124.1** (25-216)	**45.1** (14-117)	**54.2** (19-100)
	Autumn	**13.0** (9-18)	**34.9** (6-63)	**6.3** (2-18)	**115.8** (11-208)	**54.1** (17-93)	**61.6** (19-133)
Al-Shamsi, 2003							
Iraq (2003)	Spring	**7.6** (5-12)	**42.5** (32-55)	**6.9** (4-10)	**103.7** (76-137)	**58.1** (49-66)	**33.5** (27-40)
	Autumn	**12.7** (7-19)	**70.2** (46-97)	**6.9** (4-10)	**130.1** (92-163)	**89.8** (72-117)	**82.4** (56-105)

Table 2. Mean developmental time of O. lybicus eggs and nymphs at different constant temperatures (Mokhtar and Al-Nabhani, 2010).

Temperature °C	Developmental time (days±SD)							
	Egg	Nymph instars N1	N2	N3	N4	N5	Total	Egg-Adult
20.0	80.6±1.34	21.0±0.26	14.3±1.04	14.1±0.64	20.7±0.26	24.4±0.59	94.5±1.23	175.1±1.91
22.5	60.0±1.22	13.2±0.52	10.8±0.55	12.1±0.36	15.1±0.36	18.1±0.83	69.7±1.08	129.7±1.84
25.0	47.6±1.30	10.3±0.39	7.0±1.05	7.4±0.35	11.8±0.33	14.0±0.72	50.4±1.28	98.0±1.31
27.5	39.2±0.84	8.2±0.49	6.5±0.10	7.2±0.67	9.9±0.30	12.9±1.00	44.7±0.41	83.9±0.70
30.0	50.8±1.30	7.0±0.37	6.2±0.57	6.7±0.68	8.4±0.14	9.1±0.76	37.6±1.47	88.4±2.50
32.5	66.0±1.22	6.7±0.25	5.5±0.75	5.9±0.53	7.0±0.31	8.6±0.82	33.7±0.90	99.7±0.82
35.0	99.1±0.74							

3.7. Management

3.7.1. Monitoring

A common technique used to monitor the absence and the infestation level of Dubas bug in the field is visual inspection. It is conducted by selecting not less than ten infested dates randomly. The selected date palms should be scattered and not higher than two metres.

From the selected date palms, two to three fronds are selected where 20 leaflets are marked. Dubas bug individuals are then counted to determine the infestation level.

The infestation level of Dubas bug is estimated as an average number of Dubas bug individuals per leaflet (X) using the following equation (MAF, 1997; Al-Khatri, 2004):

$$X = \frac{A}{BxCxD}$$

where

A is the total number of Dubas bug individuals

B is the total number of leaflets/fronds

C is the total number of fronds/date palm

D is the total number of date palms

The infestation level is categorised as follows:

- X = 0 no infestation
- X = 1-2 as low infestation
- X = 3-4 as medium infestation
- $X \geq 5$ as high infestation

3.7.2. Biological control

Biological control is one of the essential elements in IPM, which have been successfully implemented in managing several key pests elsewhere in the world. Surveys were conducted in different *O. lybicus* infested areas in Oman, where several biological control agents were recorded at the different stages of *O. lybicus* development. These biological control agents included *Aprostocetus* sp. (Hymenoptera: Eulophidae), *Cheilomenes sexmaculata* (Fabricius) (Coleoptera: Coccinellidae), *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), *Runcinia* sp. (Thomisidae: Araneae), *Aphanogmus* sp. (Hymenoptera: Ceraphronidae) and *Bocchus hyalinus* (Hymenoptera: Dryinidae). Among the parasitoids, *Pseudoligosita babylonica* was found to be a parasite on *O. lybicus* eggs (Al-Khatri et al., 2004). It was first reported and named as *Oligosita* sp. *Oligosita* sp. was then confirmed by G. Viggiani (personal communication) as *P. babylonica*. The first identification of *Pseudoligosita babylonica* was in Iraq (Hassan et al., 2003).

In Oman, the egg parasitoid *P. babylonica* has shown more than 70% parasitism in some locations and could be considered as a potential biological control agent of *O. lybicus*. In this respect, additional surveys and in-depth research is needed to determine other parasitoids associated with *O. lybicus* (Al-Khatri, 2008).

3.7.3. Chemical control

The Ministry of Agriculture and Fisheries of the Sultanate of Oman is concerned about the control of *O. lybicus* infestation and insecticide applications are considered as an essential method in controlling the pest. The insecticides are applied using two methods, aerial with aircraft equipped with micronair sprayers for spraying insecticides of the ultra-low volume (ULV) formulation and ground application using hydraulic lance sprayers for applying insecticides of the emulsifiable concentrate (EC) formulation. These two methods have been used since the 1970s. Since then, several insecticides were evaluated and recommended for the control of *O. lybicus*. In the aerial application, insecticides used were Nogos® 50 EC (dichlorvos), Malathion® 96% ULV (malathion), Somithion 99% ULV (fenitrothion), Somicomdi Alfa® 50% ULV (fenitrothion 1% and esfenvalerate 49%), Treon® 30 ULV (etofenprox) and Decis® 12.5% ULV (deltamethrin) (Table 3). In the ground application, the insecticides used were Nogos 50 EC, Elsan 50 EC (phenthoate), Decis® 25 EC, Treon® 20 EC and Somi Alfa® 5% EC (esfenvalerate) (Table 4). Besides synthetic insecticides, botanical insecticides were also used successfully in controlling *O. lybicus* such as 1-Green® EC (angulatin A: 1% W/V) and Pyrethrum® 5 EC (pyrethrins) for ground application (Table 4) (Al-Khatri et al., 2008 and 2009).

Table 3. Insecticides used against *O. lybicus* as an aerial application in the Sultanate of Oman.

Trade Name	Active Ingredient	Insecticide Group	Application Rate (L/Hectare)	Year of Application
Malathion® 96% ULV	malathion	Organophosphorus	2.4	1970’s-1998
Nogos® 50 EC	dichlorvos	Organophosphorus	3.6	1970’s-2001
Somithion® 99% ULV	fenitrothion	Organophosphorus	1	1999-2002
Somicomdi Alfa® 50% ULV	fenitrothion 1% + esfenvalerate 49%	Organophosphorus + Pyrethroids	2.4	2003-2006
Treon® 30 ULV	etofenprox	Non-ester Pyrethroid	3.6	2007-2009
Decis® 12.5% ULV	deltamethrin	Pyrethroid	3.6	2008-2011

* El-Haidari and El-Tijani, 1977; Al-Khatri, 2004; MOA, 2009 and 2010.

Table 4. Insecticides used against O. lybicus as a ground application in the Sultanate of Oman.

Trade Name	Active Ingredient	Insecticide Group	Application Rate (ml/100L water)
Synthetic insecticides			
Nogos® 50 EC	dichlorvos	Organophosphorus	200
Elsan 50 EC	phenthoate	Organophosphorus	100
Decis® 25 EC	deltamethrin	Pyrethroid	100
Somi Alfa® 5% EC	esfenvalerate	Pyrethroid	100
Treon® 20 EC	etofenprox	Non-ester Pyrethroid	100
Botanical insecticides			
1-Green® EC	(angulatin A: 1% W/V)		150
Pyrethrum® 5 EC	pyrethrins		100

* Al-Khatri, 2004; Al-Khatri *et al*., 2008 and 2009.

Fig. 4. Hydraulic lance sprayers (Source: S. Al-Khatri)

Fig. 5. Aerial pesticides application (Source: S. Al-Khatri)

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4. IPM of Lesser Date Moth

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4.1. Scientific name

Batrachedra amydraula Meyrick

(*Cosmopterigidae* (Batrachedridae): Lepidoptera)

4.2. Description

The adult lesser date moth is a small slim insect, around 12 -15 mm in length, dark (gray-brown) in color with a silver abdomen. It has compound brown eyes and silver antennae with dark spots. The front wings of the moth are covered with white scales and very small dark spots. The wings also show a marked longitudinal gray stripe in their center. The hind wings are narrow and dark, with long, dark bristle edges. Females lay their eggs individually on the cap of fruits or on strands close to them. Newly laid eggs are yellowish green in color, turn yellow before hatching with a diameter of 0.7 mm. Young larvae are white-gray then turn pink as the larvae develop and become older. Mature larvae are about 12-15mm in length, spin a light whitish silky cocoon inside in which they later transform into pupae. Duration for adult emergence varies according to climatic factors, especially daily temperature (El- Haideri and El-Hafeedh, 1986, Ali and Hama, 2014).

4.3. Distribution

The lesser date moth (LDM) is considered to be one of the key pests attacking almost all date palm varieties in most date palm growing countries of the world, especially in Asia and Africa (Ba-Angood, 1978; El-Haideri and El-Hafeedh, 1986; El-Juhany, 2010; Kakar et al., 2010). Heavy infestations were reported in African countries, mainly Egypt, Libya, Algeria, Sudan and Asian countries such as Iraq, Iran, Saudi Arabia, UAE, India, Pakistan Oman Sultanate, Yemen, and other Arabian Gulf countries.

4.4. Host range

This pest is highly specific to the date palm, and no reports are known of infestation of other host plants by this moth (Ali and Hama, 2016). The LDM is infesting all date palm varieties with some variations according to variety, region, and season.

4.5. Damage and Symptoms

The lesser date moth is considered to be a key fruit pest on date palm. Larvae begin their attack to newly formed florescence before fruit setting and continue during the subsequent developmental stages with an intensive increase in Hababoock and Chemri stages feeding on content (Ali and Hama, 2014; Kinawy et al., 2015). The larvae start attacking small fruits and borrow through the cap inside the fruits to feed on contents leaving an empty outside wall. During the subsequent generation, larvae feed mainly on the soft pith and immature seeds. Approximately 80% of the fruits are attacked whilst being between 0.6 and 1.0 cm in diameter. The larva chews a hole near the cap, through which it penetrates the fruit and feeds on the pith and the soft immature seed (Fig.1). Damaged fruits are easily recognizable by the black feces attached to the penetration site. The larvae can move from fruit to another within the bunch, thus increasing the damage. The infected fruits become dry and turn red in color from which the insect referred to its local name (Alhumara). The resulting damage includes colored fruits, stiffness, and a dark red color. Small dried fruits can be seen tied or hanging by silken threads produced by the larvae. Dropped fruits with insect penetration holes and silky remain close to fruit cap are considered identifying characteristics or signs of infestation by the lesser date moth. High infestation causes the dropping of large quantities of fruits, leading to big losses in date yield. Late-season infestation of large fruits may cause fruit decay and fermentation, which may accelerate the build-up of sap beetle (Nitidulidae) populations (El-Haideri and El-Hafeedh.1986; Ali and Hama, 2016). The emergence of different insect generations and the severity of injury depend on location and usually coincide with the stages of fruit growth and maturity.

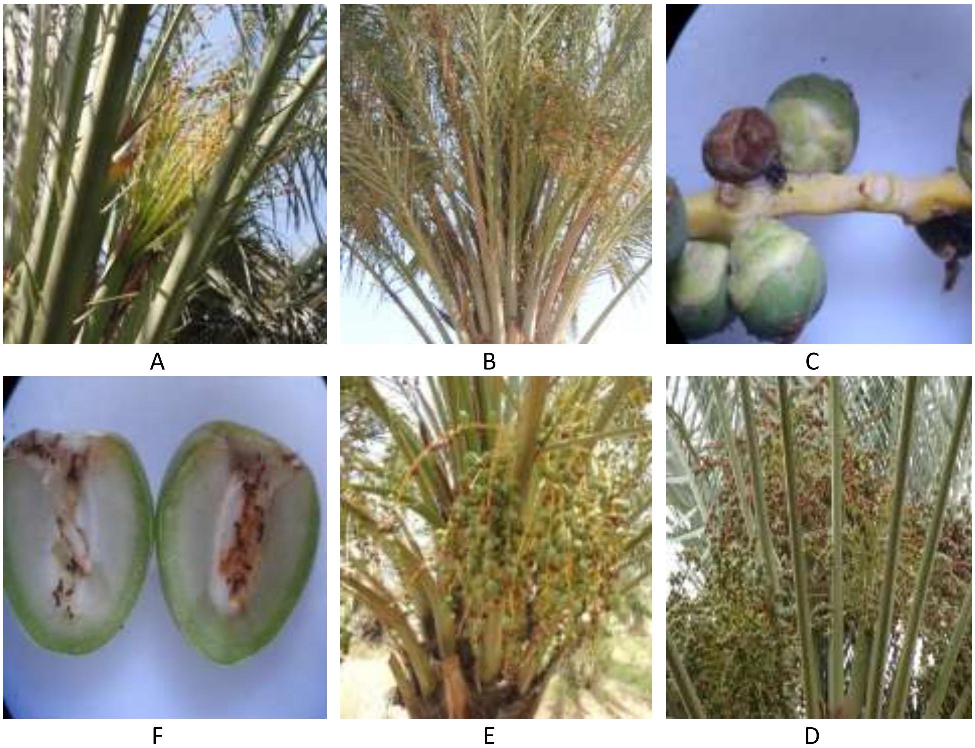
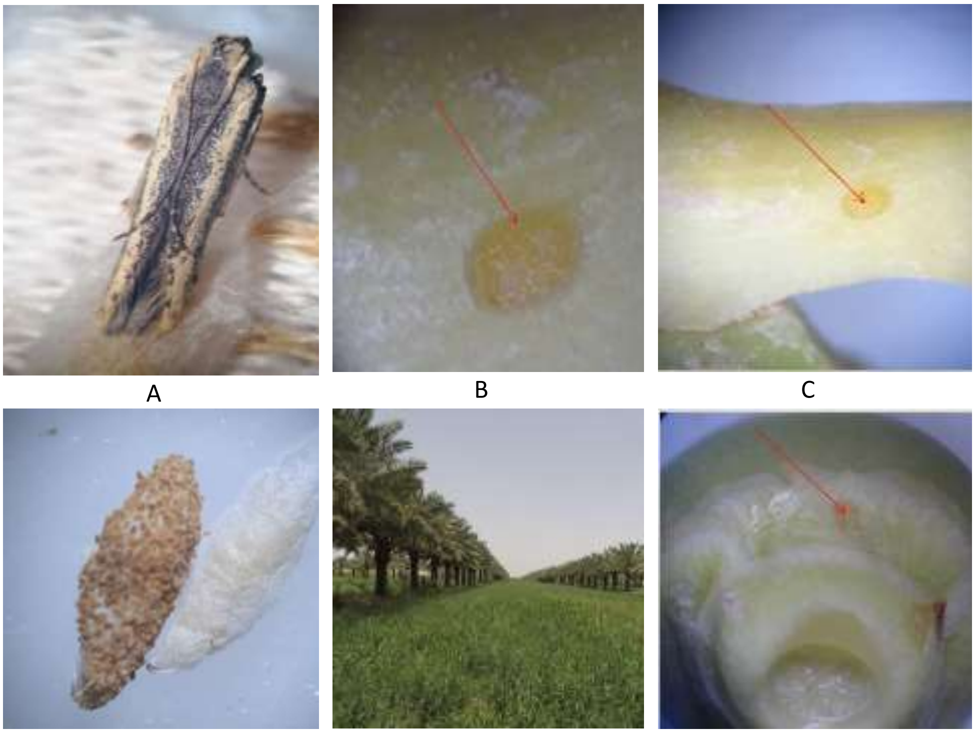


Fig. 1. Damage and Symptoms of LDM, (A, D) on early stages bunches, (C) on early stage fruits, (D, E) on Chemri stage, (F) feeding symptom (Source: Abdul-Sattar A.Ali)

4.6. Biology

The periodical activity of LDM usually starts in spring when climatic factors become favorable. After mating, the females start laying their eggs on fruits or around them (Fig.2). In middle eastern countries, larvae of the first generation are observed in the field from late March to late April, the second generation, from early to late May, and the third generation from about mid- to end of June. After this period, most of larvae observed in the field are in the third stage and by the end of August no larvae or further damage are detected on bunches or dropped fruits. Mature larvae spin a light whitish silky cocoon, in which they spend a hibernation period until the next spring of the following year. They then transform into pupae and later into adults, which are considered to be the first generation of the coming season (El-Haideri and El-Hafeedh,1986; Ali and Hama, 2014; Kakar et al., 2010). The duration for adult emergence varies according to climatic factors, especially daily temperature. Therefore, there are three overlapping generations/year in most date palm growing countries and the seasonal occurrence of larvae and the damage they cause on date fruits are restricted to a relatively short period (April to early July).



A B C

H I D

G F E

Fig.2. Life cycle of the LDM, (A) Adult, (B) Egg, (C,D) Egg on strand and fruit, (E,F,G) Larvae on fruits,(H) Pupa, (I)Date palm plantation where life cycle is completed (Source: Abdul-Sattar A.Ali)

4.7. Management

4.7.1. Population monitoring

Monitoring activities are directed towards both adults and larvae. Field studies presented by Ali and Hama (2014) indicated that photoelectric traps are installed at the rate of one trap per site in order to determine the periodic activity of the insect, the date of adult emergence, and the timing of control practices. Pheromone traps can be used for both monitoring and control measures against LDM, through male confusion and mating disruption. As for larvae and infestation, fruit samples are taken from a number of trees representing each site. The sample size is determined according to the area of the region and date palm plantation. Large areas can be subdivided into smaller areas and 3-5 trees are assigned per hectare as a representative sample depending on the availability of trained scouting personnel. One bunch is assigned randomly at each side of the tree and two random strands are taken. All fruits in the sample are counted and number of infested fruits is recorded. The percentage of infestation by the date palm lesser moth and the number of larvae per sample are also calculated. A number of 100 dropped fruits are collected from each site to determine the total infestation percentages (Ali and Hama, 2014; 2016). Data are recorded in special surveillance reports to be analyzed by specialists in the intended region to decide if further actions should be taken.

4.7.2. Cultural control

Agricultural and sanitation practices could be implemented to remove the dropped fruits that fall on the ground during the growing season and after harvest, reducing future hibernation sites. Another practice would be the removal of bunches left on the tree in order to reduce the hibernation sites of larvae, which would become the first-generation adults the next year (Ali and Hama, 2014). Bagging bunches after pollination using light cloth or plastic nets will prevent oviposition and reduce damage of this pest and other fruit pests.

Improvement of tree health by providing suitable fertilizer, optimum irrigation, and soil management would help in increasing tolerance against most date palm pests.

4.7.3. Host plant resistance

Date palm varieties vary in their susceptibly to LDM infestation, which could be attributed to wax layer and epidermis layer of the fruit, acting as a natural barrier against the penetration of larvae (Ahmed, and Al-Rubaiee, 1996; El-Haideri and El-Hafeedh, 1986). Attempts to introduce resistant varieties are still far away. However, cultural practices implemented to improve the health of the tree play an important role in the tolerance of the fruit or induction of field resistance in date fruits during some seasons. The variety source and quality of male pollen may have some influence on the resistance of formed fruits against LDM infestation.

4.7.4. Biological control

The trend of IPM at present is towards the use of safe and environmentally friendly pesticides and bio-control agents. Among these are the insect parasitoids and bacteria-based bio-pesticides (*Bacillus thuringiensis).* However, there are several local larval parasitoids reported on LDM in North Africa, such as Egypt, and in Asian countries, such as the Sultanate of Oman, Yemen, Saudi Arabia, and Iraq. These parasitoids include *Parasierola sp*, *Habrocytus sp*, *Pediobius sp*, *Bracon hebetor*, *Bracon spp., Phanerotoma sp.*, *Pteromalus sp.* The parasitic wasp *Parasierola swirskiana* Argaman (Hymenoptera: Bethylidae) is common in date plantations in many regions. *Bracon* sp. (Hymenoptera: Braconidae) attacks the larvae of the LDM, as well as those of other fruit moths, and can be found in many places (El-Haideri and El-Hafeedh, 1986). The most common predators in most regions are *Chrysopa spp.* and spiders. Therefore, these local natural enemies should be taken into consideration in applied management against the LDM. As for artificial release and field applications, all biological control agents and bio- pesticides proved to be promising and safe alternatives that can be implemented in an integrated control program against the lesser date moth. Local species proved more adapted and successful bio-control agents against this pest (Ali and Mohammad, 2014; Dhoubi and Essaadi, 2007; Gerling et al., 2006; Mohammad et al., 2011). Timing the release of bio-control agents or the application of bio-pesticides should be decided according to a good monitoring procedure (number of males caughtintraps), taking the impact of the surrounding environment into consideration (Fig.3.) Dual release of both egg parasitoid *Trichogramma sp.* (T*. evanescens*) at the rate of 300-500 individuals/tree, 1-2 release/ season plus 5 pairs of larval parasitoids *Bracon sp.* proved to be an effective combination for controlling this pest (Mohammad et al., 2014). Capsules containing the parasitoids are inserted within the fruit bunches or leaf base. The biological insecticide Bt. (*Bacillus thuringiensis*) is recommended to be used against the first generation as the efficiency of *Bt* compounds is higher at the beginning of the season, when larvae consume more than one fruit to complete their development (Mohammad et al., 2013; 2014; Sayed et al., 2001). Later in the season, when the fruits are bigger, the larvae usually complete their development in a single date fruit, and are not exposed to the *Bt* compounds. The application of the biological insecticide in spray form is decided according to the active ingredients and formulation with an application rate of 6-7 l spray solution /tree. Several commercial products based on the bacterium *Bacillus thuringiensis* Berliner (*Bt*) were found to be effective against the LDM and they are mainly used for control in organic plantations. These products are also used in dusting formulations. The dust offers good capability of penetrating into the center of the date bunches. The biopesticides proved effective in controlling the pest larvae, especially when applied together with the date pollen. This mixture would protect the young setting fruits against the first-generation moth larvae immediately at the time of pollination (Ali et al., 2010; Mohammad et al., 2011). The release of the egg parasitoid *T. cacoeciae*, at approximately 1000 adults per palm, together with an application of a commercial product of the fungus *B. bassiana* showed potential for use to control this pest.

4.7.5. Semiochemical control

Pheromone traps can be used efficiently for the control as well as for the monitoring of LDM, through male confusion and mating disruption (Kinawy et al., 2015). The trap would attract males and reduce the chance of mating, which will certainly reduce the level of infestation during the next generations. Recent identification and the successful application of the sex pheromone of LDM are considered a promising tool for mass trapping LDM males. Pheromone baited traps can be used for wide area coverage (suggested 1 trap/ ha). However, the number of traps is decided according to the area of plantation, density of trees in the orchards, height of trees, and surrounding agro-ecological conditions. The pheromone should be hung on the tree at a suitable height (2- 4 m) for better capture (Fig.3). Moreover, trap and kill technique could be of benefit if a proper formulation containing both the sex pheromone and an environmental friendly insecticide are applied on bunches after pollination. Using both light and pheromone traps at the same station (such as Pherolite type traps), both male and female populations would be attracted and could reduce the source of infestation for the next generation. Well-trained farmers through farmer field schools (FFS) or other training programs would be of great help for providing assistance in distributing and maintaining pheromone traps in the intended region.

4.7.6. Chemical control

Chemical insecticides have been the main control measures used for wide spread application against this pest in most date palm growing regions in the world. The Organophosphate and Carbamate groups were used during the sixties and eighties of the past century, followed by the Pyrethyroid group and some other recently introduced insecticides. These insecticides are used either as dust with pollination or as ground and aerial spray through large-scale campaigns supported by the national governments of many date palm growing countries (Ali et al., 2010; Al-Jboory et al., 1999; Ba-Angood, 1978; Bahar et al., 2010).

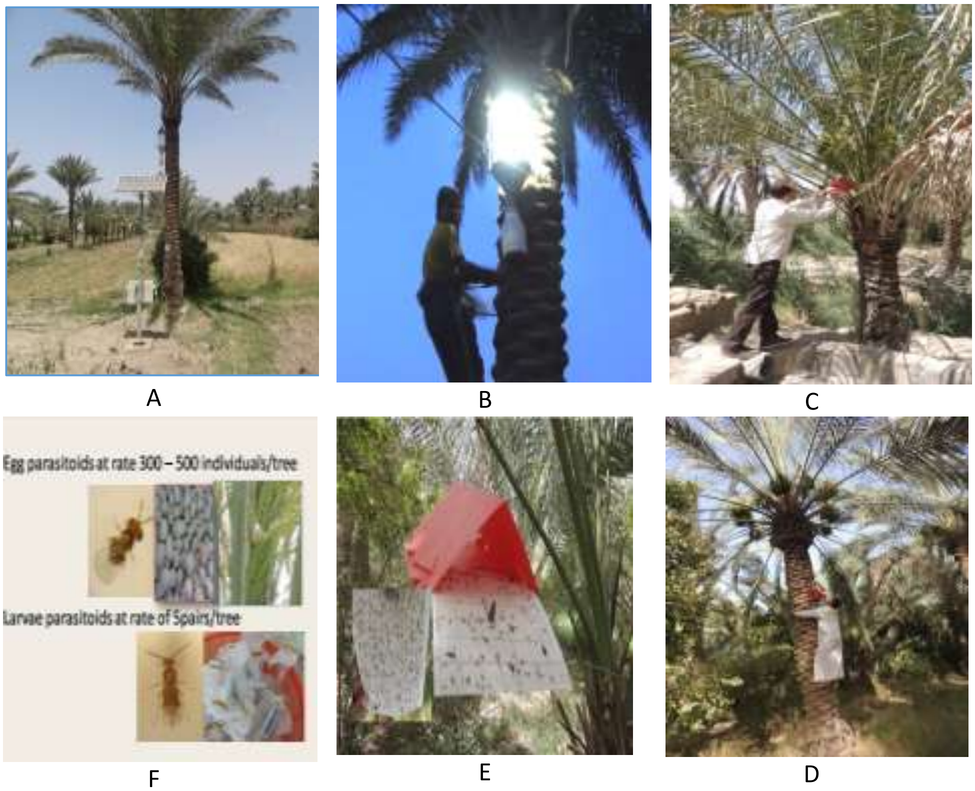


Fig. 3. Elements applied for the management of lesser date moth (A,B) , Location of light traps, (C,D), Location of pheromone traps, (E) Caches of LDM , (F) The egg parasitoids *Trichogramma* spp. (upper), The larvae parasitoids *Bracon spp.*(Source: Abdul-Sattar A.Ali)

Misuse of these pesticides for an extended period has caused many negative consequences, such as the development of multiple resistances toward various groups of pesticides, adverse effects on natural enemies, and other non-targeted organisms, resurgence of secondary pests to the level of principal pests, in addition to the effects on the environment and on human health. At present, the use of pesticides is not economically and environmentally recommened, due the low efficiency of most pesticides currently in use. Therefore, the national agricultural policy in the intended countries started moving towards safe alternatives in managing epidemic pests. Based on this concept, less toxic materials which are called environmentally friendly pesticides are considered as safe alternatives for controlling LDM and other date palm pests (Lysandrou et al., 2010; Sayed et al., 2010). However, most of these insecticides are not effective unless they are used early in the season at the time of pollination, when the first instar larvae are susceptible to insecticides and exposed to contact or stomach insecticides applied to the bunches. In organic plantations, the LDM is controlled by the application of several permitted insecticides, such as *Bt* compounds and Kryocide (cryolite), which is an inorganic stomach and contact insecticide. Other bioinsecticides include Spinosad (Tracer) summer oil, Matrine, virus (CYD-X), and some other biorational and botanical pesticides all are promising components when applied properly.

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5. IPM of Termites in Date Palm

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5.1. Introduction

Termites are social insects that live in colonies and feed primarily on cellulose and lignocellulose. They can inflict serious damage on woody agricultural and forest plants, beside building materials and furniture. Termites can also play an important role in the decomposition and recycling of lignocellulose in the ecosystem (Krishna et al., 2013). There are more than 3000 species of termites in the world. Of this number, only about 370 species are considered pests of significant importance and 70% of these pestiferous species are higher termites, belonging to the family Termitidae (Engel et al., 2009). Date palm can be severley damaged by termites, particularly by species of the families Termitidae, Hodotermitidae and Rhinotermitidae (Wood and Kambal, 1984; Logan and El-Bakri, 1990; Kaakeh, 2005).

5.2. Distribution and host range

Throughout the world, termites are widely spread in the semi-arid, sub-humid tropics and tropics, where they cause significant crop losses (Harris, 1971, Rouland-Lefévre, 2011). Termites are polyphagous pests, feeding on a wide host range of agricultural and forest crops, including coconuts, other palms, sugar cane, rice, maize, wheat, cassava, yam, cotton, coffee, tea, cocoa and pastures (Kaakeh, 2005; Rouland-Lefévre, 2011). The most important species of termites reported on date palms are found in the two genera *Odontotermes* and *Microtermes* (Wood and Kambal, 1984). The distribution of termites reported so far on date palm is shown in Table 1.

Table 1. Species of termites reported on date palm and their geographical distribution

Species	Family	Distribution	References
Odontotermes sudanensis Sjostedt	Termitidae	Sudan	Gentry,1965
Odontotermes sp.	Termitidae	Sudan	Logan and El Bakri,1990
Odontotermes obesus Rambur	Termitidae	India	Kranz et al., 1978
Microtermes najdensis (Harris)	Termitidae	UAE	Kaakeh, 2005

Species	Family	Distribution	References
Microcerotermes diversus (Silvestri)	Termitidae	Saudi Arabia, Iraq, Iran, Israel, UAE, Oman, Kuwait	Blumberg, 2008; Kaakeh, 2005; Logan and El Bakri,1990
Amitermes desertorum (Desneux)	Termitidae	Egypt	Ahmed and Mohany, 2008
Macrotermes sp.	Termitidae	Mauritania	Carpenter and Elmer, 1978
Coptotermes sp.	Termitidae	Mauritania	Carpenter and Elmer, 1978
Ibostoma sp.	Termitidae	Mauritania	Carpenter and Elmer, 1978
Anacanthotermesorchraceus (Burmeister)	Hodotermitidae	UAE	Kaakeh, 2005
A. ubachi (Navas)	Hodotermitidae	UAE	Kaakeh, 2005
Psammotermeshypostoma (Desneux)	Rhinotermitidae	UAE	Kaakeh, 2005
Heterotermesaethiopicus (Sjostedt)	Rhinotermitidae	UAE	Kaakeh, 2005

5.3. Damage and economic importance

Generally, termites attack date palm in two main ways, i) internal damage and ii) external damage. Wood and Kambal (1984) described these two types of damage on date palm caused by *Odontotermes* sp. in northern Sudan, as illustrated in Table 2.

Table 2. The differences between two types of injury inflicted on date palm by *Odontotermes* (Isoptera) in northern Sudan

External foraging	Internal foraging
Soil covering or sheeting on the outside of the trunk that rarely extend to the fronds and fruit bunches	No soil sheeting
Termites feed externally on the trunk	Feeding is internal (inside the trunk)
The damage causes gradual weakening of the palm trunk	The damage causes sudden development of big cavities in the trunk
Progress of damage is relatively slow process. Thus, the collapse of the palm may take a longer time	Progress of damage appears to be rapid and accordingly, the collapse of the palm
The damage is obvious and when the soil sheeting or tunnels are scraped, termites can be easily seen feeding on dead tissues of the trunk	Damage is cryptic and less obvious as the termites feed internally on the central portion of the trunk. Damage can only be detected after appearance of small cracks on the trunk. Enlargement of these superficial cracks reveals the hollow-out interior of the trunk
Mortality of the palm is less common	Mortality is widespread
The chance of rescuing the palm is greater	The chance of saving the palm life is little

The hollowing out of the palm roots and trunk block the passage of water and nutrients to the canopy of the plant, which may eventually lead to yellowing, withering, and ultimately the death of the palm and offshoots (Carpenter and Elmer, 1978; Kaakeh, 2005). Termites cause injury to the date palm trunk, base of frond, fruit stalks, and dates (Fig. 1).

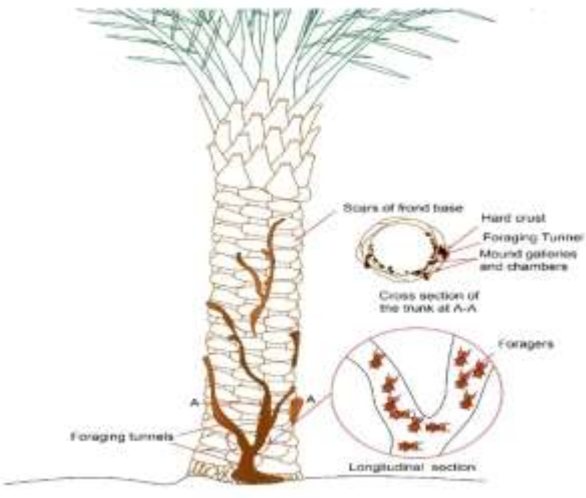
Fig. 1. Termites injury on date palm trunk (A), frond base (B), fruit stalk (C), dates (D) (Source: Hamadttu A. F. El-Shafie)

In heavy infestations, the soil sheeting made by the termite around date palm trunk and fronds (Fig. 2) may weaken the palm by reducing photosynthesis. However, there are no estimates on yield loss due to such damage (Logan and El-Bakri, 1990).

Fig. 2. Date palm trunk completely covered by termite soil sheeting in northern Sudan (Dongola) (Source: Mahdi A. A. Mohamed)

On the other hand, light infestation is characterized by the presence of external foraging tunnels (Fig. 3). Several authors have reported economic damages caused by termites on date palm (Carpenter and Elmer, 1978; Zaid et al., 2002; Ahmed and Mohany, 2008). Losses by termites on date palm can reach 70% or even 100% in case of young palm and offshoots (Wood and Kambal, 1990; Logan and El-Bakri, 1990).

Fig. 3. A date palm trunk showing termite external foraging tunnels (Drawing: Maged E. A. Mohammed)



5.4. Biology

Termites are social insects with a polymorphic caste system and incomplete metamorphosis, i.e., pass through egg, nymph, and adult stages. They live in colonies, consisting of a fertile reproductive form (queen and king) and an infertile form, which comprises workers and soldiers (Fig. 4).

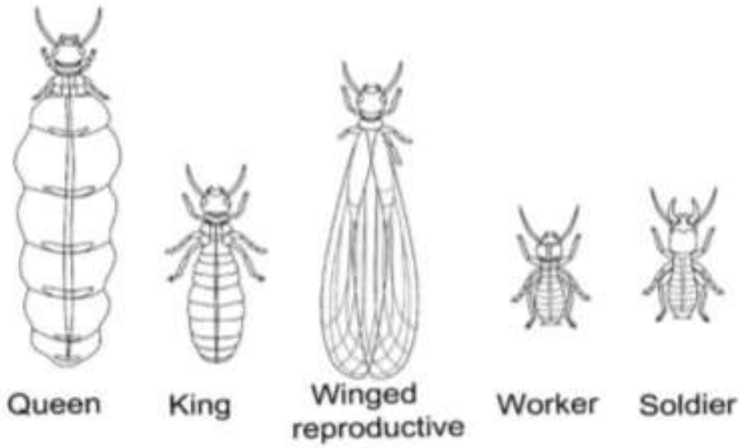
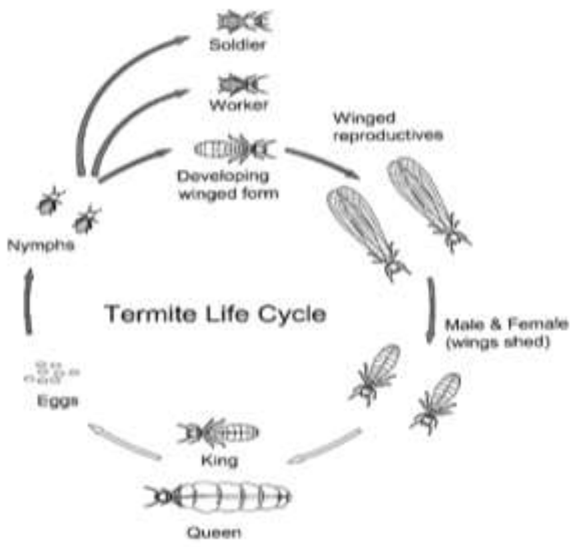


Fig. 4. Morphology of the different castes of the termite colony (Drawing: Maged E. A. Mohammed)

In higher termites, caste is determined early in development and workers and soldiers are unable to reproduce or develop into reproductive alates (Hartke and Baer, 2011). The queen has an enlarged abdomen, known as physogastric, and her sole role is to lay eggs and produce pheromones that differentiate the castes and keep the coherence of the colony. The king only performs the role of inseminating the queen. On the other hand, the workers perform activities related to foraging, attending and feeding the queen, taking care of the immature or broods, constructing and maintaining the nest. The soldiers only have the task of defending the colony against intruders and hence their mandibles or jaws are enlarged and well developed (Eggleton and Tayasu, 2001). During the rainy season, the alate reproductive forms (virgin queens and kings) mature in the colony and fly for a short while (nuptial flight) before landing on the ground and sheding their wings. It has been reported that the swarming events of termites is triggered by environmental factors (Nutting, 1969). After pair formation, the male usually follows and touches the female abdomen while she is searching for a nestting place. This phenomenon is considered by some scientists as a mating ritual and is called tandem running (Hartke and Baer, 2011). The newly formed couple then settle in the soil in case of subterranean termites and they mate. The queen then starts to lay eggs and finally a new colony is established. The life cycle of termites is illustrated in Fig. 5.

Fig. 5. A diagram illustrating a generalized life cycle of termites (Drawing: Maged E. A. Mohammed)



5.5. Integrated management

Colonies of subterranean termites are very difficult to control after their establishment, because of the concealed nature of such colonies. Moreover, when infested palms collapse due to external forces, the reproductive forms of the mother colony may stay in the stump and the rest of the colony may succeed in establisng a new colony away from the original one (Giblin-Davis, 2001). A basic understanding of the termite biology and diversity is essential for designing an effective control strategies against them (Logan et al., 1990, Rouland-Lefévre, 2011). For example, the two termite genera *Microtermes* and *Odontotermes* (both inflict serious damage on date palms) are subterranean and fungus-growing termites (Wood and Kambal, 1984). The fungal comb is essential for the survival of the colony, because it facilitates the digestion of cellulose for the termites. Thus, the removal or destruction of the fungus garden can indirectly control the termites. Other facts about termites that can be used to design control strategies include trophallaxis and grooming behavior, preference for food, cryptic nests, and mining into plant tissues (Rouland-Lefévre, 2011). Generally, the strategies for the integrated management of termites fall into three categories; i) preventing termites gaining access to the plants, ii) reducing termite densitites arround the plants, and iii) rendering plants less susceptibe to attack by termites (Logan et al., 1990). These strategies of termite management can be achieved by implementing the following tactics in an integrated approach:

5.5. 1 Monitoring

Monitoring and scouting is essential to detect termite infestation at an early stage before the established colony becomes too large. Termite activity in date palm can be monitored by placing corrugated cardboards and toil paper rolls in 10 cm deep holes among trees at 2 cm interval (Kaakeh, 2006; Ahmed and Mohany, 2008). These monitoring tools can also be used to assess the effectiveness of termiticides. Termite runways and soil sheeting can also indicate termite infestation during visual palm inspection. However, one should distinguish between old tunnels and active ones by just scraping off these galleries and looking for termite foragers beneath.

5. 5. 2. Cultural control

The aim of cultural practices is to increase plant vigor and simultaneously reduce termite numbers or modify their behavior (Logan et al., 1990). It is important to notice that newly transplanted date palm offshoots are more susceptible to termite attack, because their roots are not well established and the whole plants are still under transplanting shock. Therefore, they need to be given special care. The most important cultural methods that can be used in the management of termites in date palm are listed as follows:

- Proper palm spacing to avoid the spread of termites from infested to uninfested trees through roots frond contacts or through the soil (Giblin-Davis, 2001)
- Deep tillage of soil around palms to expose subterranean termites to the sun and predators (Rouland-Lefévre, 2011).
- Regular irrigation and proper fertilization to keep palm vigorous and healthy. It has been mentioned that a lack of irrigation, disease, wounding, weed infestation, lack of fertilization, and poor palm husbandry predispose the date palm to attack by termites (Logan and El-Bakri, 1990).
- Cleaning of weeds, which may compete with the crop for water and nutrients, hence increases the plant susceptibility to termite attack (Logan et al., 1990).
- Mulching around date palm with plant materials known to have repellent effect against insects such as *Melia azedarach*, *Cassia siamea*, and *Azadirachta indica* (Verma et al., 2009)
- Removal of debris and palm remains can reduce the potential sources of termite food that may have a negative effect on their population. However, the removal of alternative food may also urge the termites to feed on the crop (Logan et al., 1990). This generalization may not be applied to different termite species and different crops. One has to evaluate each situation individually.
- Painting date palm wounds with materials having termite repellency to avoid infestation. Dry-wood subterranean termites usually enter their living host plants through wounds or damage by fire (Harris, 1971).

5.5. 3. Biological control

The alate reproductive form of termites are subject to predation by specialist or opportunistic predators while they are swarming and settling to form new colonies. Forgaers outside their nests are also liable to attack by predators. Arthropod predators include scorpions, spiders, centipeds, dragonflies, cockroaches, mantids, cricket, beetles, flies, ants and wasps (Wood and Sand, 1978). On the other hand, vertebrate predators include fish (when alates land on water bodies), reptiles, amphibia, birds and mammals (Nutting, 1969). Among all these predators, ants are considered the most important ones in regulating the numbers of termites. It has been mentioned that farmers encourage population of ants in their maize fields by baiting them with sugar and meat in order to reduce the termites population (Sekamatte et al., 2001). However, care should be taken, if this technique is to be applied in date palm, since some ant species are harmful to date palm through fostering honeydew-producing insects that damage palms. Some ant species can also cause nuisance to laborers in date palm plantations. The fungi *Metarhizium anisopliae* and *Beauveria bassiana* were reported to be effective against termites (Sun et al., 2003). Additionally, the entomopathogenic nematodes of the genus Steinernema were used as biocontrol agents against termites (Laumond et al., 1979). Qasim et al. (2015) gave a comprehensive review on the biological and microbial control of termites. Despite the presence of many pathogens that cause diseases in termites, their biological control is difficult due to the behavioral reaction of termites towards infected individuals, which are isolated from healthy ones (Logan et al., 1990).

5.5. 4. Chemical control

In the past, persistent insecticides, such as aldrin and dieldrin (organochlorine), were successfully used for the chemical control of termites in date palm (Wood and Kambal, 1984). Organochlorines were phased out and replaced by chlorpyriphos (organophosphate) and carbamates, such as carbosulfan and aldicarb, which were less persistent. Recently, persistent insecticides such as fipronil (phenyl pyrazole) and thiamethoxam (neonictonoids) have been introduced in the chemical management of termites (Sharma et al., 2008; Maienfisch et al., 2001). Date palms and offshoots with light termite infestation can be sprayed with suitable termiticide after scratching and removal of soil tunnels. The turning of the soil around the palms (about 50 cm deep) to disrupt termite runways followed by application of insecticides or making a drench of 30 cm wide and 50 cm deep around infested palm, then treat it with proper insecticide in water (Zaid et al., 2002). Non-repellency and slow action are the two desired characteristics upon which a termiticide, for soil treatment, should be selected. Such termiticide will allow foragers to disseminate the chemical in their nest through the trophallaxis behavior (Kard, 2003).

5.6. Conclusions

Despite the difficulty of controlling subterranean termites in date palm, successful management can still be achieved through a combination of cultural practices, biological control, and minimal application of selected insecticides. Bait technology to target the colony and controlled-release formulations of non-persistent insecticides may provide potential alternatives for future management of termites in date palm plantations.

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Chapter V

Management of Mites of Date Palm

Chapter V

Management of Mites of Date Palm

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1. Scientific name

Oligonychus afrasiaticus (McGregor)

2. Description

The dust mite belongs to the order prostigmata and the family Tetranychidae. Like all members of the phylum Arthropoda, it has a jointed body and jointed legs, which are usually four pairs in the adult stage compared with only three pairs in insects. Mites can be differentiated from insects because they have their bodies divided mainly into two regions; the gnathosoma or the capitulum (combined head and thorax) and idiosoma or the abdomen. Insect on the other hand have their body regions divided into three parts, head, thorax and abdomen. Mites have neither antennae nor wings, whereas most insects do have one pair of antennae and two pairs of functional wings.

The dust mite is oval and slightly flat on the backside. Adults range from 0.2 mm to 0.5 mm in length and 0.17 mm to 0.2 mm in width (Fig. 1A). The dust mite exhibits sexual dimorphism with the end of the body being round in the female and somewhat tapering in the male. The egg is spherical and about 0.1 mm in diameter with varied colors of yellow, pink or red (Fig. 1B). Larvae have three pairs of legs and are smaller (0.15 mm – 0.20 mm) compared to the nymphs and adults (Fig. 1C). The larvae assumee orange, yellowish white or yellow colors. The nymphs possess four pairs of legs and their colors range from light yellow to light orange. They resemble adults morphologically; however, their sizes are usually smaller.

3. Distribution

Oligonychus afrasiaticus is widely distributed in the old world (the Middle East and North Africa). It is reported in the following countries: Iran, Iraq, Saudi Arabia, United Arab Emirates, Bahrain, Oman, Kuwait, Yemen, Jordon, Israel, Libya, Tunisia, Algeria, Morocco, Egypt, Sudan, Chad, Mauritania, Mali, and Niger. The Banks grass mite, *Oligonychus pratensis* is another important species found in the new world, particularly in the United

States, where it is considered as the second major date palm pest after the carob moth. It is also reported in Algeria, Egypt, Morocco, Senegal, Sudan, Iraq, Pakistan and India. Minor date palm mites of less significance and their distribution are shown in table 1.

Table 1: Minor mite species reported on date palm

Common name	Scientific name	Remarks
Spider mite	*Eutetranychus palmatus* Attiah	Egypt and Israel
Red palm mite	*Raoiella indica* Hirst	Egypt, Saudi Arabia
Red and black flat mite	*Brevipalpus phoenicis*	Saudi Arabia
Date palm bud mite	*Mackiella phoenicis*	Saudi Arabia
Brown date palm pinnae mite	*Eutetranychus banksi*	USA, Saudi Arabia
Yellow date palm mite	*Paratetranychus simplex* Banks	Saudi Arabia

4. Host range

The dust mite is an oligophagous, attacking Arecaceae and few other hosts in the families Poaceae, Cucurbitaceae, Solanaceae, and Convolvulaceae. A list of reported alternative hosts for *Oligonychus afrasiaticus* is given in table 2.

Table 2: Important alternative hosts of the date dust mite

Common name	Scientific name	Family
Canary Island date palm	*Phoenix canariensis*	Arecaceae
Sorghum or durra	*Sorghum bicolor*	Poaceae
Sugar cane	*Saccharum officinarum*	Poaceae
Bermuda grass	*Cynodon dactylon*	Poaceae
Cogon grass	*Imperata cylindrica*	Poaceae
Eggplant	*Solanum melongena*	Solanaceae
Muskmelon	*Cucumis melo*	Cucurbitaceae
Field bindweed	*Convolvulus arvensis*	Convolvulaceae

5. Damage and Symptoms

Date mites infest developing fruits in the Kimri and Khalal stages. Infestation may start immediately after fruit set (Fig. 2A, B), then increases gradually and peaks in mid-summer during June and July. The mite population decreases drastically during the Rutab stage, and a few or no mites are found during the Tamr stage (Fig. 3). Adults and juveniles (larvae and nymphs) feed upon developing fruits by lacerating the skin with their chelicerae and then sucking the sap that oozes out thereafter. This feeding behavior initially produces a silvery appearance (symptoms) on the infested fruit due to the presence of air bubbles in the damaged cells. These symptoms are similar to thrips damage, which feed in the same manner. The severely infested fruits change to a brown color, harden and become unfit for human consumption (Fig. 4). The infestation usually starts at the calyx end of the fruit and then progresses to the fruit tip. This pattern of infestation development is similar in almost all date palm cultivars (Fig. 5). Due to the sucking of fruit sap and the secretion of feeding enzymes, the skin of the fruit becomes leathery with a cork texture due to cracking. The fruit shrivels, stops its development, and its sugar content decreases. The mite spins silken webs around fruits and strands, which collect fine dust and sand particles during the windstorms of the summer (Fig. 6). The dust mite can also attack the pinnae (leaflets); however, less emphasis is given to such kind of damage. The pattern of mite infestation on fruit bunches can be clumped, i.e., heavy infested bunches may be found adjacent to non-infested ones (Fig.7). This phenomenon might be explained by the arrival of air-borne mites and their limited mobility after the initial establishment of the colony. In this respect, more investigations are needed to study the epidemiology of dust mite during the fruiting season of date palm. Infestation by the dust mite becomes severe in date palm trees grown adjacent to dusty roadways and on the margins of the orchards. Also overcrowding palm trees are more readily infested, due to activity of ambulatory mites, than in widely spaced palms. Neglected farms suffer more often from mite infestation than well-managed ones.

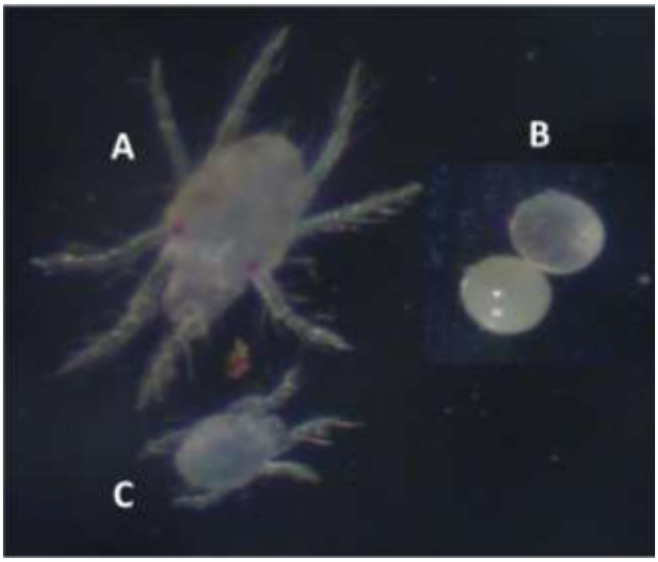

Fig. 1. Old world date palm dust mite, Oligonychus afrasiaticus, life stages; (A) adult, (B) egg and (C) larva (Source: H. El-Shafie)

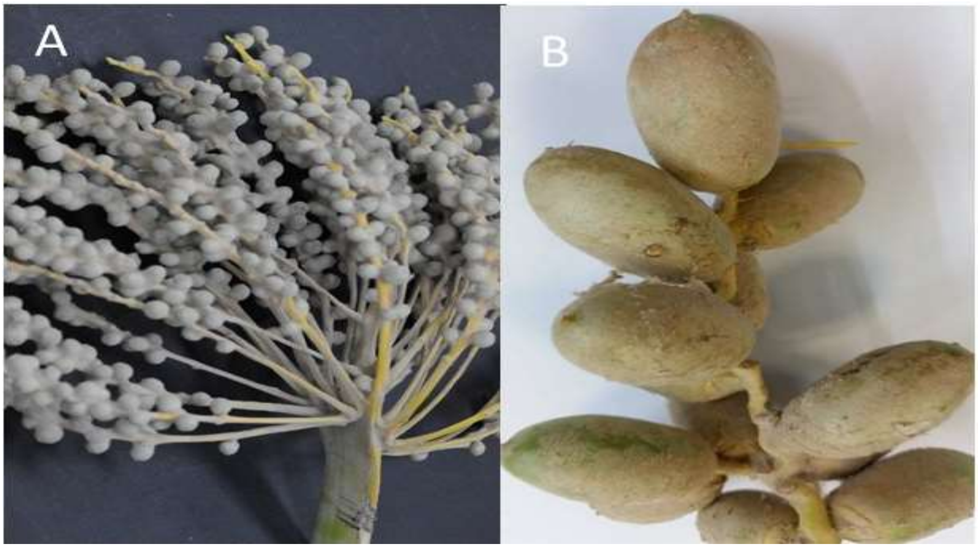

Fig. 2. Dust mite infestation on date bunch; (A) just after fruit setting (Hababouk stage), (B) at Kimri stage (Source: H. El-Shafie)

Fig. 3. A hypothetical diagram illustrating the population levels of date palm dust mite during different stages of fruit development (Source: H. El-Shafie)

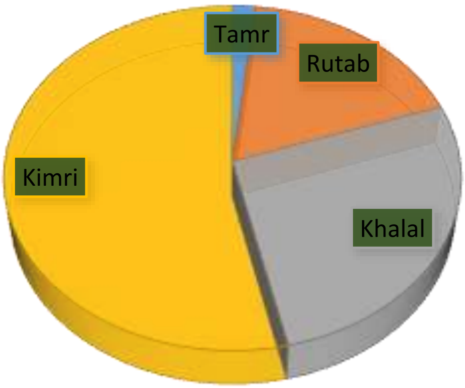

Fig. 4. Symptom of dust mite infestation on immature date fruits (Source: H. El-Shafie)

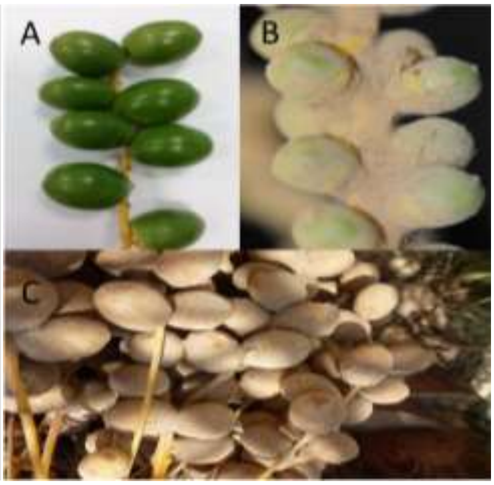

Fig. 5. Pattern of dust mite, Oligonychus afrasiaticus infestation on two different datepalm cultivars (A & B) (Source: H. El-Shafie)

Fig.6. Dust mite webbings; (A) health fruits, (B) infested kimri stage with heavy webbings, (C) fine dust attracted to webbings on Khalal stage (Source: H. El-Shafie)

Fig.7. Clumped dust mite infestation showing heavily infested bunch adjacent to non-infested one (Source: H. El-Shafie)

6. Economic importance

The dust mite attacks the developing fruits, which represent the final yield component. Such direct damage cannot be compensated for, unlike damage on pinnae (leaflets) or other parts of the palm tree. Damage loss due to mite infestation on fruits may reach 70% and sometimes a even 100% loss may occur. In addition, the expenditures on purchasing acaricides, labor cost for control operations increase cost of production, which eventually results in a negative impact on the growers' returns.

7. Biology

The date dust mite passes through four distinct developmental stages, namely egg, larva, nymph, and adult (Fig. 8). An individual female can lay about 50-100 eggs usually on fruit strands, fruits and frond and dies after completion of the egg-laying process. As a maternity care, female holds its tiny eggs on the silken webs with sticky substance to protect them from being blown away by the wind or any other factors (Fig. 9). The dusty silken webbings produced by the mites around the fruit and fruit strand provide a microclimate within which the mites feed and multiply away from predators and unfavorable environmental conditions. Eggs are usually laid in clusters and more than 100 mites may be found per fruit bunch depending on the level of infestation. Eggs hatch after 2-3 days and an oval pale green tinny larva (0.2 mm) emerges with three pairs of legs as a distinguishing character. The larva feeds for two days, then enters a period of quiescent (larval chrysalis) for one day before molting into protonymph, which has a yellow color and four pairs of legs. The protonymph feeds for 1-2 days, then enters into a quiescent period (protochrysalis) of one day. It then molts into a deutonymph that feeds for one day and enters a period of quiescent (deutochrysalis), before finally molting into an adult. Many individual mites may be found together in a small area forming a colony, which includes different developmental stages (Fig. 10). The date palm dust mite prefers hot dry weather and generation time may be two weeks depending on the prevailing temperature. Accordingly, up to 10 generations or more can be produced annually. During the date palm fruiting season, wind, birds, and insects, particularly wasps that touch the mite webs on the fruit bunches, can disseminate the dust mite. After harvesting, the mites migrate to the fronds surrounding the palm heart and pass the winter between the fiber and frond bases. It can also move on the weeds around the date palm trunk presumably from fallen infested fruits.

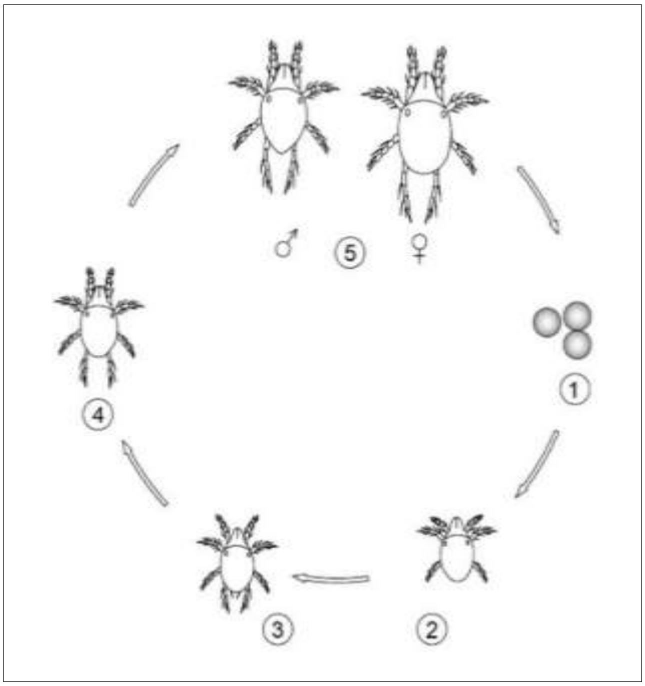

Fig. 8. Life cycle of the date dust mite, Oligonychus afrasiaticus; (1) egg, (2) larva, (3) protonymph, (4) deutonymph, and (5) adult (Source: H. El-Shafie)

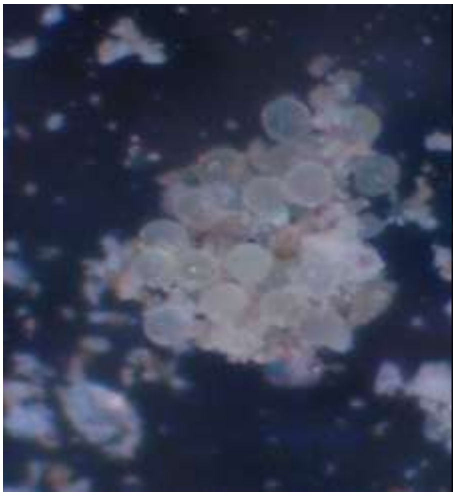

Fig. 9. A cluster of *Oligonychus afrasiaticus* eggs attached to the silken webbings (Source: H. El-Shafie)

Fig. 10. A colony of the old world date palm dust mite, *Oligonychus afrasiaticus* (Source: H. El-Shafie)

8. Management

8.1 Population monitoring

Proper identification and counting of mite species are essential in setting up monitoring and management strategies. For counting mites, the following equipment and materials are needed:

1) A paper bag to collect samples from the field.

2) An insulated icebox to transfer and store collected samples at 4ºC before examination. This cooling will stop the crawling of mites out of the collection bags.

3) A leaf-brushing machine to remove mites from date palm pinnae. The machine is a device with rollers covered with soft bristles that brush mites from the leaf onto a revolving glass plate coated with a slightly sticky substance (Fig. 11A).

4) A mite grid or paper (Fig. 11B) to be placed beneath the glass plate containing mites to help keep track during the count. The average counts of mites in three randomly selected triangles can be multiplied by the number of triangles in the grid to estimate the total number of mites present in the sample.

5) A funnel unit for extracting mites from fruits (Fig. 11C). This device is used to collect small animals, such as insects and mites, from soil or leaf litter samples. A sieve is fixed across the wide end of the funnel, where a 100-watt light bulb coated with a metal reflector is placed 25 cm above the funnel. The heat generated by the bulb warms the samples causing the mites to migrate downward and fall through the sieve into the funnel and finally into a tube containing 70% alcohol.

6) A fine camel-hair brush for manually removing the mites from fruits and pinnae, if other extraction equipment is not available (Fig. 11D).

7) Glass vials containing 70% alcohol for storing mite samples

8) A stereoscopic microscope to identify individual species or different developmental stages of the same species.

9) Hoyer's medium, microscopic slides for permanent mounting of individual mites.

Fig. 11. Equipment for extraction and counting of mites; (A) mite-brushing machine, (B) a mite grid or paper, (C) funnel unit, (D) camel-hair brush (Source: H. El-Shafie)

For monitoring date mites, 10 palms from a plantation (2 located on each cardinal direction north, south, west and east and 2 in the middle can be selected for sampling. Ten fruits and ten pinnae from each palm (100 fruits and 100 pinnae) can be collected at a weekly interval from the time of fruit setting until harvest. Fruits should be taken from bunches located in the four cardinal directions of the compass in case of uniform infestation on all bunches of the palm. If infestation is restricted to only few bunches (Clumped), then a stratified sampling procedure can be followed, i.e., categorizing infested bunches into different strata according to the level of infestation, then making random fruit selection from each stratum. Extraction and counting of mites can be carried out as described above. The percentage of infested fruits, as well as frequency of total palm infestation (number of infested palm/total number of date palm trees), can be calculated at each sampling date. The adult cumulative mite-days (ACMs) can be used to estimate the seasonal mite population dynamics. Mite-days are defined as one mite present per fruit strand for one day and is calculated as the mean of two successive counts multiplied by the number of intervening days. Due to the small size of the mite and the difficulty of counting, mite population on infested date palm can be monitored by the presence of webbing. The relationship between development of mite webbing and degree-days (DD) can also be used to monitor mite population. A sampling plan for the date palm dust mite based on the economic threshold needs to be developed.

8.2. Cultural control

Several cultural practices may be adopted against date palm dust might alleviate its negative impact on fruit quality. These practices can be summarized as follows:

1) Keeping inter-palm spacing of 8-10 meter, which provides good aeration and sun radiations sufficient to kill all stages of the mite.

2) Removing old bunches and remains of spathe, old fronds and fibers, which act as overwintering sites for hibernating mites (Fig 12A).

3) Removing and destroying fallen fruits in the leaf axil and on the ground.

4) Phytosanitation of the orchards, including removal of weeds around the palm trunk, which act as alternative host for the mite during the absence of fruits (Fig. 12B).

5) Bunch covering using suitable paper or plastic bags to avoid the arrival of airborne mites. Bagging might not prevent mite infestation, but at least it can lessen the spread of initial infestation (Fig. 13).

6) Controlling birds, wasps, and other insects that mechanically transport the mites through their movement from one palm to another.

7) Maintaining healthy palms through balanced irrigation and nutrition.

8) Spraying of infested bunches with cold water (4ºC) to remove the webbings and dislodging the different developmental stages, particularly the eggs which usually adhere to the webbings.

8.3. Host plant resistance

Some date palm cultivars may exhibit different levels of resistance to infestation by the dust mite. However, until now this resistance is not exploited for field management of this pest. Seasonal pests, such as date mites, usually synchronize their abundance with the time when most of the date fruits are in the kimri stage. The asynchrony between the pest and host plant makes it possible for the latter to escape attack by completing the development of its susceptible stage before the pest appears or after it has disappeared. In this respect, late or early maturing date palm cultivars may escape mite attacks and thus show some degrees of resistance.

Fig. 12.(above) Phytosanitation of date palm orchard; (A) removal of old fronds and fibers, (B) Bermuda grass at the base of young date palm (Source: H. El-Shafie)

Fig.13. (left) Bunch covering with plastic bags to help lessen mite infestation and dispersal by frugivorous bird (Source: H. El-Shafie)

The synchronization between the peak of mite population and the susceptible stage of date fruits is an important aspect in the biology of this mite. The variation in flowering phenology of the different date palm cultivars may be responsible for the asynchrony between the peak population of mite and the susceptible stage of fruit development. The architecture of fruit bunch, fruit hardness, and sugar composition were reported not to be responsible for the resistance observed in some date palm cultivars. Thus, further studies on the chemistry of immature date palm fruits are needed to unravel the role of different constituents, including water content, as limiting factors in the build up of mite populations.

8.4. Biological control

Many attempts have been made to utilize natural enemies for controlling the dust palm mite. The high rate of multiplication of this species may exceed the potential of native predators; nevertheless, the preservation and encouragement of these indigenous predators may yield promising results. This strategy may seem better than the introduction of exotic predators that may not be able to adapt well to the harsh summer conditions that coincide with the peak population of the dust mites. A list containing potential predators of dust mite, including both phytoseiid predatory mites and coccinellids beetles, is shown in Table 3.

Table 3: Potential predators for biological control of date dust mite, *Oligonychus afrasiaticus*

Common name	Scientific name	Family	Remarks
Predatory mite	*Phytoseiulus persimilis*	Phytoseiidae	Commercially available
Predatory mite	*Neoseiulus californicus*	Phytoseiidae	Commercially available
Predatory mite	*Neoseiulus barkeri*	Phytoseiidae	Tested in the laboratory
Predatory mite	*Cydnoseius negevi*	Phytoseiidae	Tested in the laboratory
Lady bird beetle	*Stethorus punctillum*	Coccinellidae	Voracious mite feeder
Lady bird beetle	*Pharoscymnus avoideus*	Coccinellidae	General predator
Lady bird beetle	*Pharoscymnus numidicus*	Coccinellidae	General predator
Green lacewing	*Chrysoperla carnea*	Chrysopidae	Tested in the laboratory

8.5. Chemical control

Many commercial acaricides are available on the market that can be used against date palm dust mites, including hexythiazox, Amitraz, Vertimec. Botanical acaricides, such as abamectin and neem oil, are also available. These chemicals should be used only if other control measures fail. Dusting sulfur on fibers between the frond and trunk, where large colonies of overwintering mites exist would reduce the mite population in the following season. This preventive treatment is used at a rate of 50-100g/palm according to age of the tree (Fig. 14A). Male date palms and infertile female palms should also be treated because the mites may migrate to them.

Excessive use of insecticides, particularly organophosphorus and carbamates, may change mites from a secondary pest to a primary one due to the killing of its natural enemies. Insecticides may also cause the dispersal of mites by exciting established colonies. If chemicals are chosen, then they should be selected carefully and one curative treatment with proper acaricide may be enough to control the mite population, depending on the level of infestation (Fig. 14B and C). Since mite infestation occurs simultaneously with fruit insect pests, abamectin, which acts as both insecticide and acaricide, can be used. Synchronizing management measures of many date palm pests will save efforts, ensure healthy date fruits for consumers, and lessen the adverse impact of pesticides on the date palm agro-ecosystem.

As remedial measurements, infested bunches can be dusted with Agricultural sulfur at a rate of 100-150/palm tree or sprayed with micro-fine sulfur, two weeks after fruit setting. It is not recommended to apply acaricides to combat this mite, unless really needed, because of the likelihood of emergence of resistant mite populations. Mites are known to have a high genetic plasticity and few chromosomes that enable them to develop resistance against pesticides faster than other groups of arthropods.

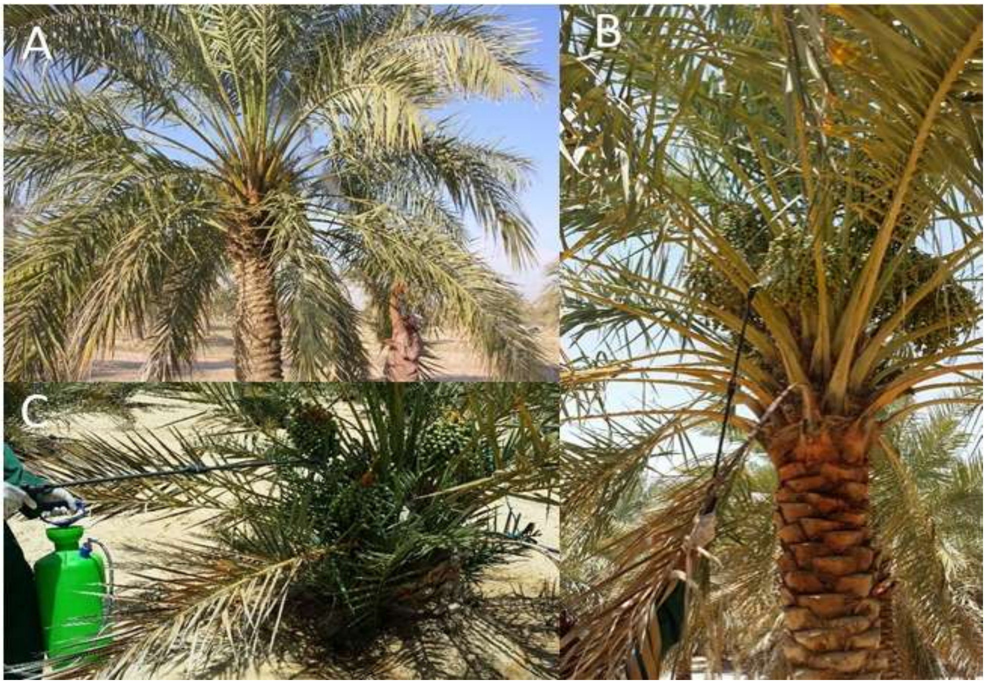

Fig. 14. Spraying of chemicals against date dust mite; (A) preventive spraying, (B, C) curative spraying (Source: H. El-Shafie)

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Chapter VI

Management of Diseases of Date Palm

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1. Fungal Diseases

1.1. *Bayoud Disease, Fusarium Wilt*

1.1.1. Scientific name

Bayoud or *Fusarium wilt* of date palm is caused by the soil-borne fungus *Fusarium oxysporum* f. sp. *albedinis* Kill. & Maire (Imperfect fungi, Moniliales, Tuberculariaceae). It is incontestably the most serious fungal disease of the date palm (*Phoenix dactylifera* L.). Research on its causal agent in Morocco has focused on the morphological, cultural, biological, biochemical, and molecular aspects of the pathogen (Amraoui et al., 2004; El-Fakhouri et al., 1997; Sedra, 1992a , 1993a,b, , 1997, 2003b, 2005a,b, 2011a,b,c,d,e,f, 2012, 2015a; Sedra and Lazrek, 2011, Sedra et al., 1993, 1998) and on the development of rapid molecular methods for the pathogen identification (Fernandez et al., 1998 ; Sedra, 2003b , 2006a , 2011f, Tantaoui et al., 1996;Sedra and Zhar 2010). In vitro culture on an artificial medium, the fungus often has a late colony and appears curly with a salmon pink color (Sedra, 1993a, b, 2003a). The figures 1d,ef show the cultural aspect of the fungus colony and spore forms.The molecular markers that gave very good results for pathogen identification are based on specific PCR using two couples of two pairs each of primers TL3 (GGTCGTCCGCAGAGTATACCGGC)-FOA28 (ATCCCCGTAAAGCCCTGAAGC) and BIO3 (GGCGATCTTGATTGTATTGTGGTG)-FOA1 (CAGTTTATTAGAAATGCCGCC) that were developed by Fernandez et al. (1998). Other complementary markers have also been developed to complete the diagnosis of strains of the pathogen (Zaher and Sedra, 2010; Sedra unpublished data).

1.1.2. Description and Symptoms

Typical external symptoms are characterized on the leaf by external hemiplegia character (one side dried) and dried palm leaves having the appearance of wet feathers (Fig. 2b,c,h). These symptoms are generally found in Morocco and Algeria and in some localities in Mauritania (Sedra, 1995b, 1999b, 2000b, 2007a, 2015b). The disease can cause atypical symptoms corresponding to bilateral drying and browning, extending to the middle of the rachis (Fig.3a,b). In some cases, atypical symptoms appear on the diseased palms (Fig. 3c,d). Internal symptoms are characterized by browning of the root vessels, trunk, and attacked leaves (Fig. 2d,e,f,g). Infected leaves dry out one after the other until the tree has died. The common symptoms of stiffness and dryness along palm rachis generally characterize Bayoud disease (Fig. 2h). However, these symptoms are not enough to diagnose Bayoud disease because other diseases can cause the same symptoms, such as rotting of the leaf base due to *Botryodiplodia theobromae* that was frequently found when the Bayous disease was discovered in Mauritania (Sedra, 1999a,b, 2000b , 2002, 2003a,b , 2006b, 2007a,b , 2011f , 2015b). In addition, it is possible to meet palms attacked by two diseases including Bayoud with the appearance of different symptoms (Fig. 4 a,b,c)

1.1.3. Distribution

According to Pereau-Leroy (1958), the Bayoud disease most probably had its origin in the Draa Valley of Morocco from which it has advanced both westward and eastward, now affecting most of Morocco's palm groves. In this country, the spread of the disease was particularly rapid and spectacular. Because of its easy dissemination, it advanced from oasis to oasis, following the strings of palm groves that are more or less continuous along the valleys: Draa, Ziz and Gheris. Date palm cultivation in Morocco has been suffering from the effects of Bayoud, which is an epiphytotic disease which is difficult to control, for more than a century. The figures 1 a,b,c illustrate destroyed date palms by the disease in an oasis located in Morocco’s Draa Valley, Algeria and Mauritania. In recent years, about 1,000 Moroccan oases have been affected. Results from satellite imagery, confirmed by field surveys, have permitted the location of 60 foci of the disease in the area of Aoufous in Ziz Valley alone. Also causing significant damage in Algeria, the disease has contaminated several oases in the Centre, West and South of Algeria (Djerbi, 1988, Brac De La pérrière and Benkhalifa, 1991)). This continued spread of Bayoud highlights the dangerous problem, particularly threatening the important plantations of Deglet Nour in Oued Rhir and the Zibans (Algeria) and even in Tunisia as well as all date growing areas in the world.

As mentioned above, the disease was discovered in the North of Mauritania in 1999 and the localities where the Bayoud has been confirmed in Ammaria and Chanker oases not far from Atar city in the region of Adrar (Sedra, 1999a;b, 2000b, 2002, 2004, 2003a,b, 2006b, 2007a,b, 2011f, 2015b). The disease occurs in the majority of the Moroccan date groves and has spread, in recent years, to areas beyond traditional oases (Sedra, 2003b, 2006a, 2009, 2015a).

Similar symptoms of the disease were reported in Egypt, Saudi Arabia and Sudan. Based on molecular markers, some of these strains isolated from diseased roots and leaves showed a great similarity with the pathogen (Sedra and Zhar, 2010). The symptoms on the leaf having external hemiplegia character were found in the Sultanate of Oman and Yemen, but no fungus has been isolated from diseased leaves (Sedra, 2006b,c and Sedra, 2008a) and in

Saudi Arabia (Ammar and El-Naggar, 2011). These symptoms are attributed to the disease called *false Bayoud* (Fig 5a,b,c,d), whose causes are not yet known. The *false Bayoud* shows symptoms characterized by the presence of colour on the fronds, golden yellow wicker on one side of the leaf palm with the survival of wicker opposite green and normal (Fig 5a). In contrary to Bayoud disease, the disease does not cause any change or discoloration in the internal tissues of rachis (Fig. 5d,e). Research on this disease should be strengthened to identify the causes of this phenomenon and develop management options for its control.

Sedra (2001b, 2003b, 2004, 2006a, 2011a,f) summarized the works on Bayoud over several decades. The exact origin of Bayoud disease is not yet known. Sedra (2003a, 2015a) discussed and formulated new hypotheses on the origin of *Fusarium oxysporum* f. sp. *albedinis* (Foa). This author suggested that the pathogen could have evolved from saprophyte strains in the individual countries.

1.1.4. Host range

Date palm is the main host for this pathogen, but it can attack other palm species, such as the Canary Islands palm (*Phoenix canariensis* Chab.). Other species serve as healthy carriers of the pathogen: henna (*Lawsonia inermis* L.) and lucerne (*Medicago sativa*). Based on aggressivness levels and molecular markers, researchers have shown genetic variability in the pathogen population of strains isolated from different hosts and geographical areas (Sedra 1993b, 2003b, 2006b, 2007b, 2008a, 2011f; Tantaoui et al., 1996; Sedra and Zhar 2010).

1.1.5. Damage and economic importance

Bayoud disease is considered to be the most serious disease of date palm, especially in Morocco and Algeria, where it has destroyed more than 13 million date palms of the best date quality and the best known commercial cultivars (Djerbi, 1988, Sedra 2001b, 2003a, 2006a, 2011c, 2015a).

In Morocco, the consequences of Bayoud attack are harmful to oases and have a heavy negative impact on the country’s palm patrimony. Thus, 10 million of date palms were destroyed (i.e., two-thirds of the total), and several cvs. have disappeared, i.e, Berni and Idrar. The best commercial cultivars (Mejhool, Boufeggous, Bouskri, Jihel, Bourar, Aziza Bouzid, and Bouittob) are significantly affected by this disease. Indeed, the groves have lost more than 50 % of the date palms, including productive commercial cultivars, resulting in a loss of a vital source of income for oasis residents. Morocco became an importer of dates because the disease was difficult to control after its spread. For example, last year, the Moroccan importation of dates reached 40% of the national production (Sedra, 2015a). The number of Bayoud foci has considerably increased in the last decades. In fact, within the traditional plantations at the Draa valley for example, the distance between outbreaks of the disease ranges from 50 to 200 m (Sedra, unpublished data). In addition, Bayoud has not only reduced planting density, but also significantly decreased the extent of annual associated plants that were protected by the palms and this has accelerated the process of desertification.

In Algeria, more than three million trees have been destroyed, especially the best commercial cultivars, like the Deglet Noor, which is the dominant cultivar in Algeria. A great part of Algerian oases are now threatened by the Bayoud disease.

In Mauritania, the disease has caused damages and losses estimated to several thousand palms in some contaminated date palm orchards.

1.1.6. Biology

Figure 6 shows the development of the disease on trees from infection to destruction of the palm. In fact, in the same contaminated plot, it illustrates the different stages of the evolution of symptoms on susceptible palms until death. Under favorable conditions in the soil, the fungus spores (Fig. 6) germinate and attack the roots, develop in vessels, and colonize the trunk to infect palms in the apical part of the tree (Fig. 2a). As mentioned above, the typical external symptoms are characterized on the leaf by external hemiplegia character and the internal symptoms are characterized by browning of vessels of the roots, trunk, and attacked leaves (Fig. 6). Infected leaves dry out one after the other until the tree has died, which may be between 6 months and 2 years depending on response level and age of the plant and on the environmental conditions. The dead trees decompose and release the spores of the pathogen into the soil. All organs of the tree can be infected except the spines and dates. The means and the modes of dissemination are numerous, i.e, offshoots, leaves, contaminated soil, decomposed parts of diseased palms, irrigation, root contact, labor tools, transplantation, contaminated manure, and sand-laden wind.

1.1.7. Management

In the contaminated Maghreb countries, different control research strategies were proposed according to date palm grove situations and the importance and the distribution of the foci of the disease (Sedra, 2003a). Thus common, specific and complementary strategies were cited, and these must be co-ordinated in order to ensure durable protection of the Maghreb date palm grove.

The common strategies must: (i) preserve genetic pool without exceptions (particularly rare and threatened cultivars), (ii) develop regulation laws to stop the movement certified offshoots and plants into each country or between countries, (iii) reinforce the system of heightening awareness of farmers, producers, palm product users, public, traders and custom officers on the danger of bayoud disease, (iv) update information maps of Bayoud disease and brittle leaf disease distribution in North African, (v) train staff to be engaged in surveys to monitor the spread of the disease in date palm groves, in surveillance at frontier posts, airports, nurseries, rural markets, and in disease diagnostics in laboratories, (vi) reinforce the popularisation of actions of modern techniques in order to guarantee good incomes for farmers and consequentil encourage them to effectively manage their palm orchards.

The specific strategies depend on the contamination level in each country by Bayoud disease. This imposes:

- For very contaminated areas (Algeria-Morocco): (i) reinforce research for efficiency improvement of rapid eradication methods of new foci of Bayoud using chemical soil treatment, (ii) reconstitute eradication of non-eradicated foci by planting selected resistant cultivars, (iii) research genetic improvements to develop new resistant cultivars using modern methods based on molecular markers, (iv) reinforce research on natural suppressive soil in pre-existent and potential areas, (v) encourage fundamental research on the parasite, the host, and their interaction in order to exploit this knowledge for direct, indirect, or integrated control methods against Bayoud disease, (vi) reinforce research on tissue culture and the production of date palm vitroplats, (vii) encourage research on antagonist micro-organisms against the pathogen in order to develop microbiological control measures adapted to the date palm tree and the oasis environment, (viii) develop a method of early detection of the pathogen, (ix) reinforce research to develop rapid methods of *in vitro* selection (cells, tissues, callus, plantlets,…) for resistance using toxins or other parasite metabolites or molecular markers, which are linked with interesting characters, such as resistance, fruit quality, sex of young plants,..

- For little contaminated areas (Mauritania): (i) implement a short-term programme which has an urgent character, eradication of contamination foci and prophylactic measures, (ii) implement a mid-term programme aimed at reinforcing plant protection services and personnel in oasis areas (engineers, technicians) to be engaged in disease control programmes, (iii) establish long-term programmes at research laboratories and stations working on date palm production and protection.

- For uncontaminated areas (Tunisia and Libya): in addition to prophylactic measures which must be implemented and reinforced, the situation and the geographic proximity of these two countries to contaminated areas impose the necessity to know in the short or medium term the behaviour of their main cultivars towards Bayoud disease. The evaluation of resistance or susceptibility of genetic patrimony will allow these countries to be prepared, if the pathogen gets introduced.

In conclusion, it is also recommended that collaborations among scientists in the Maghreb countries should be strengthened. This would create synergy of the different actions to combat the Bayoud disease.

Measures to be applied for different situations:

1. *In free zones*

- Strengthen awareness and prevention activities at the level of rural associations (intensify campaigns to raise awareness of the danger of Bayoud and other dangerous diseases and pests through posters and audio-visual aids, etc.); this is in order to inform the oasis population, traders and nomads about the threat of this disease.

- Provide training and guidance to date palm farmers and date producers and traders on disease dissemination and preventive measures in order to encourage producers to take phytosanitary measures, by avoiding the introduction of Bayoud into their zones and orchards.

- Avoid planting and transplanting of palm trees and the exchange of any plant material (offshoots, palms ...) coming from contaminated palm groves, which are likely to harbor the pathogen.

- It is preferable to use vitroplants for new plantings. If this type of plant is not available, traditional offshoots should be taken from free palm trees and orchards. In any case, it is necessary to immerse these offshoots in a systemic fungicide solution (e.g., Methyl-thiophanate (0.2%) and Hymexazole (0,2 %), then to put them in envelopes, to place them in a shaded shelter and to ensure regular sanitary control for at least three months, by spraying them every two weeks. If planting emergencies occur, sprays are required every two weeks during the first three months.

- Avoid planting crops recognized as healthy carriers (Henna, Lucerne and Alfalfa) from contaminated palm groves.

- Avoid the introduction and planting of Canary palms in villages or gardens near the date palm groves and from localities contaminated with *Fusarium oxysporum* f.sp. *canariensis* and suspectednurseries and soils.

- Avoid the use of agricultural equipment and tools used in contaminated orchards. If necessary, disinfection with alcohol (90 °) or bleach is recommended.

- Assess the level of soil receptivity of target soils towards Bayoud disease according to the method developed by Sedra (1993a, 2003a, 2008b, 2010b) and Sedra et al. (1994a, b) in order to estimate the potential risks of disease development in this area in case of accidental introduction.

- Proceed with cultivation practices unfavourable to the development of the disease:

- Irrigate the palm plants from their planting at a young age using the "drip" system and bring necessary fertilizers, especially potassic fertilization (fertigation if possible), to fortify the behavior of palm trees.

- In case of gravity irrigation, use if possible the associated crops that may depress the pathogen. At present, very few of these plants are known in the case of Bayoud, for example vetiver (*Chrysopogon zizanioides* L.), whose roots and leaves inhibit the growth of the parasite in the soil (Essarioui and Sedra, 2010).

- Bring organic fertilizers, if possible, amended with antagonist microorganisms. This method exists in several cases of diseases but is not yet finalized in the case of Bayoud (Sedra, 2001c). Some antagonistic bacteria, actinomyceta and fungi, that have been isolated from date palm rhizosphere and rhizoplane and from suppressive soils, have been able to inhibit the development of the pathogen in vitro, in soil and in vivo under glass house on young palm plans (Sedra 1993a,b; Sedra 1994a,b, 2001c, 2003b , 2006a , 2008b , 2010b; Sedra, 2003a, 2015a). The examples of antagonistic microorganisms are: for bacteria: *Pseudomonas* fluorescent, *Pseudomonas* sp and *Bacillus* sp., for fungi: *Stachybotrys* sp., *Fusarium oxysporum*, *Fusarium* sp. *Gliocladium* sp., *Rhizoctonia* sp., *Penicillium* sp. and *Trichoderma* sp. and several strains not identified for actinomyceta.

- On experimental soil, the amendment of organic fertilizers by shrimp wastes, rich in chitin, dried and ground, can not only inhibit the growth of the pathogen, but also promote the development of antagonistic actinomycetes that use this waste as a source of food (Essarioui and Sedra, 2010).

- Enrich the soil with potash up to a certain limit. Potash is known as a mineral element that generally depresses the development of vascular wilts.

- On-site incineration of all contaminated plant material, accidentally introduced into date palm free orchards. If, for example, dubious or contaminated offshoots have already been planted in a plot, as a preventive measure, it is recommended to demarcate the area, eradicate the disease by disinfection (fumigation and solarization) of the contaminated soil and place it under quarantine for a period of at least three years (fenced area and isolated by trenches 1.5 to 2 m deep). This area should be occupied by resistant date palm varieties or non-host plants of the Bayoud disease (eg. almond, fig, apricot and olive trees).

- Possible alternative methods of control based on soil solarization, fumigation by metam sodium, and the use of antagonistic microorganisms have been demonstrated in the field at experimental stations and research applications should be continued (Sedra 1993a,b, 2001c, 2003b, 2006a, 2008b, 2010b; 2003a, 2015a; Essarioui and Sedra, 2007, 2010, 2017).

- When planting varieties and clones of excellent date quality, but susceptible to the Bayoud disease, proceed to the mixed plantations of the susceptible and resistant material and non-host fruit species (almond or apricot trees etc.) (2008b by 2008a).

- In almost all date-producing regions, there has been a tendency by the farmers towards intensive planting of high-value varieties, which are extremely susceptible to Bayoud, e.g., Mejhool in Morocco and Deglet Noor in Algeria. In this case, draconian measures of prevention must be taken on a regular basis by the extension services in order to avoid the introduction of Bayoud in these areas.

2. In contaminated areas

- Avoid the plantation of susceptible cultivars in the foci of the disease. This may promote the multiplication of the fungus in the soil and its dissemination.

Reconstruct devastated orchards by planting resistant varieties and clones to Bayoud. It was shown that the best commercial cultivars are susceptible to the disease: Morocco (Mejhool, Boufeggous, Bouskri, Jihel), Algeria (Deglet Noor), Mauritania (Soukani, Tijeb, Lamdina, and probably Ahmar), Tunisia (Deglet Noor, Boufeggous, Besser Lahlou, Gondi, Horra, Kenka, and Kentichi), and Iraq (Barhi, Halawy, Khastawy, Khadrawy, Sair, and Zahidi) (Sedra 1992b , 2003b, 2006a , 2011a,f). The resistant cultivars are very few: in Morocco, Black Bousthammi, White Bousthammi, Iklane, Boufeggous Moussa, Sairlayalate, and Tadmainte have exhibited resistance since 1973 (Louvet and Toutain, 1973; Saaidi 1992 ; Saaidi et al., 1981), and Boukhanni (Sedra, 1992b, 1993a , 1995a).

Other new resistant varieties were selected and characterized: Najda, Al-Amal, Sedrat, Bourihane, Daraouia, Mabrouk, Al-Faida (Sedra, 2003a, 2011a, 2015a). In Algeria, two resistant vaieties have been developed: Takerbouchte and Akerbouch (Bulit et al., 1967; Tirichine, 1991).

- Encourage plantations of resistant varieties and clones to restructure neighboring orchards threatened with contamination.

- Proceed with cultivation practices unfavorable to the development of the disease:

- Avoid too frequent and unnecessary irrigation.
- Practice localised irrigation from non-communicating basins to avoid dissemination of the parasite by irrigation water.
- Removing affected palms, incinerating them on site, treating the surface of contaminated soil by solarization and chemicals, if possible with degradable and less polluting chemicals. After a period of latency, plant the depressive plants of the parasite and / or fill the microbiological vacuum of the disinfected soil by soil amendment with microorganisms antagonistic to the parasite, once this biological control method has been developed. It is important to reinforce the antagonist capacity of the soil by simultaneously modifying the soil with an organic substrate favorable to the development of these antagonists but unfavorable to that of the parasite.

- Quarantine the contaminated area at an orchard by fencing off and isolating the affected palms, using ditches or trenches more than 1.5 to 2 m deep and 1 m of width to avoid root contact of diseased palms and healthy palms.

- Avoid planting susceptible palm varieties and plants recognized as healthy parasite carriers in contaminated plots.

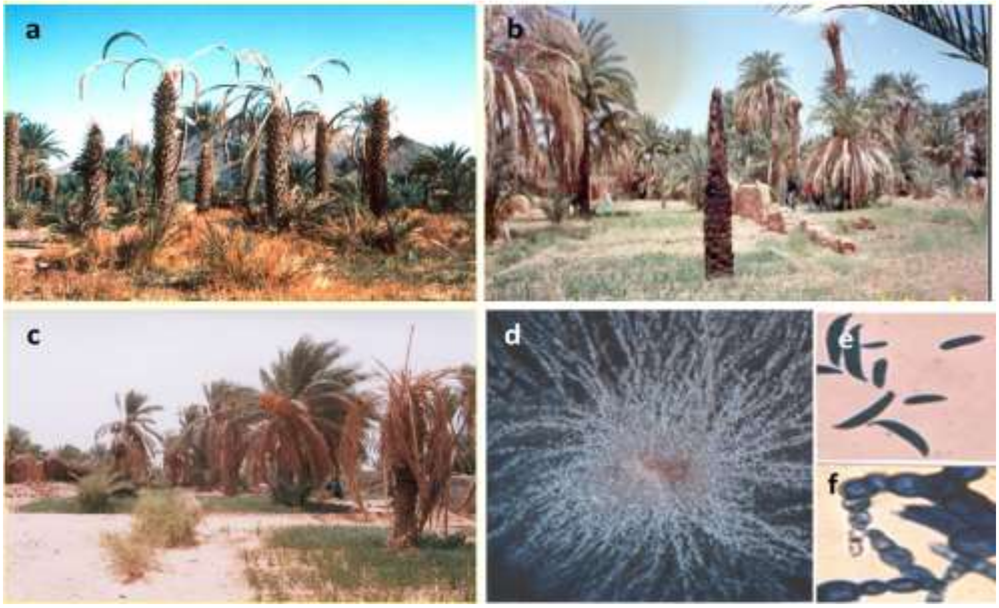

Fig. 1.Bayoud disease focus indicating destroyed palm orchard in Morocco (a), Algeria (b) and Mauritania (c), cultural aspect of the fungus colony (d), microconidia and macroconidia (e), and chlamydospores (f) of causal agent *Fusarium oxysporum* f. sp. *albedinis* Kill. & Maire.Sources of all photos: Sedra My.H.

Fig. 2.Typical symptoms of the Bayoud disease on date palm. Path vascular invasion of the vessels by the pathogen (a), external symptoms (hemiplegic symptom) on leaves and roots (b,c), internal symptoms on leaves (rachis), trunk (d,e,g), dried palm leaves having the appearance of wet feathers (h). Sources of all photos: Sedra My.H.

Fig. 3. Atypical symptoms of the Bayoud disease on date palm. Bilateral drying and browning extending to the middle of the rachis (a,b), atypical symptoms on the diseased palms as initially drying out of the leaves of the center and then of the middle (c), small size of palms and inclination of the apical part observed on the Moroccan cultivar *Aguelid* (d). Sources of all photos: Sedra My.H.

Fig. 4. Atypical symptoms of the Bayoud disease on date palm associated with those of disease on the same tree. Palm trees attacked by the Bayoud and partial heart rot (a), and Black scorch (b) and *Diplodia* disease (c). Sources of all photos: Sedra My.H.

Fig. 5. Symptoms of *False* Bayoud in Yemen.External symptoms (hemiplegic symptom) on leaves with the presence of color on one side of rachis (a), internal symptoms with any change or discoloration (d,e), Dr Sedra My.H. (b) and Yemeni researchers (c) making the diagnosis of the disease (December 2006). Sources of all photos: Sedra My.H.

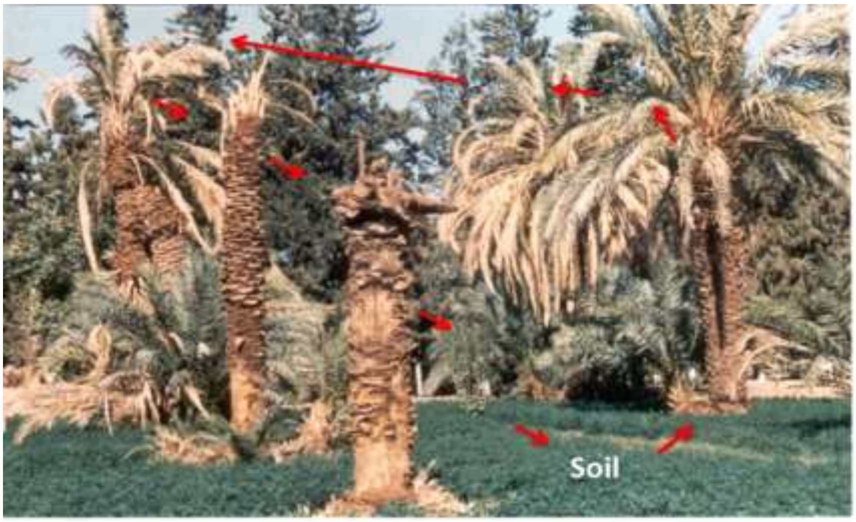

Fig. 6. Different stages of the evolution of symptoms on susceptible palms since the infection until death. The pathogen returns to the soil after destruction and decompostion of infected dead parts of palm. Sources of all photos: Sedra My.H.

1.2. Black Scorch Disease

1.2.1. Scientific name

Generally: *Thielaviopsis (Chalara) paradoxa* (Dade) C. Moreau *(*asexual-stage*)* (Imperfect fungi, Moniliales, Dematiaceae) and its perfect form *Ceratocystis paradoxa* (Hohn) (ascomycetes). Recently: *Thielaviopsis punctulata* has been reported as causal agent of black scorch disease on date palm in Qatar and in United Arab Emirates (Al-Naemi et al., 2014) and *Chalara radicicola* (Suleman et al., 2001).

The pathogen causes different names of diseases according to the type of infection and the developed morphological symptoms. These names include: *Thielaviopsis* bud rot, Bending head, Crazy disease (*Al-Majnoona*), Inflorescence blight, Terminal bud rot, Trunk rot, Leaf black scorch, Stem bending, Leaf black spot, Dry basal rot and Heart rot.

1.2.2. Description and Symptoms

Black scorch, also called locally *Al-Majnoona* or Fool's disease, is caused by *Ceratocystis paradoxa* (Hohn), which is a sexual-stage and the perfect form of *Thielaviopsis paradoxa* (Dade) C. Moreau. This asexual-stage is most often encountered. The fungus produces two different types of asexual spores, endoconidia and chlamydospores (Fig. 2(d-e-f-g). The latter will survive for long periods in the soil. The stage of *C. paradoxa* is rarely observed in natural settings.

This fungus causes the rot of the terminal fronds. If not properly controlled, it usually spreads and kills the palm.

Symptoms are usually expressed in four distinct forms, meaning four diseases: black scorch on the leaves, inflorescence blight, heart or trunk rot, and bud rot on palms of all ages (Fig. (1a-d)). Infections are all characterized by partial to complete necrosis of the tissues. For black scorch, the pathogen attacks the area of the palm heart and secretes toxic substances, leading to these primary symptoms and the appearance of blackening and charring (Fig. (1(b-e),2a). The importance of these symptoms depends on the level of date palm resistance and environmental conditions. On palm leaves, typical lesions are dark brown to black, hard, carbonaceous, and, as a mass, give the petioles stalks a scorched, charcoal-like appearance (Fig.1b,2a). This leads to dwarfism and charring of rachis and leaves (Fig. 1(a-c),2c)). The pathogen can attack spadice of regime bearing dates (Fig.1f) and small fruits at green stage and causes rot and their fall.

The damage is most serious when the pathogen attacks the terminal bud and heart leading to the death of the palm (Fig.1c). Some palm trees recover, probably by development of a lateral bud from the healthy portions of meristematic tissue. Their bending in the region of infection may be the reason why it is called *Al-Majnoona*. In fact, at some stage of its prognosis the fronds of the infected palm take different directions giving the phenomenon of *Al-Majnoona*, followed by the death of the palm. According to their tolerance levels, these palms set normal growth back by several years.

1.2.3. Distribution

This disease has been observed on date palm in all date growing areas of the world, particularly in Morocco, Mauritania, Algeria, Tunisia, Libya, Egypt, Sudan, Jordan, Saudi Arabia, Yemen, Oman, Iraq, Qatar, Bahrain, Kuwait, United Arab Emirates, Iran, India, and USA. The disease incidence and intensity depend on the level of favorable conditions in those countries and regions.

1.2.4. Host range

The main hosts are date palm (*Phoenix dactilyfera* L.) and some other palm species. In USA, the disease has also been observed on areca palms, oil palms, sugarcane, coconut, and pineapple (Klotz and Fawcett, 1932). In India, in addition to date palm, it attacks other plant species such as plantain, mango, *Saccharum spontaneum*, *Rhapis* sp. (Sundararaman et al., 1932)

1.2.5. Damage and economic importance

In Morocco, the disease is among the major diseases of date palm. It is considered the second most important disease after the Bayoud (Sedra, 2003c, 2015a). In some Arab countries, the disease incidence is relatively important in some localities in Saudi Arabia, Mauritania, Yemen, Egypt and Sultanate of Oman (Sedra, 2006b,c,d) and in many Arab countries, the disease has no economic importance.

1.2.6. Biology

The pathogen can infect leaves, inflorescence, fruit, heart or trunk base, bud and roots, mostly when a fresh wound is present. The fungus may produce volatile substances, specifically ethyl acetate and ethyl alcohol, which give the diseased tissue a fermented fruit odour (Elliott, 2015). Without cleaning and protection, the pathogen may be stored in these parts of the palm tree and may contaminate other healthy parts when the conditions are favorable. The pathogen penetrates through wounds caused by the operations of pruning of leaves and spadices, weaning of offshoots, and through the galleries caused by insects foraging trunk and spadice. The infection may progress more rapidly if the palm is stressed. Transmission of the disease from one palm to the next is facilitated by rain, insects, contaminated work tools used for cultivation activities (leave pruning, spines cutting, chiselling of regimes, cleaning, etc). The pathogen infects and invades the tissue provoking necrosis and carbonaceous lesions, secretes substances responsible for dwarfism, and produces chlamydospores that lead to charcoal-like appearances of blackening, charring and dwarfing. The chlamydospores constitute the inoculum for pathogen store and for the disease dispersal. When the conditions are unfavourable, the pathogen may produce a perfect form.

Fig.1. Symptoms on date palm caused by black scorch disease caused by *Thielaviopsisparadoxa* (Dade) C. Moreau. Partial or total with symptoms and the appearance of blackening and charring (a,b,c,e) and dwarfism on palms of all ages of rachis and leaves (a,c,d) and spadice of regime bearing dates (f). Sources of all photos: Sedra My.H.

1.2.7. Management

In order to control the disease, the following integrated management is recommended:

a. Cultural control

- Avoid injuries of young palms and the apical region of the tree during pruning and harvest
- Avoid removing the spines by pulling which causes injuries to rachis of leaves
- Good sanitation, pruning, collecting and immediately burning of infected palms (Fig 2(a-b-c)).
- Protect the cut wounds of leaves and healing by disinfectant products and especially the leaves of the crown top (Fig 2(a-b-c)).
- Ensure proper operation, maintenance and cleaning palm trees. Proper maintenance can reduce the incidence of disease and limit their extension.
- Avoid planting the contaminated offshoots and transplanting the infected young palms
- Remove and burn severely affected palms

b. Host plant resistance

Several commercial Moroccan cultivars show susceptibility to the disease (i.e. Mejhool, Boufegous, Jihel, Bouskri, Black Bousthammi and Deglet Noor (oasis of Figuig)) (Sedra unpublished). 17 other cultivars from different countries are highly susceptible: Thoory, Hayani, Amhat, Saidy and Halawy (Djerbi, 1983), Zahdi, Menakher, Baklany, Gantar, Halooa, Fteemy, Sukkar Nabat, Horra, Besser Haloo, Nakleh-Zianeh and Koroch varieties (Klotz and Fawcett, 1932).

c. Chemical control

- Disinfect wounds and prune cuts and surrounding tissues resulting from pruning leaves, with a copper compound (e.g., copper oxychloride 0.4 %) (Fig 2(a-b-c)).
- Spray the tree with fungicide such bordeaux mixture (0.3 %), methyl thiophanate (0.2 %), polyram thiram (0.2 %), and Mancozeb (0.2 %) (Fig 2(a-b-c)).
- Other chemical products are: lime-sulphur solution, copper sulphate lime mixture, dichlone, thiram or any new copper-based fungicides.

The chemical treatment can be repeated twice, depending on the level of satisfaction of the first treatment.

Fig. 2. Structures and spores of *Thielaviopsis paradoxa* (Dade) C. Moreau causal agent by black scorch disease and steps of fungicide treatment of disease palm tree (a,b,c). Endocomidia, conidia in chain, free conidia (d,f) and chlamydospores (a,e,f,g) of the pathogen. Sources of photos a, b, c, d, g: Sedra My.H.; sources of microscopic photograph: e:https://www.forestryimages.org, f: https://www.researchgate.net)

1.3. *Diplodia* Disease

1.3.1. Scientific name

Diplodia disease, also called Basal Leaf Rot, is generally caused by *Diplodia phoenicum* (Sacc.) Fawc. & Klotz (Imperfect fungi, Sphaeropsidales, Sphaerioidaceae), syn. *Macrophoma phoenicum* Sacc., *Strionemadiplodia phoenicum* (Sacc.) Zambett and *Neodeightonia phoenicum* (Phillips and Crous 2008). The causal agent of this disease is sometimes *Diplodia natalensis* P. Evans, which was reported on date palm in Israel (Minz, 1958).

1.3.2. Description and Symptoms

The pathogen can attack young and adult palms. Symptoms appear on the central and external tissues of rachis of offshoot leaves or palm fruits (Fig.1(c-d)). These infected tissues are yellow in color at the beginning. These tissues have diagonal structures with longitudinal sizes, starting from the base and extending to the summit for a distance of up to one meter (Fig.1(b-c)). Yellowish-brown streaks extend along the leaf base and rachis. The lesions become brownish; internal infection and necrosis may be extensive in leaf tissues (Fig.1(b-c-d)). Afterwards, these symptoms are characterized by dryness in these infected tissues and necrosis as blisters along the rachis of the palm and by pustules containing conidia of the fungus (Fig.1-a). The pathogen may infect and kill the outside fronds, the younger shoots and buds, and the terminal bud (Fig.1(c-d-e)). The central leaf cluster may die before the older leaves. Sometimes, the symptoms are confused with those caused by *Botryodiplodia theobromae* (Sedra, 2006 b,c).

1.3.3. Distribution

The *Diplodia* disease is generally a minor disease affecting many date growing areas of the old world: Morocco, Mauritania, Algeria, Tunisia, Libya, Egypt, Sudan, Jordan, Saudi Arabia, Yemen, Oman, Iraq, Qatar, Bahrain, Kuwait, United Arab Emirates, Israel and in USA (California and Arizona). The disease causes damage on offshoots in Bahrain and it is less important in Qatar and Kuwait.

1.3.4. Host range

Date palm (*Phoenix dactilyfera* L.) and other palm species.

1.3.5. Damage and economic importance

The disease incidence and intensity depend on the countries and regions within countries in relation to the levels of precautions taken during the activity of pruning and the conditions of maintenance and management of palm trees (faulty irrigation, etc). In some cases, the damages are significant on young plantations.

1.3.6. Biology

The pathogen is stored in infected parts of palms. It usually enters the palm through wounds made during pruning or cuts made when removing the offshoots. When the conditions are favourable, the pathogen infects the tissues and provokes necrosis and lesions along the leaf base and rachis. The fungus produces the pustules (pycnidia) containing conidia (Fig.1(a-f)). When the disease takes place at the offshoots and at the outer fronds, then the outside fronds, it later spreads to the young fronds and progressively attacks the younger shoots and buds and finally the terminal bud. The disease can kill the offshoots, either while they are still attached to the parent or after they have been detached and transplanted. In case of heavy attacks, the disease can cause significant damage on releases and especially on young plantations. When environmental conditions are favourable and maintenance of palm trees is insufficient or missing, the disease can cause severe dryness and the death of palm trees. Insufficient irrigation may cause the death of some roots and contribute to the development of the infection.

1.3.7. Management

In order to prevent and control the disease, the following integrated management is recommended:

a. Cultural control

- Disinfect all tools and the weaning and pruning equipment of the palms as well as the wounds of the cut and cut places with disinfectant and cleansing treatments
- Incinerate fragments of palm trees
- Avoid planting infected offshoots and young palm trees
- Avoid hurting palms and offshoots during pruning operation, planting and hoeing soil around these offshoots

b. Host plant resistance

- The disease has been recorded on 20 date varieties all around the world, although it appears to be most common on cv. Deglet Noor in Tunisia and Algeria. In Morocco, several cvs and clones had showed their susceptibility to the disease.
- Survey should be conducted in date palm groves to know the behavior of the date palm cultivars to this disease.

c. Chemical control

- Immerse the offshoots before planting in a fungal disinfectant, such as copper sulphate or copper carbonate for some time (5 to 10 minutes)
- Spray palm trees with a fungicide such as Bordeaux mixture or methylthiophanate or thiram. The chemical treatment can be repeated twice depending on the level of satisfaction of the first treatment.

Fig. 1. Symptoms of *Diplodia* disease of date palm caused by *Diplodia phoenicum*. Pycnidia (a) and brown bi-cellular conidia of the fungus (f), infected tissues at the beginning coloured yellow and having diagonal structures with longitudinal sizes starting from the base and extending to the summit (b), attack of young and adult palms (c,d) and necrotic lesions on outside fronds and central leaf cluster (b,c,e). Sources of photos a, b, c, d, e: Sedra My.H.; source of microscopic photograph: f:https://www.researchgate.net/figure/259155846_fig5_Neodeightonia-phoenicum-A-Conidiogenous-layer-B-E-Conidiogenous-cells-F-Hyaline

1.4. Leaf Spots Disease

1.4.1. Scientific name

The disease is caused by many fungi. Different fungal species have been isolated from palm leaves showing leaf spot symptoms and the main ones are: (a) *Cladosporium herbarum* (C. *cladosporioides*) (Imperfect fungi, Moniliales, D*ematiaceae*), (b) *Alternaria alternata* (Imperfect fungi, Moniliales, D*ematiaceae*),(c) *Drechslera australiensis* (Imperfect fungi, Moniliales, D*ematiaceae*), (d) *Pestalotia palmarum Cooke* (*Pestalotiopsis palmarum (Cooke) Steyaert*) (Imperfect fungi, Xylariales), *Helminthosporium* sp. (Imperfect fungi, Moniliales, D*ematiaceae*) and (e) *Thielaviopsis paradoxa*(Dade) C. Moreau or *Botryodiplodia theobromae*. The fungus *Mycosphaerella tassiana* (De Not) Johns (Ascomycetes/Pyrenomycetes, Pseudosphaeriales, Mycosphaerellaceae) is the perfect form of *C. herbarum*.

Other fungi which cause leaf spot symptoms on palm trees include *Bipolaris australiensis*, *Colletotrichum* sp. (antrachnose disease), *Stemphylium* sp., *Pestalosia* syn. *Pestalotiopsis palmarum*, *Chaetosphaeria* sp., *Phomopsis* sp. and *Phoma* spp., (Carpenter and Elmer,1978; Sedra, 2001a; Livengston et al., 2002; Fayad and Mania, 2006; El-Deeb et al., 2007; El-Gariani et al., 2007).

1.4.2. Description and Symptoms

Generally, infection is more severe on the lower whorls and old leaves than on upper young leaves. Furthermore, the infection rate and severity increases with increasing palm age. The same palm tree may be infected by several pathogens, showing leaf spots that sometimes are difficult to distinguish. Symptoms due to different causal agents are:

(a) Rectangular brown leaf spot

This disease caused by *Cladosporium herbarum* (*Mycosphaerella tassiana*, teleomorph) is the most common. Symptoms of the disease occur on the rachis, pinnae, and spines as rectangular dark lesions with well-defined margins on green leaves and on drying leaves. The margin of the lesion remains reddish brown as the centre becomes pale (Fig.1a,d).

(b) Rectangular pale brown-gray leaf spot

The following symptoms due to the attack of *Alternaria alternata* are characterized by the appearance of gray spots with dark brown margin to reddish on the center. The pathogen may cause angled lesions with color light brown and flanged structure of reddish color on both shallow wickers. The disease may cause blight to leaves (Fig.1b,f).

(c) Longitudinal reddish brown parallel leaf spot

The fungus *Drechslera australiensis* is the main agent causing spots in longitudinal and parallel rows with reddish-brown color on all parts of the leaf, which leads to the death of the wicker parts with coloration of the lower surface of the center with brown color (Fig.1c). These symptoms may be caused by *Helminthosporium* sp.

(d) Longitudinal- circular black-dark leaf spot

These symptoms are caused by the fungi *Thielaviopsis paradoxa* or *Botryodiplodia theobromae* (Imperfect fungi, Moniliales, Dematiaceae) (Fig.1e,f)

(e) *Pestalotia* leaf spot

The fungus *Pestalotia* syn. *Pestalotiopsis palmarum*may attacks date palm, but frequently it also infects coconut. The symptoms are characterized by blight lesions on the rachis, which appear black and sunken. As the lesions expand together, larger areas of blighted rachis tissue develop (Fig.1g).

1.4.3. Distribution

The leaf spots are minor diseases affecting most date growing areas of the world for example: Morocco, Mauritania, Algeria, Tunisia, Libya, Egypt, Saudi Arabia, Iraq, Kuwait, Bahrain, United Arab Emirates, and the USA. The brown leaf spot is the most common disease which affects palm trees. The disease incidence and intensity depend on the climatic conditions and date palm cultivation.

1.4.4. Host range

Date palm (*Phoenix dactilyfera* L.) and other crops

1.4.5. Damage and economic importance

In general, leaf spot diseases are of minor economic importance. These diseases are very common on date palm trees in all date palm growing countries. Research is essential to ascertain the effect on the palm and its production.

1.4.6. Biology

The disease development increases in hot and humid areas. Infection is more severe on the lower whorls and old leaves than on upper young leaves. The disease incidence and severity increase with increasing palm age. The parasites are conserved on the tree in the infected parts of the palm in the form of spores and mycelium or in perfect form depending on the diseases. The pathogens may survive on dead tissue and other substrates. *C. herbarum* can also be isolated from dust and air. When environmental conditions are favourable, spores germinate and attack pinnae, spines and rachis. After incubation, the parasites sporulate and release new spores that contaminate and infect other parts of the leaves.

1.4.7. Management

In order to control the disease, the following integrated management package is recommended:

a. Cultural control

- Annual pruning of old infected leaves and their immediate burning is advised. This reduces the infected parts of the tree and avoids the spore dissemination on young leaves.
- Proper maintenance of palm orchards

b.Host plant resistance

In the world, several commercial cultivars are susceptible to leaf spots, for example, the cultivars of Mejhool, Khalas, Sukkari, and Barhi

c. Chemical control

If it is necessary and in order to avoid the disease dissemination at an early stage of the disease, it is advised to spray with mancozeb, mancozeb added to copper or other fungicides used for the control of black scorch disease, like Methylthiophanate added to Maneb. In the case of low levels of infection, chemical treatments are not recommended and only good annual pruning is sufficient.

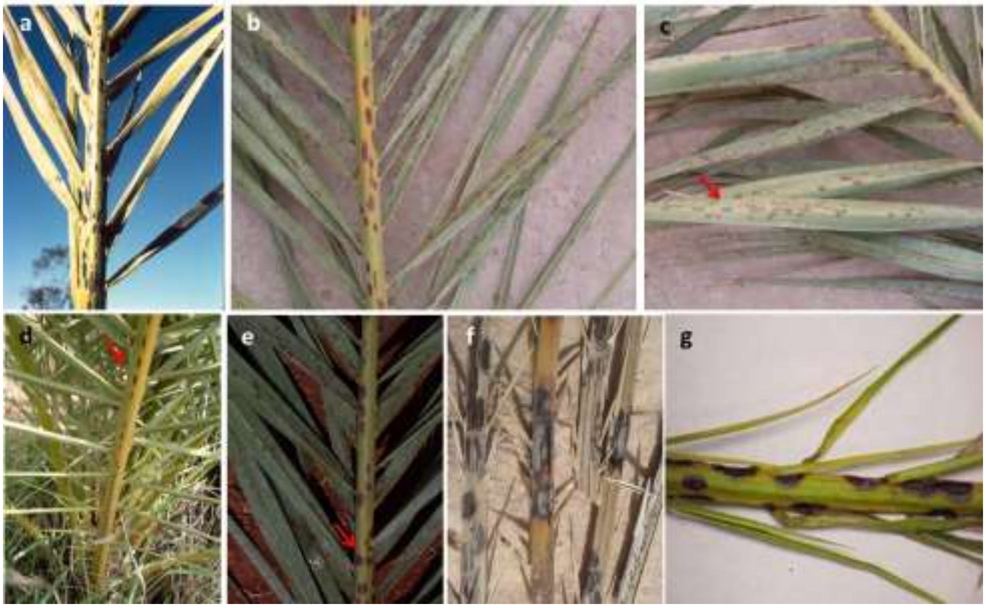

Fig. 1.Different symptoms of leaf spots diseases caused by several fungi.brown leaf spot (a) caused by *Cladosporium herbarum* , rectangular pale brown-gray leaf spot caused by *Alternaria alternata*(b), longitudinal reddish brown parallel leaf spot caused by *Drechslera australiensis* or *Helminthosporium* sp. (c), longitudinal-circular black-dark leaf spot caused by *Thielaviopsis paradoxa* or *Botryodiplodia theobromae*(e,f), blight lesions on the rachis caused by *Pestalotia* syn.*Pestalotiopsis palmarum*(g). Sources of photos a, b, c, d, e, f: Sedra My.H.; source of photo g: https://www.forestryimages.org

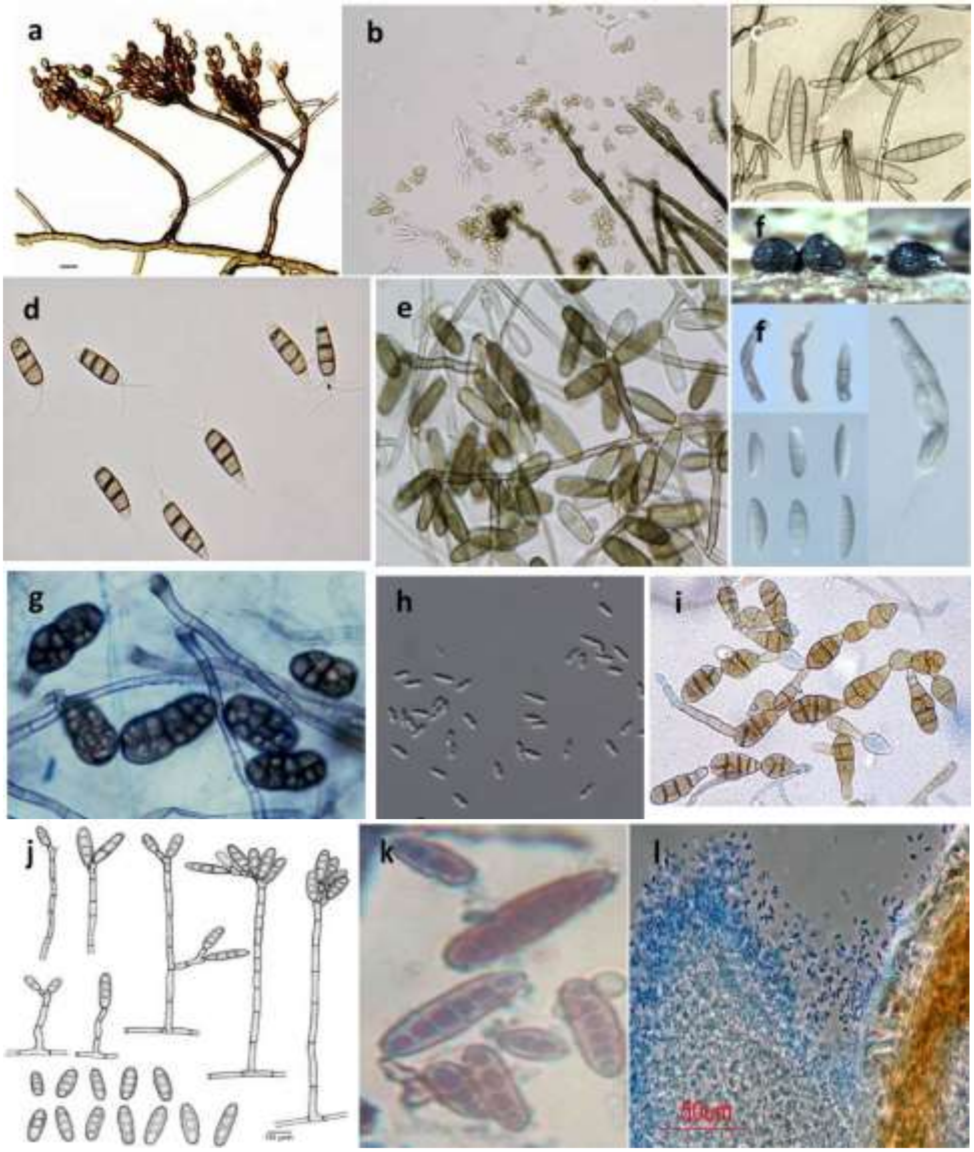

Fig. 2.Structures, conidia and chlamydospores of some causal agents of leaf spots.*Cladosporium herbarum* (a,b), *Helminthosporium* sp. (c), Pestalotiopsis palmarum(d),*Colletotricum* sp. (e), *Chaetosphaeria* sp. (f), *Stemphylium* sp. (g), *Phomopsis sp.*(h),*Alternaria alternata*(i), *Drechslera sp.* (j,k),*Phoma* sp. (l).Sources of microscopic photograph: http://old.vscht.cz (a), http://www.fungi.org.uk (b) http://www.iriisphytoprotection.qc.ca (c), http://www.padil.gov.au (d), https://www.emlab.com (e), http://www.discoverlife.org (f), http://ephytia.inra.fr (f), http://fungi.myspecies.info (h), https://www.forestryimages.org (l), https://www.slideshare.net (j,k)

1.5. Bending Head Disease

1.5.1. Scientific name

Bending Head of date palm is caused frequently by *Thielaviopsis paradoxa* (De Seynes Hohn), also called *Chalara paradoxa* (De Seynes) Sacc (Imperfect fungi, Moniliales, Dematiaceae) and the perfect shape of which is *Ceratocystis paradoxa* (Dade) C. Moreau. *Botryodiplodia theobromae* Pat (Imperfect fungi, Sphaeropsidales, Sphaerioidaceae) is also a fungus commonly isolated from declining palms (Brun and Laville, 1965, Sedra, 2001a, 2003a,b, Sedra, 2012). *Thielaviopsis punctulata* may cause the rot of apical meristem (bud) and provoke similar symptoms of bending head. The pathogen *T. paradoxa* adapts around the world, mainly in warm climates; this why it has a worldwide distribution. *Thielaviopsis punctulata* appears to be limited to Kuwait, Mexico, South Africa, and the USA (California only). This disease can be caused by a fungal parasite complex, or the beginning of a cause of non-parasitic origin attributed to the weight force of some regimes, heavily loaded with dates that pull to one side of the apical region of the heart containing the palm (Sedra, 2012). *T. paradoxa* is also often isolated in association with *Fusarium moniliforme* (Imperfect fungi, Moniliales, Tuberculariaceae).

1.5.2. Description and Symptoms

T. paradoxa attacks the non-lignified or minimally lignified tissues under the apical meristem, degrades them, and provokes rot. The disease is most often observed in adult palms with considerable trunk height. In the case of palms with shorter trunks, which have less lignified tissue overall, the disease may occur anywhere on the trunk and may cause the rot at the base or at the center or at the top or on the heart. Unfortunately, often there are no visible indications that a palm has *Thielaviopsis* trunk rot until the trunk collapses. This means the trunk tissue has rotted to such an extent that the trunk can no longer support itself. Figure 1(a-b-c) illustrates the evolution of the symptoms. Generally, the diseased portion of the trunk is located only on one side of the trunk and if the zone of apical meristem is non-infected this may cause the palm tree to grow after chemical treatment. Visible symptoms are characterized by wilting and necrosis of leaves, due to the disappearance of the color of weak heart with crispiness, and drying of fronds which become light in color (Fig.1 (b-d). The rotten areas on the trunk may be darkened and very soft. The fronds adjacent to the heart begin to gradually die and they join in the form of a beam with a tilted head before dying. This central cluster of fronds takes the form of an erect fascicle with a bent tip. At the end, the head hangs and bends on the trunk and may even break and fall (Fig.1c). If the attack is partial and the palm is healed following an intervention with a fungicide, the palm allows the emergence laterally of the part of the apical bud that is still healthy and continues to produce a new head tilted with healthy green leaves (Fig.1d).

1.5.3. Distribution

Globally, this is a disease of little importance, but it is extremely dangerous if it is spread in the palm groves. In traditional palm groves of many countries, the disease has, in recent years, a considerable extent (Sedra, 1995b, 2003a,b 2006b,c,d, 2015a,b). It was observed in Mauritania, Morocco, Algeria, Tunisia, Egypt, Yemen, Oman, Iraq, Kuwait, Mexico, South Africa, USA and other countries. The disease incidence and intensity depend on the level of maintenance level of the palm trees and of their treatment efficiency. The pathogen attacks palms weakened by drought or by poor cultural practices.

1.5.4. Host range

Date palm (*Phoenix dactilyfera* L.), Canary Island palm (*Phoenixcanariensis* L.), Cocnut (*Cocus nucifera*), African oil palm (*Elaeis guineensis*), Washingtonia palm (*Washingtonia robusta*, *W. filifera*) and other palm species.

1.5.5. Damage and economic importance

If no control is applied to the disease, this may be spread and kill the trees. For example, in Morocco and especially in marginal palm grove, e.g., around Marrakech city, many hundreds of palms are affected by this disease and killed after a short period of time. In Mauritania, the high diseased date palm trees are remarkably numerous in several oases (Sedra, 1995b, 2002, 2003b, 2006b, 2015b).

1.5.6. Biology

The pathogen attacks the bases of the injured fronds and the apical bud of the palm tree and degrades non-lignified or minimally lignified tissues under the apical meristem. After an incubation period, symptoms externalize and are characterized by more or less dry rot on the same mid-level fronds and those of the centre which become white. Subsequently, the disease develops to reach the apical tissue and causes rot. This central cluster of fronds takes the form of an erect fascicle with a bent tip, which rapidly dies and falls. Several microorganisms and insects may grow on rotten tissues. These symptoms are usually associated with terminal bud rot; the infection may continue below the bud. So, the degree of attack defines the extent of the damage. In the absence of any intervention, and any control, the disease can cause death of the palm after few months if the heart of the tree is fully affected and rotten. When the attack is partial, only a part of the apical bud is reached, the heart of the palm tree bends, hence the need to intervene as quickly as possible to save the diseased palm tree. The significance of the attack determines the speed of the development of heart disease that leads to the general decay of the apical region of the palm.

1.5.7. Management

In order to control the disease, the following integrated management package is recommended:

a. Cultural control

- First, ensure good sanitation and efficient maintenance of date growing areas in order to control the disease
- Avoid hurting the base of palms, spadix, and the apical area

- Disinfect the tools and equipment used for tree pruning and the wounds of the cup by disinfectants and cleaning treatments
- Collect and burn or incinerate diseased parts and fragments of infected palms on site and clean residues in order to limit the spread of the disease

b. Host plant resistance: Several best commercial cultivars are susceptible to the disease. In Morocco, some cultivars which are resistant to the Bayoud disease show susceptibility to the bending head, for example, Black bousthammi and Iklane.

c. Chemical control

- Spray the diseased heart of palm with fungicides such as maneb, methylthiophanate, Bordeaux mixture at the onset of early symptoms
- Inject fungicides, such as methylthiophanate and thiram, in the diseased part of the apical area, in case of an advanced attack.
- The chemical treatment can be repeated twice depending on the level of satisfaction of the first treatment.

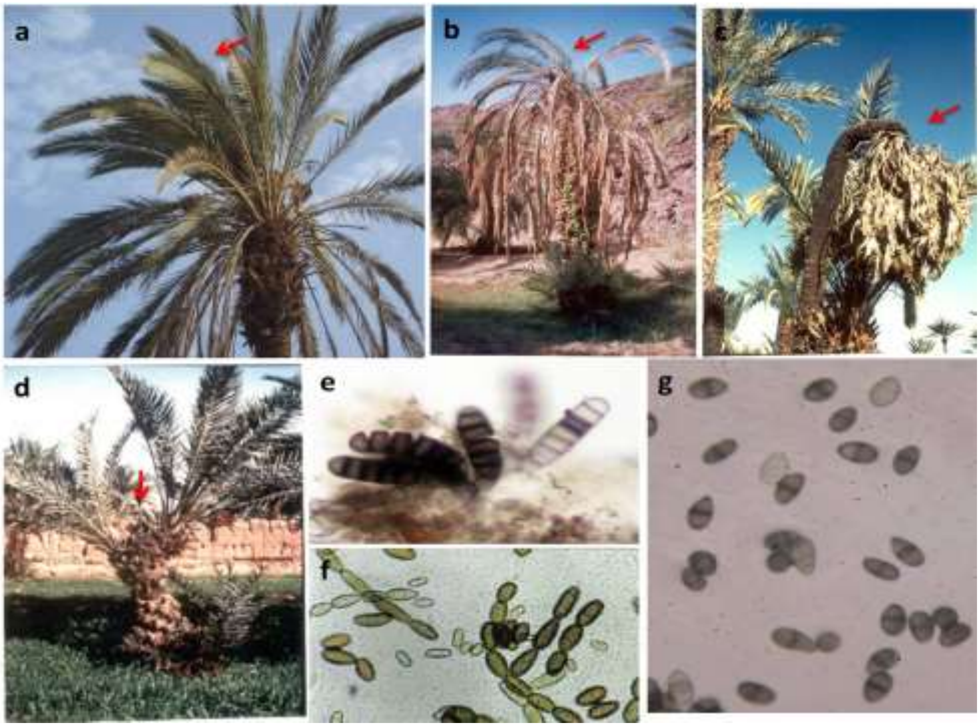

Fig.1. Symptoms on date palm due to the bending head disease caused usually by *Thielaviopsis paradoxa* and/or *Botryodiplodia theobromae*. Different steps of the disease development until the dead of palm tree (a,b,c), emergence laterally and development of new head tilted with healthy green leaves after healing of the infected part of apical bud following fungicide treatment (c), Conidia and chlamydospores of *Thielaviopsis paradoxa* (e,f), conidia of *Botryodiplodia theobromae* (g). Sources of photos a, b, c, d: Sedra My.H.; sources of microscopic photograph: e:https://www.forestryimages.org, f: https://www.researchgate.net; g: photo. Latha et al (2009).

1.6. Heart and Trunk Rot Disease

1.6.1.Scientific name

There are many pathogenic fungi that may be responsible for the infection that causes heart and/or trunk rots, including: *Fusarium* spp. (Imperfect fungi, Moniliales, Tuberculariaceae), *Botryodiplodia theobromae* (Syn. *Lasiodiplodia theobromae*) (Imperfect fungi, Sphaeropsidales, Sphaerioidaceae), *Chalara paradoxa* syn. *Thielaviopsis paradoxa* (Dade) C. Moreau *(*asexual stage*)* (Imperfect fungi, Moniliales, Dematiaceae) and *Gliocladium* spp. (pink rot of the heart). In Mauritania, this disease is called *Takakt* (Sedra, 2002, 2006 b,c, 2015b).

1.6.2. Description and Symptoms

This disease in date palm can occur at the base, middle or top of the stipe or at the heart of the palm (Fig.1(a-c-e-f), 2(h-i)). Symptoms begin to appear on the leaf group surrounding the apical bud, starting with death from the top, heading to the base, turning the infected leaves brown or black (Fig.1a). With favourable conditions, infection continues to progress until the apical bud leading to the death of the palm. At the end, easy removal of dead leaves presents the heart of the palm. The outer leaves are intact at first but soon die. It may be observed that there are fungal growths of the causal agents on the bases of the infected leaves, such as pycnidia of *Botryodiplodia theobromae* or chlamydospores of *Thielaviopsis paradoxa* (Fig.1d,2(k-n-i-o)) or the presence of a mass of pink colonies of the fungus *Gliocladium* spp. (Fig.2(a-j-m)). Sometimes, it may be noticed that the infection has started from the apical bud directly, causing heart rot and leading to the death of the palm (Fig.1 (g-e-f)). Sometimes, the rot is located in all region of the trunk, from the base to the top (Fig.2 (h-i)).

The diagnosis made in Mauritania showed that the symptoms of brown spots of rot may be accompanied by liquid that has a characteristic odor and the existence of some species of contaminants on the tree during a trunk injury, probably due to the presence of the liquid. Laboratory analysis of a sample of the rotten tissue permitted the frequent isolation of bacteria and fungi known to infect date palms that cause these symptoms (Sedra, 1995b, 1999a,b, 2002, 2003a,b, 2006b,c, 2008b), i.e., *Chalara paradoxa* and *Botryodiplodia theobromae*. In Morocco, the heart rot observed on Canary Island date palm showed the presence of pink colonies of the fungus *Gliocladium vermoeseni* (Biourge) Thom but was rarely found on date palm (Fig.2 (j-m)) (Sedra, 2003a). This disease of Canary Island date palm has been reported in Europe and the USA.

1.6.3. Distribution

Heart and trunk rot disease of date palm is present in a number of date-producing countries around the word: North of Africa, Gulf Arab countries, Iran, India, etc. This disease is largely distributed in Mauritania and Yemen and in some oases of the Sultanate of Oman (Sedra, 1995b, 2006c,d, 2008a,b, 2015b).

1.6.4. Host range

Date palm (*Phoenix dactilyfera* L.), Canary Island date palm (*Phoenix canariensis* L) and several other cultivated palm species i.e *Cocos nucifera*, *Elaeis guineensis* and ornamental palm species i.e *Areca catechu*, *Sabal palmetto*, *Washingtonia filifera*, *Brahea edulis*, *Caryota spp., Phoenix africanus, Raphis sp., Roystonea elata, Sabal palmetto, Sygarus romanzoffinia* (Nelson, 2005).

1.6.5. Damage and economic importance

It is a disease that causes great loss particularly in traditional oases in some countries and also in modern farms and nurseries, if the conditions are appropriate. The disease incidence and intensity depend on the countries and regions and is related to the level of sanitation and maintenance of palm trees.

1.6.6. Biology

After the affected palms fall to the ground, the vegetal tissues decompose and contaminate the soil. The pathogen is preserved in the forms of mycelium, spores, and chlamydospores according the pathogen species. These spores attack the base of planted offshoots and the palm trunk through wounds, invading the tissues. When the conditions are appropriate, for example, unusual irrigation frequency, the pathogen invades, moves up, and causes rot in the base and along the trunk. This rot attracts other insects that multiply within infected tissues. If the rot is severe, the trunk can break and fall and a hole in the trunk can be observed. In the case of heart rot, the pathogen which is conserved on the base of leaves, attacks the tissues of apical bud through the wounds caused during pruning operations of the leaves. The rot prevalent in this area leads to the death of leaves in apical bud leading to the rot of the heart. If the invasion of the heart is partial, a new lateral bud emerges, but the tree has difficulties maintaining its normal growth. After the death of the tree, the infected parts decompose and release the pycnidia, spores, and mycelium in the soil based on the pathogen species.

1.6.7. Management

The control of this disease cannot be effective if the rot has progressed into the trunk or the heart is completely invaded, because there is only one bud. In this case, it is necessary apply preventive measures when the infection is at an early stage. The following integrated management is recommended:

a. Cultural control

- Remove and burn dead trees and offshoots and other infected parts. This reduces pathogen inoculum in the orchard.
- Avoid the occurrence of wounds and rots.

- Take care during the processes of separation and circulation of the offshoots and treatment of the place of separation by a recommended pesticide.
- Treat wounds at the base of the offshoots before planting or at the base of the trunk against attacking fungi and other microorganisms.
- Apply appropriate agriculture practices: planting offshoots at the soil surface leads to their drought, because planting deep leads to their death as a result of rotting the roots or the submersion of the terminal bud in water which leads to rot.
- Add dissolved and non-polluting organic fertilizers.
- Soil ventilation around the palm tree or offshoots recently planted.

b. Host plant resistance: Several good commercial cultivars are susceptible. There is no information about the resistant cultivars.

c. Chemical control

If the attack is initially at the trunk or apical level, it is advised to spray the apical part with a systemic fungicide followed by a contact fungicide or inject the fungicides into the trunk at the level of the infected area. Generally, the chemical treatments used against the disease Black scorch are also effective against heart and trunk rot of date palm.

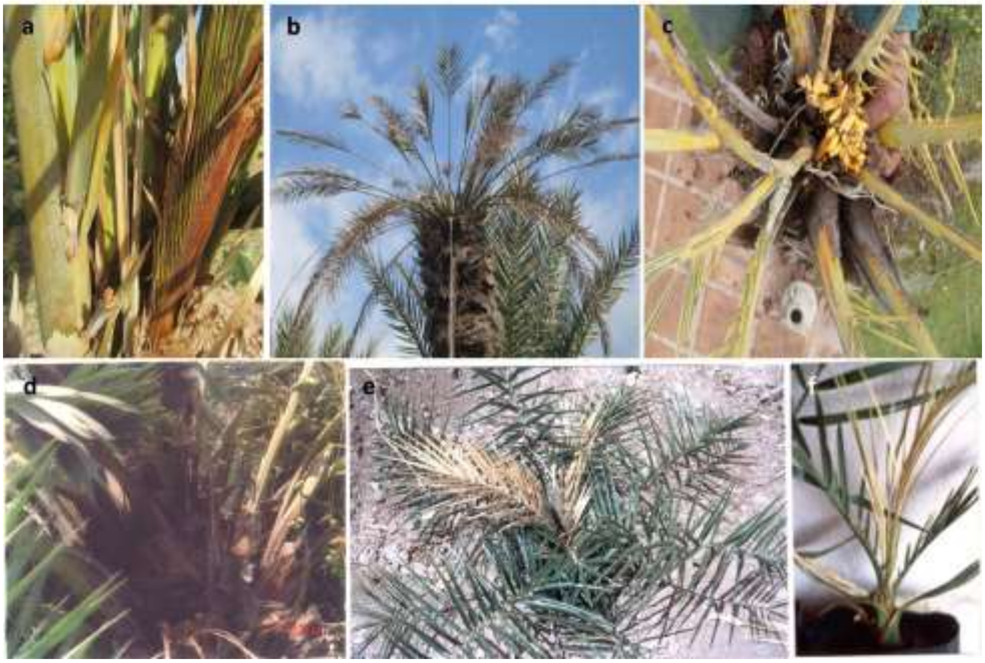

Fig.1. Symptoms of heart and trunk rot disease caused by *Botryodiplodia theobromae* (Syn. *Lasiodiplodia theobromae*) and *Chalara paradoxa* (syn. *Thielaviopsis paradoxa*). Appearance of symptoms on the leaf group surrounding the apical bud (a), rotten tissues at leaf bases meristematic region in central frond of apical bud with outer intact leaves (b,c,d), infection started from the apical bud directly, causing rot heart of young palm tree (a,f). Source of all photos: Sedra My.H.

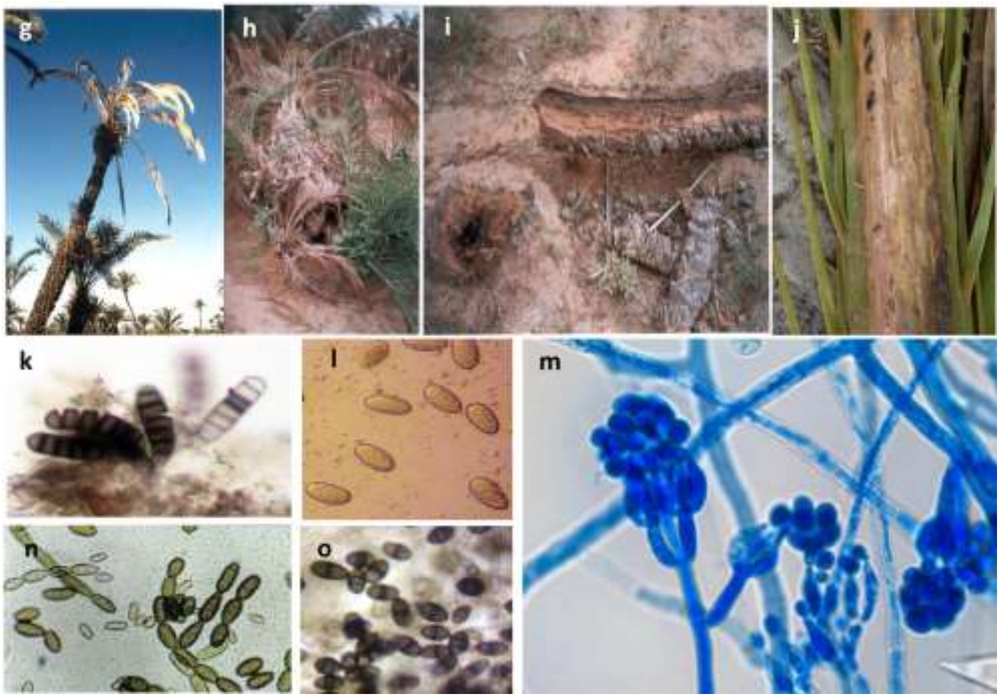

Fig.2. Symptoms of heart and trunk rot disease caused by *Botryodiplodia theobromae* (Syn. *Lasiodiplodia theobromae*) and *Chalara paradoxa* (syn. *Thielaviopsis paradoxa*) and spores of the pathogens. Infection started from the apical bud directly ,causing rot heart of adult palm tree (g), rot located in all regions of the trunk from the base to the top (h,i), heart rot observed on Canary Island date palm with the presence of pink colonies of the fungus *Gliocladium vermoeseni* (j), Conidia and chlamydospores of *Thielaviopsis paradoxa* (n,k) conidia immature (l) and mature (o) of *Botryodiplodia theobromae*, structure of sporulationand conidia of *Gliocladium spp.* (m), (sources of microscopic photograph: k:https://www.forestryimages.org, n: https://www.researchgate.net; i and o: (Photo. Latha et al. 2009), m: http://thunderhouse4-yuri.blogspot.fr.

1.7. Belaat Disease

1.7.1. Scientific name

Belaat disease is caused by *Phytophtora* spp. (Phycomycetes, Oomycetes, Perenosporales, Perenosporaceae), similar to *P. palmivora* (Djerbi, 1983).

1.7.2. Description and Symptoms

Symptoms of *Belaat* disease appear at the crown of the palm. They are characterized by destruction of the heart of the palm which is reflected by the presence of a hollow in the form of a volcanic ridge (Fig 1 (a-b)). At the first stage, the entire cluster of young fronds whiten and die in a quick and surprising manner, followed by the infection and death of the terminal bud (Fig.1a). The infection then progresses downwards in the trunk as a conical wet heart rot form (Fig. 1a), releasing an odor of acetic and butyric fermentation. The pathogen *P. palmivora* can attacks young palm trees which were poorly planted, for example, when the trunk base is little emerged in the soil allowing the irrigation water to submerge the heart of the palm trees or in the case of flooded irrigation. The terminal bud rot produced at the beginning of the attack is similar to those produced by other pathogens like *Thielaviopsis paradoxa* and *Botryodiplodia theobromae*.

1.7.3. Distribution

The *Belâat* disease is of minor importance and sporadic. It was reported in some North African countries (Algeria, Morocco, Tunisia, etc.) (Maire, 1935; Monciero, 1947; Calcat, 1959; Toutain, 1967, Djerbi, 1988; Sedra, 2003 a,c; 2015a). A similar terminal bud rot was also observed on young plantations in the United Arab Emirates.

1.7.4. Host range

Date palm (*Phoenix dactilyfera* L.) and Canary Island date palm (*Phoenix canariensis* L.)

1.7.5. Damage and economic importance

The disease is considered minor, but sometimes it has mini-epidemic proportion in young plantations when small date palms were wrongly planted (planted deep) and due to excess of flooded irrigation. The disease incidence and intensity depend on the countries and regions and is related to the maintenance of palms.

1.7.6. Biology

The pathogen may be stored in the form of chlamydospores (oospores) (Fig.1f) after sexual reproduction. These structures may be disseminated to other palm trees. If the conditions are favorable, the oospores germinate and produce the sporangia (Fig.1(c-d)), which release zoospores that infect the base of young leaves and terminal buds. Infected young fronds became white quickly and soft rot occurs at the terminal bud after the deterioration and death of tissues. The infection progresses down in the trunk and conical hole and develops, with other contaminant microorganisms, soft rot and odor of fermentation. This moves to the apical area. If the disease lesion does not permeate all the developing top tissues, the affected palm restores its growth by growing a lateral bud but the infected area can permanently interfere with the normal development of the tree. When the conditions are not favorable, the fungus preserves itself by producing oospores.

1.7.7. Management

In order to control *Belaat*disease, the following integrated management is recommended:

a. Cultural control

- Take care of the plantation by adopting the best practices with regard to planting, fertilization, irrigation, and pruning.
- Avoid the use of gravity irrigation and connecting cups between trees when some the palms are infected.

- Ensure normal development of a lateral bud, which will replace the destroyed apical bud.

b. Host plant resistance: Several good commercial cultivars are susceptible. There is no information about the resistant cultivars.

c. Chemical control

- Perform preventive treatments (once) and curative (repeated two or three times within 12 to 15 days). Examples of fungicides: Bordeaux mixture containing copper (preventive); injection metalaxyl or fosetyl-aluminum (preventive and curative).
- Spray the tops of palm trees with fungicides with powerful spears.

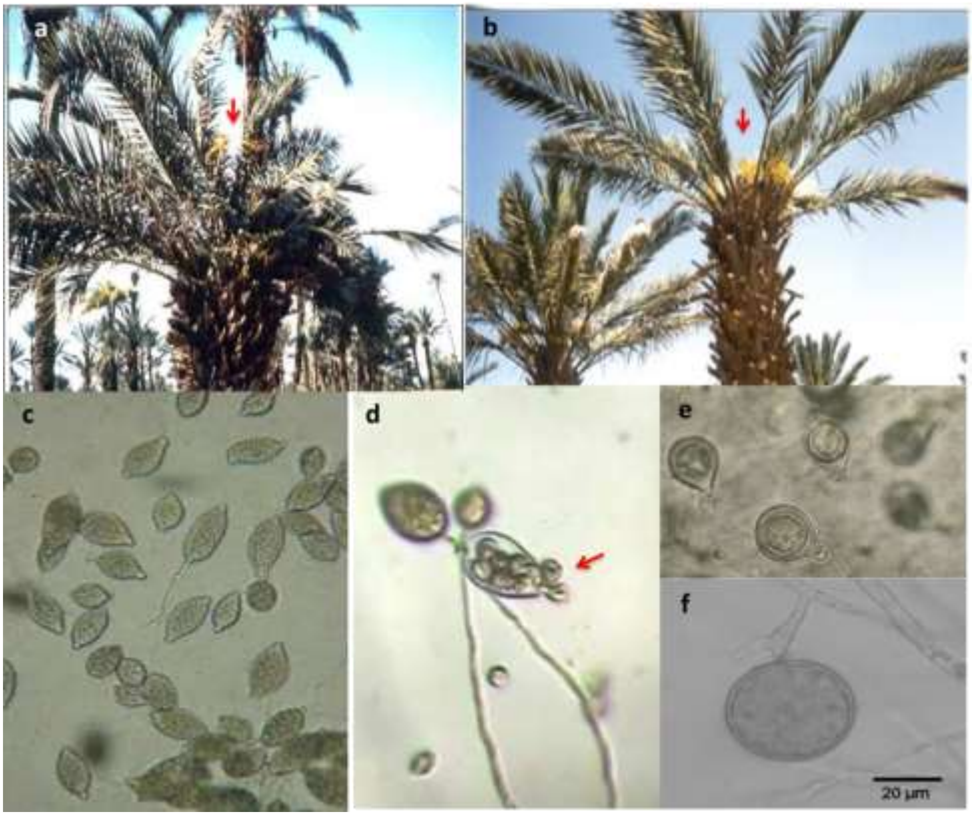

Fig.1. Symptoms on date palm due to the belaat disease caused bty *Phytophtora palmivora*. Beginning of symptoms development and progression of the infection downwards in the trunk (a) as a conical wet heart rot or a volcanic ridge form and death of the terminal bud (b), sporangia (c), zoosporangia releasing zoospores (d), chlamydospores (oospores) (e) and oogonia with antheridia (f) of the pathogen. Sources of photos (a,b): Sedra My.H.), sources of microscopic photograph: c: https://alchetron.com/Phytophthora-palmivora-4144064-W, d: https://www.youtube.com/watch?v=hsdYrSgR4Ag,e-f: http://journals.oregondigital.org/ForestPhytophthora/article/view/3557/3332

1.8. Apical Drying of Leaves

1.8.1. Scientific name

The disease is caused by the fungi *Alternaria* sp. and *Phoma* sp. (Imperfect fungi, Moniliales, D*ematiaceae*) and other unidentified pathogens (Sedra, 1995b, 2001a, 2003b,c). In Pakistan, according to the symptoms, the probable causal agent is *Fusarium solani* (soil-born pathogen) (Abul-Soad, 2011).

1.8.2. Description and Symptoms

This disease is known in its initial phase by dryness of apical date palm leaves (rachis, then the pinnae) followed by the desiccation of apical leaflets (Fig.1(a-b)). In fact, within a single frond, drying begins from the terminal part to cover the whole frond. This symptom starts from outer-lower frond whorls toward central younger fronds (Fig.1c). Symptoms then evolve to include the entire leaf and may affect its base. At first glance, the symptoms resemble those caused by Bayoud disease, especially dried leaves that have the appearance of a wet feather (Fig.1(b-c)). When conditions are favorable to the disease (drought or lack of irrigation water), it spreads to all leaves and can infect the superficial zone of the meristem and the heart of the tree area, thus threatening the tree's life.

Abul-Soad et al. (2011) reported similar syndromes in Pakistan and called this disease the palm wilt disease (Sudden Decline Syndrome). The authors have reported that, during the final stages of the disease, the entire frond **e**ventually turns pale brown and the tree dies within few months. They suggested that the probable infection source is *Fusarium* spp., associated with an adverse condition(s) found to be responsible for date palm wilt disease. Later, the fungus has been identified as *Fusarium solani* (soil-born pathogen). The same pathogen *F. solani* is reported as a causal agent of a serious disease of date palm associated with yellowing and the death of the fronds in Iran (Mansoori and Kord, 2006) and Iraq (Al-Yaseri et al., 2006).

1.8.3. Distribution

The disease is considered to be a minor disease, affecting most date growing areas in several countries particularly in the traditional and / or marginal oases, i.e Morocco, Algeria, Mauritania, Libya, Egypt, Yemen, Saudi Arabia, etc. It generally develops in palm groves, where palm trees are poorly maintained and where irrigation is insufficient. Recently, similar symptoms have been observed in Pakistan.

1.8.4. Host range

Date palm (*Phoenix dactilyfera L.*)

1.8.5. Damage and economic importance

Although the disease is minor, it can reduce date production and sometimes causes palm mortalities when the infection reaches the heart of the palm and when there are no control measures of the disease. The disease incidence and intensity depend on the countries and regions and related to maintenance of date palm.

1.8.6. Biology

The pathogen is stored on the rest of infected palm leaves. Spores may be disseminated by the wind and rain and attack the apical leaf and provoke dryness of the tissues, which descend along the rachis and can reach the base and even the apical part of the meristem of the trunk. The produced spores may attack other leaves.

1.8.7. Management

In order to control the disease, the following integrated management is recommended:

a. Cultural control

- Remove and burn infested leaves and pruning the trees.
- Ensure proper maintenance and adequate care of date palms.

b. Host plant resistance: Several good commercial cultivars are susceptible. No information is available about date cultivars resistant to this disease.

c. Chemical control: Chemical treatment with fungicides such as Methylthiophanate and Thiram in case of advanced disease development.

Fig.1. Symptoms on date palm due to the apical drying of leaves disease caused by *Alternaria* sp. and *Phoma* sp. and spores of these pathogens. Beginning of dryness of apical date palm leaves (rachis then the pinnae) followed by desiccation apical leaflets (a), evolution of symptoms to include all the leaf (b,c), spores of *Alternaria* sp.(e) and spores of *Phoma*sp. Sources of photos a, b, c and d: Sedra My.H., sources of microscopic photograph: e: http://www.caltexmoldservices.com, f: https://www.forestryimages.org.

1.9. Graphiola Leaf Spot

1.9.1. Scientific name

Graphiola leaf spot, also called false smut, is caused by *Graphiola phoenicis* (Moug) Poit. (Basidiomycetes), and is a smut fungus.

1.9.2. Description and Symptoms

The disease often attacks older leaves and rarely attacks young leaves. Without fungicidal protection, the disease invades the populations of young plants grown under green house in production nurseries (Fig.1b). It may cause large necrotic lesions in leaflets of the young plants (Fig.1d). The symptoms appear as sub-epidermal spots on both sides of the pinnae (leaf flat) and on the rachis with small black sori (fruiting structures) developing in abundance on old fronds (Fig.1d). The prominent pustules are about 0.5 cm above the surface of the leaflets; with a 1-1.5 cm diameter and cylindrical solid-coloured yellow turning black or dark brown at the end stage (Fig.1a). Figures 1(c-d-e-f) illustrate in detail the pustules and sori produced by the pathogen. The sori are abundant on three-year-old leaves, conspicuous on two-year-old, but absent or infrequent on one-year-old leaves.

1.9.3. Distribution

Around the world, *Graphiola* leaf spot disease is the most widely spread disease and occurs wherever the date palm is cultivated under humid conditions, but is absent in less humid regions. It is present in mostly marginal date growing areas (Mediterranean coast), i.e., Egypt, Libya, and Morocco (El-Deeb et al.,2007; El-Gariani et al.,2007: Sedra, 2003a,c, 2012) but also in the southern most humid regions of Mali, Mauritania, Niger, and Senegal. This disease is rare and often absent in the Saharan oasis and inland areas; but it is present in areas close to the sea, i.e., countries near the seaside of the Arab Gulf (Djerbi, 1983; Zaid et al., 2002; Abbas and Abdulla, 2004). In Egypt (Delta region and Fayum) and Saudi Arabia (Kattif, Demam and Jeddah), the disease is the most common in most humid oases but absent in the less humid ones. It is also reported in Algeria, Qatar, Argentina, Vietnam, and USA. In Morocco, this disease only exists in some places in wet marginal palm groves without any apparent effect (Sedra, 2003a,c). However, the disease has been observed on palms invaded by the pathogen in some coastal areas on *Phoenix* species, such as Rabat, Kenitra and Agadir and certain regions in humid high plateaus. In addition, this disease is very harmful to young plants grown under green house in production nurseries (Fig.1(b-c)) (Sedra, 2003a,c, 2012, 2015a).

1.9.4. Host range

The disease attacks the date palm (*Phoenix dactilyfera* L.) and it is reported on other *Phoenix* species, such as *Phoenix canariensis* (Canary Island date palm) and it is rarely observed on *P. sylvestris* (wild date palm), *P. sylvestris* and *P. theophrasti*. The disease has been observed on other palms including: *Acoelorrhaphe wrightii, Arenga pinnata, Butia odorata, Chamaerops humilis, Coccothrinax argentata, Cocos nucifera, Dypsis lutescens, Livistona* *alfredii, Livistona chinensis, Prestoea acuminata, Roystonea regia, Sabal minor, Sabal palmetto, Syagrus romanzoffiana, Thrinax morrisii,* and *Washingtonia robusta* (Elliott, 2015).

1.9.5. Damage and economic importance

Severe infection reduces tree growth and date production through a premature death of leaves. The disease incidence and intensity depends on the countries and regions and the prevailing air conditions.

1.9.6. Biology

The pathogen attacks the leaves and develops sub-epidermal, in small spots on both sides of the pinnae leaves, on the rachis, and on the leaf base. The incubation cycle for the pathogens is about 10-11 month. The numerous fruiting structures emerge as small-yellow/brown to black sori, with two layers. On a leaf, sori are abundant on apical pinnae, less abundant on the middle section and even less abundant on the basal section. The mature pustules release the spores (Fig.1(e-f)). Spores are spherical to ellipsoidal, 3-6 µm in diameter, with a smooth hyaline wall and appear as powdery yellow spores on whitish filaments (Fig.1 (f-g)). The spore dissemination is facilitated by water gusts, wind, insects, and birds. The normal 6-8-year life span of date palm fronds will be reduced to three years by *Graphiola* disease and heavily infected leaves die prematurely, which consequently reduces the yield of the palm.

1.9.7. Management

In order to control the disease, the following integrated management is recommended:

a. Cultural control

- Follow the appropriate distance (spacing) between palm trees in plantations.
- Prune and then burn the infected leaves every year to prevent new infections.

b. Host plant resistance

Date palm cultivars show variability in their response to the pathogen. In fact, genetic tolerance has been found in some cultivars. For example, Barhee, Abdal Rahman, Gizaz showed resistane, while cultivars Khastawi, Iteema, Jouzi and Tadala are tolerance. In contrast, the cultivars Khisab, Ashrasi, Maktoom, Zahdi and Bream are very susceptible (Nixon, 1957; Sinhaet al., 1970).

c. Chemical control

For field plantation, spraying the palms after pruning with appropriate fungicides such as bordeaux mixture, cupric hydroxide and maneb or copper oxychloride + maneb + zineb (3 to 4 applications on a 15-day schedule after sporulation, has been recommended).

For palm nurseries, spray the young plants with a mixture of fungicides cited above.

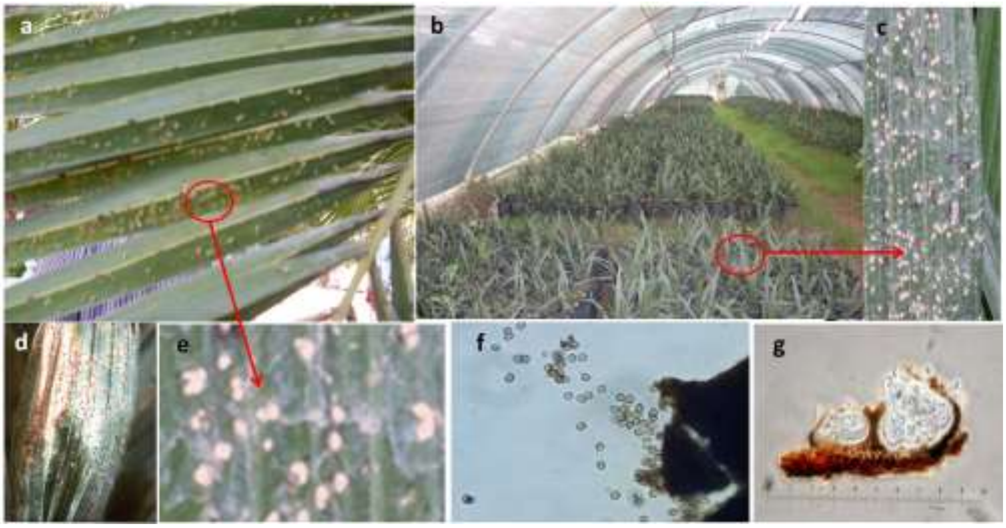

Fig.1. Symptoms on date palm due to *Graphiola* leaf disease caused by *Graphiola phoenicis* and the structure and spores of the pathogen. Symptoms of leaflets of adult palm tree (a) and young plant (c,d) in the nurseries (b), pustules of the pathogen in detail (e), mature pustules (g) releasing spores (h). Source of photos a, b, c, d, e: Sedra My.H., sources of microscopic photograph: f and g: https://www.forestryimages.org

1.10. Khamedj-Inflorescences Rot

1.10.1. Scientific name

Khamedjor inflorescences rot is caused frequently by *Mauginiella scaettae* Mich. & Sabet (Moniliales, Moniliaceae) and sometimes by *Fusarium moniliforme* J. Sheld. (Moniliales, Tuberculariaceae) or/and *Thielaviopsis paradoxa* (Dade) C. Moreau (Moniliales, Dematiaceae). Both of these fungi belong to the class of imperfect fungi.

1.10.2. Description and Symptoms

Locally called khamedj or inflorescence rot is caused by three pathogens according the different-colour symptoms (Sedra, 2001a, 2003a,c 2015b): *Mauginiella scaetae* Mich. & Sabet, causes the white creamy symptoms (Fig.1b), *Fusarium moniliforme* J. Sheld. has pinkish ones (Fig.1c) and in the case of Thielaviopsis paradoxa (Dade) C. Moreau, the symptoms are dry and brown inflorescence rot (Fig.1d). The pathogen M. scaetae can attack young fruits and cause their rot even at the green stage. However, the two other pathogens may rarely cause inflorescence rot. The first visible symptom of the disease appears on the external surface of unopened spathes and is in the form of a brownish or rusty-colored area (Fig.1a). The symptom is most apparent on the internal face of the spathe, where the fungus has invaded the inflorescence and sporulated abundantly. Inflorescence rot may be partial or total (Fig. 1(b-c-d). The pathogen is easy to isolate and sometimes from numerous samples of infected spathes and diagnosed in laboratory, we have noticed the presence of a mixture of two pathogens M. scaetae and F. moniliforme. The disease attacks both male and female palms but the males are more attacked as a result of lack of attention and care given to male palms as compared to female trees. In case of severe attack, female and male palms produce dry spathes and do not bear fruit or pollen. In Saudi Arabia, the same symptoms as inflorescences rot may be caused by other species, i.e., *Alternaria alternata* and A. chlamydospora, but with very low frequencies. In Morocco, the pathogens F. moniliforme and T. paradoxa are frequently responsible of drying and browning of spikelets of regimes bearing dates; this attack causes fruit drop before maturity and actually reduces the number of dates on diets (Sedra, 2003a, c 2015a).

1.10.3. Distribution

The inflorescence rot is a serious disease, affecting most date growing areas of the old world: Morocco, Mauritania, Algeria, Tunisia, Libya, Egypt, Sudan, Palestine, Saudi Arabia, Qatar, Iraq, Kuwait, Bahrain, United Arab Emirates, Italy (Europe), and USA. The disease causes damage on inflorescences in neglected palm groves in hot and humid regions, or in areas with prolonged periods of heavy rain, 2 to 3 months before the emergence of spathes. The disease incidence and intensity depend on the countries and regions and is related to the prevailing humidity.

1.10.4. Host range

Date palm (*Phoenix dactilyfera L.*)

1.10.5. Damage and economic importance

The disease is one of the most dangerous fungal diseases affecting palms in the world. It causes considerable damage on production during some favorable years. Some researchers estimated losses were from 2 to 15% and up to more than that to about 50 % in some countries during the years when the disease is epidemic. Some years when the conditions are favourable, the disease frequently affects more than 50% of spathes. This is recorded in Morocco, particularly in the date palm groves of Ziz and Tafilalet, Tinghir and Marrakech (Sedra, 2003c). Al Hassan and Waleed (1977) reported that, during the 1940s and 1970s, the disease affected male and female palms and destroyed 80% of the harvest at Basrah in Iraq. Serious damage was also recognised in Al-Qatif in the Kingdom of Saudi Arabia in 1983, with losses ranging from 50 to 70 %. In Morocco, during some wet years, the damage is significant especially in plantations of Mejhool cultivar that has a significant commercial value (Sedra, 2003c, 2012, 2015a).

1.10.6. Biology

The pathogen can be stored for several years in mycelium in dried and contaminated inflorescences and their casings that are still hidden in the leaf bases and *lif* tissues. The spores usually persist in an infected palm until the following flowering season to infect the new inflorescence. Transmission of the disease from one palm to the next occurs through the contamination of male inflorescences during the pollination period and through the stored inoculum. The infection begins during spathe formation from a primary bud and before its appearance on the tree. The development of the disease is favored by conditions including low temperature and high air humidity or rainy weather and injury of young spathes. Its dispersal is by rain, wind, contaminated pollen, insects, and cultivation activities involving the apical part of the tree.

1.10.7. Management

In order to control the disease, the following integrated management is recommended:

a. Cultural control

- Clean and incinerate infected inflorescences and tissue fragments.
- Avoid the use of pollen from contaminated spathes or pollen collected from diseased male trees in order to prevent the disease spread.

b. Host plant resistance

There are different levels of cultivar susceptibility to the disease; in Morocco, highly susceptible cultivars are Mejhool and Boufeggous and several selected varieties (Sedra, 2012, 2015a). Laville (1973) has reported that some other varieties are particularly susceptible to the disease as Ghars in Algeria, Khadrawy and Sayer in Iraq while other cultivars manifest a good capacity for resistance: Hallawi, Hamrain, Takermest and Zahdi.

c. Chemical control

- Use preventive chemical treatments with fungicides after harvest (September to November), followed by another treatment before or at the beginning of the output spathes next year (December to March) (Sedra, 2003c, 2012, 2015a).
- Chemically treat palm trees at the onset of symptoms. If the symptoms are highly obvious, chemical intervention is not effective. Examples of fungicides used: a bordeaux mixture (0.3–0.5 %), methyl thiophanate (0.2 %), thiram (0.2 %), and copper oxychloride (0.4 %) (Sedra, 2003c, 2012, 2015a). Al Hassan et al. (1977) recommended spraying one month before the emergence of spathes: a bordeaux mixture or a copper fungicide, sulphate-lime mixture or a dichlone spray or a thirame spray at the rate of 8 litres per palm or with tuzet at the rate of 125 g/hl.
- Repeat spraying in late winter and early spring.

The chemical treatment can be replicated twice depending on the level of satisfaction of the first treatment.

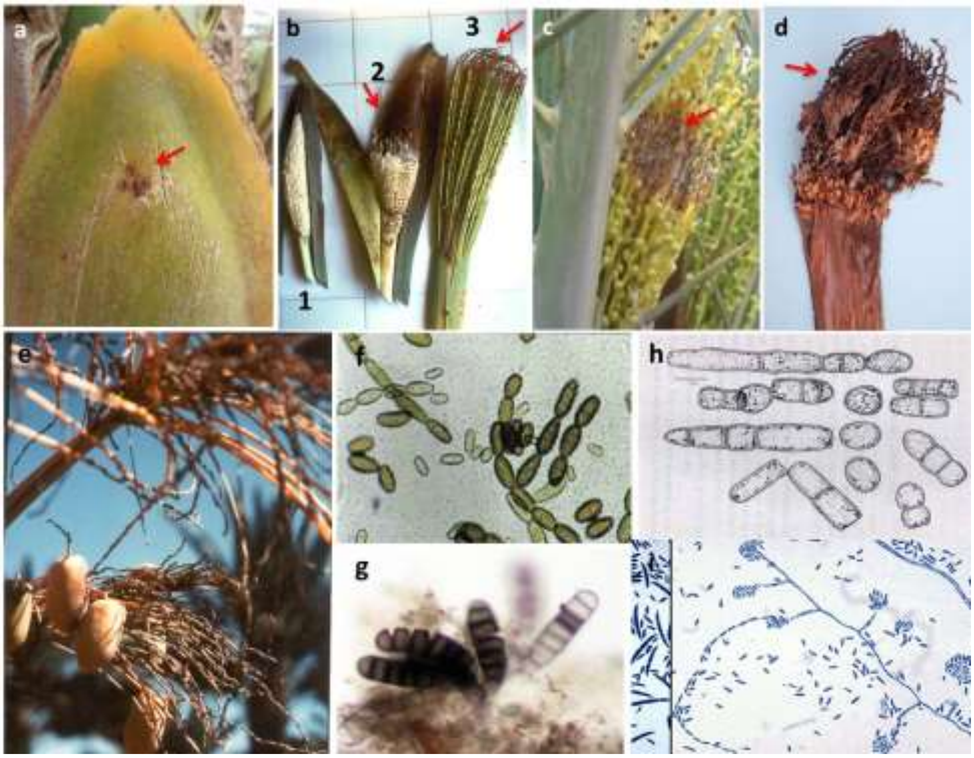

Fig. 1. Symptoms on date palm inflorescences due to the Khamej disease (inflorescences rot) and structures and conidia of pathogens. Beginning of attack of inflorescence rot (a) at different stages: 1 free, 2 (white creamy symptoms) and 3 partially attacked by *Mauginiella scaettae* (d), partial attack on inflorescences with pinkish symptoms caused by *Fusarium moniliforme* (c) or total attacked by *Thielaviopsis paradoxa* with symptoms on inflorescences as blackening and charring (d) and on diets as browning and drying (e). Conidia and chlamydospores of *T. paradoxa* (f,g), unique chlamydospores, bilateral and multicellular spores of *M. scaetae* (h), conidia of *F. moniliforme* (c). Sources of photos a, b, c, d: Sedra My.H.; source of drawing h: Djerbi M., 1988);sources of microscopic photograph: f: https://www.researchgate.net; g: https://www.forestryimages.org, i: http://umvf.omsk-osma.ru

1.11. *Omphalia* Root Rot

1.11.1. Scientific name

Omphalia root rot, also called decline disease, is caused by the two species *Omphalia* (*O*. *tralucida* Bliss and *O*. *pigmentata* Bliss) (Basidiomycetes, Agaricales, Tricholomataceae). The disease was recorded in California, USA and in Mauritania by Fawcett and Klotz (1932) and Bliss (1944), respectively. It is also called a decline disease because of its association with declining date palms.

1.11.2. Description and Symptoms

Palm trees previously appearing normal lose vigor and become worthless. The main disease symptoms are characterized by retardation and cessation of growth of the tree, loss of vigor, becoming unfruitful that usually leads to the death of the palm (Fig 1(a-b)). The disease results in the rotting, necrosis, destruction and abortion of roots. This is associated with the loss of vigor, stunting of the tree, and the premature death of fronds. When the attack is advanced, the palm may eventually fail to fruit and produce dates. These symptoms are similar to those observed on diseased palms by other diseases, such as *Faraoun* disease that exists in Mauritania but no causal agent for this disease has been identified (Sedra, 2002, 2003b, 2006b,c, 2008a,b; 2015b).

1.11.3. Distribution

The disease is widely spread in date plantations of Coachella Valley, CA-USA and in Kankossa (Mauritania) (Djerbi, 1983) and recently in several important date palm groves in Mauritania (Sedra, 2002, 2006b,c, 2015b). In other countries, based on the symptoms of fronds, this disease is confused with other diseases attacking the base of the trunk of date palm.

1.11.4. Host range

Date palm (*Phoenix dactilyfera* L.)

1.11.5. Damage and economic importance

Omphalia root rot is relatively speaking the most destructive fungus disease of date palms in California. In Mauritania, the disease has occurred in several oases by the dissemination of the fungus and by irrigation conditions which are favorable to the fungus. No statistical data of losses are available. The disease incidence and intensity depend on the level of palm maintenance.

1.11.6. Biology

The pathogens *O. tralucida* and *O. pigmentata*, either singly or in combination, attack the roots and provoke necrosis and rotting. Sometimes, it is difficult to find rotten roots and the pathogen is most readily isolated from large rotten roots but occasionally isolated from small secondary and tertiary diseased roots. The favorable conditions for the disease development are inadequate water irrigation and/or difficulty of water to circulate in compacted or tight soils. The spores of the fungus released from the degraded necrotic roots can be disseminated to palm trees by water and the tools for hoeing under the diseased palms.

1.11.7. Management

In order to control the disease, the following integrated management is recommended:

a. Cultural control

- As a preventive measure, care must be taken to aerate the soil by hoeing and to avoid stagnation of water in the rhizosphere of the palm.

- For young plantations, the use of free offshoots and plants produced from tissue culture.
- The practice of drip irrigation can reduce the spread of the disease.
- Clean and disinfect hoeing tools after use in the rhizosphere of diseased or suspected palms to prevent the spread of spores of the parasite.
- Avoid transplanting infected palms to healthy orchards.
- Incinerate diseased trees.

b. Host plant resistance

Four Mauritanian varieties (Ahmar, Marsij, Mrizigueg and Tinterguel) were found to be susceptible to this disease (Sachs, 1967). Sedra (2003b, 2008b) has recorded the symptoms on the majority of Mauritanian commercial cultivars. Unlike other date varieties planted in California, Deglet Nour was the most susceptible to the disease. It is necessary to promote research of resistant varieties among natural populations of date palm.

c. Chemical control

- The use of Brestan or Dexon at the rate of one spray every two weeks for eight weeks was recommended by Sachs (1967) as a chemical control measure.
- Disinfection of the soil by carbon disulphide or ethylene oxide or metham sodium

Research should be intensified on this important disease.

Fig.1. Symptoms on date palm due to *Omphalia* root rot caused by *Omphaliatralucida* and *O. pigmentata*: beginning of retardation and cessation of growth of the palm tree and loss of vigor (a), death of tree (b) in Mauritanian oasis.

1.12. Fruit Rot

1.12.1. Scientific name

The fruit rot is caused by fungi in the field and during marketing, with or followed by some species of yeasts such as *Saccharomyces* sp. and bacteria, for example *Acetobacter* sp. Several fungi that cause the rotting of the dates are: *Alternaria alternata*, *Penicillium* sp., *Aspergillus niger*, *Aspergillus flavus*, *Aspergillus ochraceus*, *Aspergillus japonicas*, A. fumigatus, *Fusarium* spp., *Thielaviopsis paradoxa, Cladosporium* sp., *Botryodiplodia* sp., *Stemphylium botryosum*, *Aurobasidium* sp., *Geotrichum rosemium*, *Geotrichum* sp., *Macrosporium* sp. (syn. *Alternaria* sp.), *Helminthosporium* sp., *Citromyces sp.* (syn. *Penicillium* sp.), *Mauginiella scaettae*, *Fusarium lateritium, F. moniliforme, Paecillamyces sp., Syncephalastrum sp. Phomopsis diospyri*, *Ceratostomella* sp. (syn. *Ceratocystis*sp.).The structures and spore forms of fungi are illustrated in figure 2.

Some pathogenic fungi attack fruits before maturity, for example, Alternaria sp. and *Thielaviopsis paradoxa* and *Cladosporium* sp. whereas others attack them after harvest and during marketing, such as *Penicillium* sp. *Penicillium expansum, Aspergillus* sp., *Nigrospora* sp. and *Fusarium* sp.

The most common fungi causing fruit spoilage are the calyx-end rot caused by *Aspergillus niger* and the side spot decay caused by *Alternaria* sp.

1.12.2. Description and Symptoms

Symptoms in the form of rotting fruit appear at the beginning of their development, resulting in their fall when small or they may rot during the green and *khalal* stages (Fig.1c,h,i,j,k)) before and after coloring. However, most rots appear after coloring and fruit maturity as a result of the wounds or cracks on the fruits. At the end, the rots usually appear as soft brown spots that are black in the center. Different symptoms can be observed depending on the wounded part of the fruit and also according to the causal agent. Three types of symptoms can be observed:

- Brown spots rot on fruits wounded or cracked in the stages of *Khalal* and *Routab* caused by *Thielaviopsis paradoxa* and *Cladosporium* sp., but frequently by *Alternaria* sp. The attack may occur in the field by these fungi and *Nigrospora* sp. after rainy weather and high humidity during the period of maturity of dates (Fig.1a, h1, h2,j, k)
- Rot appears in the calyx, where the cuticle is absent in the *Khalal* or *Routab* stages caused by *Aspergillus niger* syn. *A. phoenicis* and *A. flavus* (Fig.1(d-e))
- Fruit rot on dates during the storage and marketing characterized by the invasion of the fungus of fruit tissue, caused by *Aspergillus* sp. (Fig.1f) and generally by *Penicillium* sp. (Fig.1b).

During storage, soft rot produces an aromatic odor if the moisture content of the dates exceeds 25%. Soft rot is caused by *Acetobacter* sp. and *Saccharomyces* sp.

1.12.3. Distribution

Rots of dates exist in all areas around the world, where the date palm is cultivated and dates are produced. This disease causes significant damage particularly when strong rains occur during the later stages of date maturation and in storage. The economic importance of fruit rots varies greatly, since their incidence is governed by the occurrence of rain and high humidity during the *Khalal* and later stages of ripening (Carpenter and Elmer, 1978).

1.12.4. Host range

Date palm (*Phoenix dactilyfera* L.)

1.12.5. Damage and economic importance

Fruit rot damage varies from one year to another, depending on humidity and rain and also on the prevalence of these factors from the *Khalal* stage until fruit maturation. Even though losses vary from one country to another and from one cultivar to another, they are estimated to be between 10% and 50% of the harvest (Darley and Wilbur, 1955; Calcat, 1959; Djerbi et al., 1986). For example, in Algeria and Tunisia, the Deglet Nour cultivar is particularly vulnerable to fruit rot and damage may exceed 25% and 50%, respectively, during the wet years. In Morocco, the losses on Mejhool cultivar may reach 40% in some favorable years. In USA, the estimated damages on these cultivars vary from 10 to 40% depending on the years. The cost of control measures and the cost of damaged fruit make fruit rots the most important economic disease of dates in California (Carpenter and Elmer, 1978).

1.12.6. Biology

Fruit rot in dates is caused by some fungi in the field and during the marketing and storage, in association with some species of yeast and bacteria. This rot is due to the presence of high concentrations of sugars and the high osmotic pressure. The development and spread of the disease is facilitated by high air humidity and poor and inadequate fruit packaging and storage facilities. The spores of the fungi are preserved in the rest of the residual fruits left on the tree or in the packaging and warehouse and store walls. These spores can be disseminated by wind and rain water. The infection is favored by wounds and cracks of fruits in the field and in stores. The fungi produce colonies, sporulate, and release new spores which are easily disseminated. The rot fruit development increases when high relative humidity prevails. As mentioned in this chapter, some other parts of the palm tree may be attacked by fungi, such as *Alternaria* sp. *Cladosporium* sp. *Fusarium moliniforme*,*Helminthosporium* sp., *Mauginiella scaettae, Botryodiplodia* sp. and *Thielaviopsis paradoxa*.

1.12.7. Management

The control of fruit rot is often difficult but it is more effective when preventive measures are adopted. However, in order to control the disease, the following integrated management is recommended:

Fig.1. Symptoms of dates due the rot diseases caused by different pathogens. Fungal colonization of dates in field after rainy weather and high humidity during the period of maturity dates by *Alternaria* sp. and *Cladosporium* sp. (a), beginning of attack of dates by *Penicillium* sp. sp. during inadequate storage of date (b), beginning of rot development at green (c) and *khalal* (g,h1,j) stages of date caused by *Thielaviopsis paradoxa, Cladosporium* sp. and *Botryodiplodia* sp., rot developed from the calyx where the cuticle caused by *Aspergillus flavus* (d,e), invasion of the fungus of fruit tissue caused by *Aspergillus niger* syn. *A. phoenicis* during the storage and marketing (f),beginning of rot developed on *khalal* stage caused by *Alternaria* sp. associated with *Thielaviopsis paradoxa* (i), rot developped on *khalal* stage by *Nigrospora* sp. (k, h2). Sources of photos a, b, g, h, i, j, k: Sedra My.H. , photos c, d, f: E. Edongali (Libya) and e: http://bioweb.uwlax.edu

a. Cultural control

- Ensure good practices of date palm cultivation.
- As a preventive measure, in high moisture areas, harvest dates in the *Khalal* and *Routab* stages and proceed for their artificial maturation in order to protect them against rot
- In the field, it is advised to improve the ventilation, reduce moisture and lower the humidity inside the bunch. This can be done by installing wire rings between the spikelets and/or by removing a few fruit strands from the centre of the bunch to provide ventilation and drying the wet fruits.

- Cover the fruit bunch in the early *Khalal* stage with strong paper bags or wrapsin the form of bells to avoid fruit wetting with rain and dew.
- Prevent fruit injuries and attack by insects and birds.
- There is a need to sort healthy fruits, to exclude injured and deformed fruits, and to dry the fruits during the postharvest stage.

b. Host plant resistance: Soft dates are often the most predisposed to rots.

c. Chemical control

- In the field, in the case of fruit infection in early stages after fruit set, in particular by *Alternaria* sp. or *Thielaviopsis paradoxa*, it is possible to spray the fruit with an appropriate fungicide (used for control of leaf spot disease and black scorch). It is important to also control insects during this period.
- Fungus spoilage could also be limited by dusting the fruit bunches during the *Khalal* stage with 5% ferbam, 5% malathion, 50% sulphur and an inert carrier (40 %) (Djerbi,1983).
- Other measures of control may be developed, such as irradiation of dates during postharvest process, to control date palm pests and diseases and using microbial biopesticide as alternative of methyl bromide.

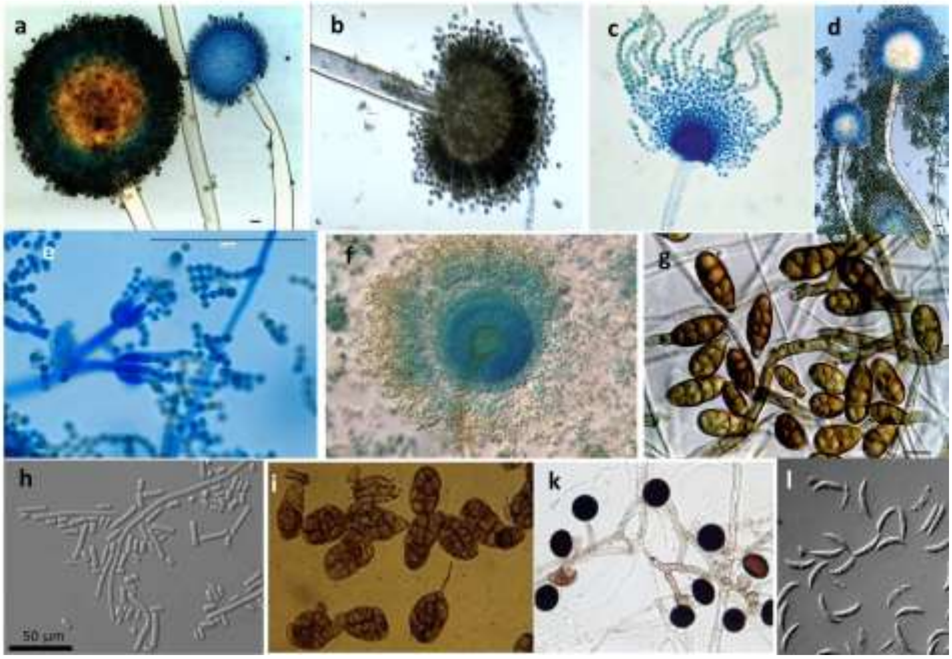

Fig.2. Structures and spore forms of fungi. Aspergillus niger (a,b), Aspergilus flavus (c,d), Penicillium sp. (e), Aspergillus ochraceus (f), Alternaria alternate (g), Geotrichum sp. (h), Stemphylium botryosum (i), Nigrospora sp. (j) and Fusarium moniliforme (k). Sources of microscopic photograph: a: http://old.vscht.cz, b: https://www.indiamart.com, c: http://life-worldwide.org, d: http://old.vscht.cz, e: http://thunderhouse4-yuri.blogspot.fr, f: http://www.iam-europa.com, g: http://old.vscht.cz, h: http://healthpills.biz, i: http://www.schimmel-soforthilfe.de, j: http://www.cram.com, k: http://agritech.tnau.ac.in

2. Phytoplasmic Diseases

2.1. Lethal Yellowing Disease

2.1.1. Scientific name

Lethal yellowing (LY) is a systemic disease caused by a phytoplasma transmitted by a planthopper (*Haplaxius crudus*, syn. *Myndus crudus*). The phytoplasma, an unculturable wall-less cell bacterium, has been classified as a member of group 16S rDNA RFLP group 16SrIV, subgroup A (16SrIV-A) (Harrison and Elliot, 2008). The proposed name for the pathogen is "*Candidatus Phytoplasma palmae*."

2.1.2. Description and Symptoms

The difficulty with LY diagnosis is that symptoms vary according to the palm species, and in the case of coconuts, the particular cultivar involved (Harrison and Elliot, 2008). Generally, the symptoms are characterized by fruit drop and flower necrosis, foliage discoloration, and the death of the apical meristem (bud).

On the coconut tree, the symptoms start by fruit dropping before their maturity, and their color is blackish-brown and seems to be boiled on the side of the blow of the fruit (Fig.1b). The stems of the floral shoots take on a black color and may not open, rapidly becoming necrotic and eventually die. Old leaves turn yellow and bend around the trunk then turn brown. Later, the new leaves turn yellow and the apical bud dies and releases a bad odor (Fig.1a). At the end, the tree has rapid and generalized yellowing leading to the death of the palm; the palm head can separate from the trunk (Al-Zayat et al., 2000; Harrison and Jones, 2004)

In date palm, the green leaves take on a pale green color then turn brown (Fig.1c) instead of becoming yellow before finally dying due to a sudden death of the roots at the base of the trunk. In the case of adult trees, the symptoms are characterized by the drying of the inflorescences, falling of the fruit and death of the meristematic area which rots and produces an unpleasant odor. The leaves lose their natural shape, fade, and the diseased apical part can topple over the trunk leaving it naked (Fig.1c). Infected trees typically die within four months.

Symptoms of LY may be confused with other palm diseases, such as basal trunk bulb rot (caused by the fungus *Ganoderma zonatum*, basidiomycetes) (Elliot and Broscha, 2000) or boron deficiency or potassium deficiency on the palms.

2.1.3. Distribution

The lethal yellowing was reported for the first time in 1830 in the Cayman Islands. It then spread to other regions: USA (Florida, Texas) and parts of the Caribbean, Central America and Oceania (Mexico, Cuba, Dominican Republic, Honduras, Jamaica, Belize, the Bahamas) and the Indian Ocean region. In 1930, the LY spread to East Africa in Togo and localized outbreaks continue to occur (Tanzania, Mozambique, Ghana, Nigeria, and Cameroon). The disease is known by various local names, including: Awka disease (Nigeria), Kaïncopé disease (Togo), Cape St. Paul wilt (Ghana), Kribi disease (Cameroon), unknown disease (Jamaica), jaundice lethal palm, terminal bud rot (Haiti). In 2008, for the first time in Oceania, symptoms of lethal yellowing disease have been reported in coconut plantations in Papua New Guinea (Kelly et al., 2011). All these forms of disease are now attributed to the phytoplasm of the lethal yellowing of the palm. On date palm, lethal decline (LD) is associated with a phytoplasma belonging to the 16SrIV Group, subgroup D; While other phytoplasmas of the 16SrIV group, a diverse group of phytoplasmas, cause lethal diseases of coconut and other palms in Central America, the Caribbean, east and west Africa (Harrison and Jones, 2003).

In Arab countries, Al-Awadhi et al. (2002) and Ammar et al. (2005) detected phytoplasma associated with yellowing disease of date palms in Kuwait and Egypt, respectively. The disease displayed similar symptoms of *Al-Wijam* disease as expressed on leaves, spathes and bunches of date palm; such as the disease of *Al-Wijam* that exisits in Saudi Arabia (Al-Hudaib et al., 2007) and Bahrain. The disease incidence and intensity depend on the countries and regions into countries according to palm species and varieties.

2.1.4. Host range

At least 37 palm species have been documented with LY and reported as susceptible to lethal yellowing around the world (Harrison and Elliot, 2008). In fact, this phytoplasma disease attacks many genera and species of palms, including some commercially important species, such as the coconut (*Cocus nucifera*) and date palm (*Phoenix dactilyfera* L.) and ornamental palms as *P. canariensis* Hort., *P. reclinata* Jacq. *P. sylvestris* , and other species bellowing to the genera as such *Adonidia* sp., *Aiphanes* sp., *Allagoptera* sp., *Arenga* sp., *Borassus* sp., *Caryota* sp., *Chelyocarpus* sp., *Copernicia* sp., *Corypha* sp., *Crysophila* sp., *Cyphophoenix* sp., *Dictyosperma* sp., *Dypsis* sp., *Gaussia* sp., *Howea* sp., *Hyophorbe* sp., *Latania* sp., *Livistona* sp., *Nannorrhops* sp., *Pritchardia* sp., *Ravenea* sp., *Syagrus* sp., *Trachycarpus* sp. and *Veitchia* sp.

2.1.5. Damage and economic importance

The deadly yellowing of the palm is a threat especially for the production of coconuts and copra. This disease can destroy a coconut plantation in one or two years. The importance of the disease was first realized in the USA (Florida) on coconut palms destroying about half a million coconut palms (McCoy, 1976) and one million coconut trees in 30 years along the coast of Ghana, near Cape St. Paul (Mariau, 1999). LY disease is a serious threat to date palm plantations in date-producing countries.

2.1.6. Biology

Phytoplasma was first discovered in 1967 in aster plants in Japan. They are uncultivable bacteria and obligate parasites of the phloem in the infected plants (Abdullah et al., 2010, Bertaccini and Duduk, 2009). They are mainly transmitted by insect vectors of the Hemiptera order, families Cicadellidae, Fulgoroidea and Psyllidae (Weintraub and Beanland, 2006).

The phytoplasm lives only in the screened tubes of the phloem of infected trees. In a classification based on similarity coefficients derived from RFLP analysis of 16S rRNA gene sequences amplified by PCR, this phytoplasm is classified in group 16SrIV, subgroup A (16SrIV-A) 6.7. Other phytoplasmas isolated in other countries were classified in the 16SrIV group with different subgroups. The pathogen is disseminated by wind-born arthropod vectors. As mentioned above, phytoplasma cannot survive outside a host organism and it is transmitted by insect vectors (order Hemiptera). In the Caribbean and in the United States, this vector has been identified as *Haplaxius crudus* (leafhopper, family Cixiidae) (Fig.1d), whose adult feeds on palm leaves, without causing serious direct damage (Howard et al., 1983). The vector of African forms of the disease has not been identified and different vector species are suspected. Heavy turf grasses and similar green ground cover will attract planthoppers to lay their eggs and the nymphs develop at the roots of these grasses. The planthoppers' eggs and nymphs can pose a serious threat to coconut and other palm species. The insect moves the phytoplasma from palm to palm as it moves during its feeding cycles (Harrison and Elliot, 2008).

Mycoplasma of leaf yellowing has been listed in the EPPO quarantine pest list A1 since 1986. It is also classified as a quarantine pest by plant protection organizations in the world: the Asia and Pacific Plant Protection Commission (APPPC), Committee on Plant Protection in the Caribbean (CPPC), Inter-African Phytosanitary Council (IAPSC) and North American Plant Protection Organization (NAPPO).

2.1.7. Management

The LY of palms is one of the most difficult diseases to control in the world. No economically viable control methods exist to protect coconut plantations. Chemical control can only delay the advancement of symptoms in the case of an early infection without eradicating the disease. The best option in combating lethal yellowing is to plant palms resistant to the disease. Disease management via control of planthopper populations is insufficient to justify repeated insecticide applications in landscapes. Planthoppers are flying insects and they can also be blown around by wind (Harrison and Elliot, 2008). However, in order to control the disease and to minimize the losses, the following integrated management is recommended:

a. Cultural control

- Symptomatic palms with >25% discolored leaves should be removed, since they are unlikely to respond to chemical treatment. For susceptible *Phoenix* species, if the apical meristem (bud) is already dead, the palm will not respond to chemical treatment (Harrison and Elliot, 2008).

- It is only possible to limit the extension of outbreaks of infection by eradication and burning of the diseased trees.
- Although there is no evidence that the disease can spread through the tools and instruments used to clean or cut infected palms, it is wise to take precautions and to disinfect these tools.
- Seed transmission has never been demonstrated, although phytoplasma can be found in coconuts, but phytosanitary quarantine procedures that prevent the movement of coconut seeds, seedlings and mature palms out of the coconut, an epidemic zone of the LY should be applied to grasses and other plants likely to transport infected vectors

b. Host plant resistance

As mentioned above, the use of host palm resistance represents the most practical long-term solution for LY control. Many palm species are apparently not susceptible to LY and so provide important alternative choices for ornamental landscape plantings (Harrison and Elliot, 2008). In fact, LY has not been reported on most palm species native to Florida or regions of the Caribbean Basin, where LY has been active. These include *Sabal palmetto* (Cabbage palm), *Roystonea regia* (Royal palm), *Acoelorraphe wrightii* (Paurotis or Everglades palm), and *Thrinax morrisii* (Key Thatch palm). Other common imported palms resistant to LY are: Alexandra Palm (*Archontophoenix alexandrae*), Carpentaria Palm (*Carpentaria acuminata*), Yellow Cane Palm (*Chrysalidocarpus lutescens*), Pygmy Date Palm (*Phoenix roebelenii*), MacArthur Palm (*Ptychosperma macarthurii*), Solitaire Palm (*Ptychosperma elegans*), Mexican Washingtonia (*Washingtonia robusta*), Foxtail Palm (*Wodyetia bifurcata*) and Queen Palm (*Syagrus romanzoffianum*). This gene pool of resistance to LY can be used in the future for the genetic improvement of palm species.

For cultivars of date palm, no information is available about susceptibility and resistance to LY. Investigations of the grass species hosting nymphs of the LY vector insect have not identified grass species suitable for lawn and turfgrass development, particularly for golf courses.

c. Chemical control

The antibiotic oxytetracycline HCl (often referred to as OTC), administered to palms by liquid injection into the trunk, can also be used preventively to protect palms when LY is known to occur in the area. The amount recommended depends on the size of the treated palm. As a therapeutic measure, systemic treatment on a 4-month treatment schedule should begin as early in symptom expression as possible (McCoy, 1975, 1982; Harrison and Elliot, 2008).

Fig.1. Symptoms on palms due to Lethal Yellowing disease (LY) caused by *Candidatus Phytoplasma palmae*. Foliar yellowing symptoms (a) and fruits prematurely dropped (b) from infected coconut (*Cocos nucifera*), foliar browning symptoms on infected date palm (*Phoenix dactylifera*) (c), insect as vector of LY on palms: *Haplaxius crudus* (leafhopper, family Cixiidae, Hemiptera) (d). Source of all photos: Harrison and Elliot (2008), website: http://edis.ifas.ufl.edu.

2.2. *Al-Wijam* Disease

2.2.1. Scientific name

In Arabic, Al-Wijam means poor or unfruitful, expressing that the palm stopped growing and giving fruit. First investigations and attempts to associate viral, fungal and nematode pathogens with the disease have so far failed (Abdusalam et al., 1992, 1993, Elarosi et al., 1982). Previous research on *Al-Wijam* which affected date palms suggested a phytoplasma as the possible disease (Abdusalam et al., 1993), further supported by (El-Zayat et al.,2000). Al-Hudaib et al. (2007) identified a phytoplasma of 16SrI group, *'Candidatus Phytoplasma asteris*' associated with *Al-Wijam* disease in Al-Hassa (Al-Hudaib et al., 2015). However, an extended survey carried out to identify the possible occurrence of phytoplasma infections in Al-Hassa and other date palm-growing neighboring areas in Saudi Arabia revealed two phytoplasma groups identified:16SrI (*Candidatus Phytoplasmas asteris*) in Al-Hassa, and 16SrII (*aurantifolia*) in other locations of Saudi Arabia (Al-Hudaib et al.,2017). This recent finding also showed that *Ocimum basilicum* (basil) and *Medicago sativa* (alfalfa) were found as possible alternative hosts for *Al-Wijam* 16SrII phytoplasma. Phytoplasmas in general are vectored by Auchenorrhyncha insects: leafhoppers, planthoppers, and psyllids.

2.2.2. Description and Symptoms

The main symptoms of the disease are leaf stunting with yellow streaking of the leaves and a marked reduction in fruit and stalk size by around 36-40% (Al-Hudaib et al., 2007). Leaves develop chlorosis (Fig.1(a,b)) and have very short lifespan. Stunting and yellowing increases with age, leading to the death of the leaves. Symptoms also appear on the palms, where they become dwarfed, shorter in length and bloom earlier than in normal palms. Figure 1c illustrates the general symptoms on the frond of the tree. Diseased spathes are shorter than healthy ones and split open before their complete emergence. The flowers get shorter and shorter in length (Fig.1d). The fruits are small in size and are not suitable for marketing and are similar to non-pollinated fruits and do not reach maturity unless they reached the *Khalal* stage (Fig.1e). Unlike *Al-Wijam*, lethal yellowing gets its name from the yellowing and drooping of palm fronds beginning with the lower fronds and advancing up through the crown after that entire crown falls from the tree.

2.2.3. Distribution

Al-Wijam is a disease similar to lethal yellowing disease that exists in the USA, Central America, Oceania, and East Africa. The disease displays similar symptoms to that of lethal yellowing disease, as expressed on leaves, spathes and bunches of date palm. Palm trees are infected with Phytoplasmas disease like *Al-Wijam* and lethal yellowing diseases. Recently, these diseases were recorded in many part of the world, which may threaten millions of palm trees. In Arab countries, *Al-Wijam* is a dangerous and devastating disease where the infected palm stops growing and producing dates before eventually dying. The disease spread initially in the eastern region (Al-Hassa and Qatif) of Saudi Arabia and the first mention of the existence was in 1945 (Badawi, 1945) and Nixon (1954). It was also recorded in Bahrain. In fact, El-Zayat et al. (2000) and Al-Hudaib et al. (2007) have detected phytoplasma in date palm trees infected by *Al-Wijam* in Saudi Arabia. Cronjé et al. (2000a,b) have reported a phytoplasma associated with a new disease of mature date palms (slow decline) in North Africa (Egypt and North Sudan) and white tip die-back, which is a newly recognized disease on young date palms (North Sudan). Al-Awadhi et al. (2002) and Ammar et al. (2005) detected phytoplasma associated with yellowing disease of date palms Kuwait and Egypt, respectively. Date palm lethal decline (LD) is associated with a phytoplasma belonging to the 16SrIV Group, subgroup D, which is different to other subgroups and groups of phytoplasmas, causing lethal diseases of coconut and other palms in Central America, the Caribbean, east and west Africa (Harrison and Jones, 2003). The incidence and intensity of *Al-Wijam* disease depends on the countries, regions within a country, and also the date palm varieties.

2.2.4. Host range

Al-Wijam disease has been reported only on date palm (*Phoenix dactilyfera* L.) with basil (*Ocimum basilicum*) and Alfalfa (*Medicago sativa*) as possible alternative hosts for *Al-Wijam* 16SrII phytoplasma. Basil is herbaceous plant (family of Lamiaceae), cultivated as an aromatic plant and condiment and alfalfa (*Medicago sativa*) (family of Fabaceae) is an herbaceous forage plant.

2.2.5. Damage and economic importance

According the available literature, there is no quantitative estimation of the global losses due to the *Al-Wijam* disease. In Saudi Arabia, the estimated number of infected palms in the eastern region of the Kingdom varies between 5-50% of the palm farms surveyed (Al-Hudaib*,* 2008). It seems that the disease already exists in many areas (Al-Hudaib et al.,2017) in this country.

2.2.6. Biology

As in the case of the LY, the phytoplasm lives in the screened tubes of the phloem of infected trees. It cannot survive outside a host organism and it is transmitted by insect vectors. Phytoplasmas in general are vectored by Auchenorrhyncha insects: leafhoppers, planthoppers, and psyllids. *Al-Wijam* 16SrII phytoplasma may have two possible alternative hosts: basil or Roman basil and alfalfa (Al-Hudaib et al., 2017). Therefore, these hosts may play a role as hosts for the 16SrII phytoplasma currently affecting date palms in Al-Hassa and Al-Kharj the neighboring regions of Saudi Arabia, which may also have common polyphagous Hemiptera vectors. There is a need to promote research in order to identify the putative vector of the disease and further study the etiology of *Al-Wijam* disease and the host-pathogen-vector relation, in the oasis ecosystem.

2.2.7. Management

As in the case of lethal yellowing on palm, there is no direct treatment for *Al-Wijam* disease, but there are some measures that help in the prevention of the disease and that reduce its spread, as mentioned below. However, in order to control the disease, it is necessary to carry out more studies on disease etiology, host-pathogen-vector relation and control techniques in order to plan sustainable control strategies. However, based on the current state of information on the etiology of the disease, an integrated management should be developed and recommended. If the spread of the disease becomes significant, the phytosanitary quarantine procedures that prevent the movement of offshoots of date palm, suspicious grasses, and other plants likely to transport infected vectors from an epidemic zone should be applied. In fact, the application of internal and external agricultural quarantine rtegulations will help to reduce the spread of the disease. In order to build human resources and increase their ability to cope with the disease, the training of agricultural engineers, those interested in palm trees, and farmers to examine the symptoms of the disease in the early stages is also required, which ultimately will reduce the spread of the disease.

a. Cultural control

As in the case of lethal yellowing, it is only possible to limit the incidence and severity of the disease and the extension of outbreaks of infection by eradication (removal) and burning of diseased trees. In fact, cleanliness of palm orchards is one of the most important factors of palm protection against *Al-Wijam*. In addition, the elimination of weeds reduces the number of insect carriers of the disease.

b. Host plant resistance

The intensity of symptoms due to *Al-Wijam* disease varies with date palm variety. In fact, Al-Hudaib et al. (2007) have reported that fruits and fruit stalk were reduced in size by 36-40% in different varieties. In the advanced stages, there was significant stunting and yellowing depending on the variety, until the palm died. No precise information exists about date palm varieties resistant to *Al-Wijam* disease.

c. Chemical control

As in the case of lethal yellowing disease in USA, the antibiotic oxytetracycline administered to palms by liquid injection into the trunk, can also be used as a preventive measure to protect palms when *Al-Wijam* disease is known to occur in the area. However, European countries prevent the use of antibiotics (Oxytetracycline) as a therapeutic application. Chemical protection against this disease requires further study in order to devlop sustainable control strategies against this disease of date palm.

Fig.1. Symptoms on date palm due to *Al-Wijam* disease caused by *Candidatus Phytoplasma palmae*. Yellow streaking on leaf base and rachis (a,b), general symptoms on the frond of tree (c), short diseased spathes open before their complete emergence (d), incomplete fruit growth on infected trees and fruit stalks reduced in size (e). Sources of the photos: http://www.aleqt.com/2008/01/08/article_123665 (El-Hudaib et al.).

3. Diseases with Undetermined Causal Agents

3.1. Faroun disease

3.1.1. Scientific name

Laville and Sachs (1967) first reported *Faroun* disease of unknown cause from Mauritania. Based on investigations in the field in Mauritania and in the laboratory, Sedra (1995b, 2001a, 2003a,b, 2015b) described two types of the disease called *Faroun* in this country: white *Faroun* and black *Faroun*.

The latter causes the same symptoms as well as the emergence of some blackening or charring on dwarf leaves (Sedra, 1995, 2003a,b , 2007a,b, 2008b, 2012, 2013). These symptoms are attributed to an attack by the fungus *Thielaviopsis paradoxa,* which is the responsible agent of Black scorch disease. White *Faroun* is a fatal date palm decline of unknown cause and several symptoms resemble those of *Al-Wijam* disease in Saudi Arabia (Sedra, 2015b).

3.1.2. Description and Symptoms

The first symptom is a failure of apparently normal palms to flower for one or two seasons before foliage symptoms appear. Symptoms are characterized by yellow streaking on rachis, dwarfism of the trunk, and leaves with spines and leaflets growing irregularly (Fig.1 (a-b-c-d)) before yellowing appears on inner dwarf leaves. The disease leads to abnormal growth of buds, stopping tree growth over a long period and even leading to tree death (Fig.1d).

The terminal bud of affected palms grows a conical shape, then it takes a parasol form, or a stunted rosette, produced by the old and mid-level fronds, while new fronds present a short rachis with an irregular arrangement of pinnae and spines (Fig.1 (b-e)). Affected offshoots on some diseased palms show dwarfism of the trunk and leaves (Fig.1c). Both female and male palms are affected. Internally, palms in advanced stages of decline have numerous brown gum pockets and long dark-colored cracks in the crown tissues and in leaf bases near the point of attachment to the trunk. No causal biotic agent has been identified. Carpenter and Elmer (1978) frequently observed the presence of the insect *Piezodorus pallescens* in the crown tissues of affected palms.

3.1.3. Distribution

The white *Faroun* disease has not been recorded with this name around the globe. The development of the disease is endemic to North Africa. The disease has been rampant in Mauritania for several decades and is present in many date-producing areas in the country (Sedra, 1995b, 2003b, 2015b).

3.1.4. Host range

Until now, the characteristic disease symptoms have only been recorded on the date palm (*Phoenix dactilyfera* L.).

3.1.5. Damage and economic importance

The white *Faroun* disease is one of the most serious in Mauritanian oases; it is widespread and impacts fruit production. The disease incidence and intensity may depend on the maintenance and care conditions of date palm. No statistical data are available about the losses caused by the disease.

3.1.6. Biology

The local name *Faraoun* was attributed to the force that kills rapidly and leads to a fatal date palm decline. Until now, the cause is unknown and there is a need to promote research and further studies on the etiology of white *Faraoun* disease and the relation host-causal-palm and other components interfering in the oasis ecosystem. Sedra (2015b) suggested three hypotheses as to the cause of the disease:

(a) Aggravated occurrence of white *Faroun* is related to the care level of the date palms. The disease often appears in date palm groves, where there is insufficient irrigation water and drought. Under such conditions, the palm reacts by reducing the length of the leaves, trunk, bud, and spathe production. This leads to a lack of mineral nutrition, causing physiological disorders in leaves and spine growth and yellowing of sensitive internal leaves (Fig.1(a-b)). In this case, the diseased palm tree can be treated by proper agricultural services, including fertilization, soil tilling to aerate roots.

(b) The weakness of date palms due to nutritional problems can lead to infection with fungi, nematodes, or other soil-transmitted parasites, which can provoke the symptoms. The soil pH may be involved to the assimilation of nutriments.

(c) Possibly, in some cases, white *Faroun* is a stage of black *Faroun* (black scorch mentioned above), where the fungus is still in the heart of the palm and secretes toxic substances leading to these primary symptoms and the appearance of blackening and charring.

(d) The hypothesis of phycoplasm (other genetic sous-group) as a possible cause may also be considered. Most symptoms of the disease are similar to those caused by *Al-Wijam* disease.

3.1.7. Management

The cause of this disease is unknown and no cure exists yet. In order to control the disease, it is necessary to do more research on disease etiology and control techniques in order to develop sustainable control strategies.

If the spread of the disease and the losses become significant, the phytosanitary quarantine procedures that prevent the movement of offshoots of date palm need to be reinforced.

a. Cultural control

- It is possible to limit the extension of outbreaks of infection by eradication and burning of diseased trees.

- Ensure good sanitation and efficient maintenance of date palms orchards.

b. Host plant resistance

The disease has been reported in most Mauritanian cultivars, for examples Ahmar, Tiguedert and Tinterguel, as well as on seedling trees (*Khalts*) and male palm trees. No information is reported about resistance/toleranance to this disease.

c. Chemical control

No chemical product has been developed and applied.

Fig.1. Symptoms on date palm due to white *Faroun* disease. Yellow streaking on rachis (a), development and yellowing of leaflets and dwarfism of leaves with spines and leaflets growing irregularly (b), slowdown of growth leading to trees and foliar drying symptoms (d) and offshoot decline (c), focus of disease showing a stunted rosette produced by the old and mid-level fronds in dead palm trees (e). Sources of all photos: Sedra My.H.

3.2. Brittle Leaf Disease

3.2.1. Scientific name

Brittle leaf disease, also called "*Maladie des Feuilles Cassantes* MFC" in French, is a new lethal disorder of date. The disease has been reported from Tunisia since the 1960s, but it has reached epidemic levels since 1986. The studies of etiology showed that the possible causes of the disease were numerous. The first hypothesis was manganese deficiency, but sprays or injections of manganese did not solve the problem (however, there was a delay in symptom expression) (Namsi et al., 2006, 2007). The second one is related to minerals in the soil, but the analysis could not reveal differences between diseased and healthy plots (INRAT reports (2000s), McGrath, 1988, Mehani, 1988). The third hypothesis suggests a biotic origin because patterns of diseased trees observed in the field and affected trees seem to cluster into foci. In fact, no phytoplasm was isolated from diseased leaves and microorganisms isolated from the rhizosphere of the diseased palm did not show their role in the expression of the observed symptoms. In fact, if pathogens (viroids or phytoplamas, nematodes, fungi, endogenous and exogenous bacteria) are involved, there may be a risk associated with planting material since the disease is not transmitted by planting young palms (Triki et al., 2003). Histochemical analyses of date palm tissues showed alterations in lignin content and in the phenylpropanoids pathway in tissues affected by the disease. In fact, there is a hyperlignification thicker suberin layer in roots cortical cells. Furthermore, the phenylpropanoids pathway was also disrupted in leaves and roots and cinnamoyl-CoA reductase and cinnamyl-alcohol dehydrogenase gene expression was affected by the disease, which severely affects the cell wall integrity. A last finding based on molecular research showed that a small double stranded RNA of host origin (dsRNA), associated with symptomatic trees (Namsi et al., 2006, 2007), could not be related to a known pathogen. Further work is required to understand the etiology of the disease.

3.2.2. Description and Symptoms

Symptoms of the disease were first described by Takrouni et al. (1988). On trees with early symptoms, some fronds show chlorosis and have a dull, olive green color (Fig.1a). The figure 1b illustrates the different steps of symptoms evolution on leaf and leaflets from the left to right (Fig.1b). In fact, leaflets become brittle, twisted, frizzled, and shriveled with a scorched appearance (Fig.1a). The most characteristic symptom is the ease with which leaflets break when flexed and squeezed. Necrotic streaks develop on the pinnae. Fig.1c showed an example of disease focus in the Nefta date palm grove. The different steps of symptoms evolution on trees are illustrated in Fig.1 (d to j). Symptomatic fronds may appear on the inner part of the crown (heart), the middle part, or the outer part. Symptoms extend to adjacent upper fronds, until the whole tree becomes affected. Many fronds acquire a jagged appearance resulting from wind damage to weakened leaflets. In extreme cases, only frond midribs without leaflets remain (Fig.1j). Affected trees stop growing, have shorter fronds with irregular size, and eventually die. Death occurs quicker if the first symptomatic fronds appeared in the heart of the crown. During the period of tree affection, yields drops significantly. Four to six years may elapse between appearance of the first symptoms and the death of the tree. Symptoms occur on trees of all ages, including offshoots and small seedlings, and symptoms are in fact similar to those of manganese deficiency (Tiriki et al., 2003).

3.2.3. Distribution

Brittle leaves disease (MFC) was first observed in the Nefta, Tozeur, and Degache date plantations (Tunisia) and in Adrar, M'zab, and Biskra (Algeria) (Djerbi, 1988). It has been disseminated to other Tunisian regions: Al-Hamma, Tamarza, Gafsa, Kebili and Gabes. In Algeria, the presence of the disease has also been confirmed in the regions of Biskra (Saadi et al., 2006), Ghardaia (Chikh-Issa, 2003), and Adrar (Algeria) and has been reported in the Waddan region of Libya (Ezarug Edongali, unpublished data).

Date palm and ornamental palms are important plantations around the Mediterranean basin, especially in the Maghreb countries. If no effective eradication and prevention measures are implemented, the disease may continue to destroy palm trees. The effectiveness of these measures needs to be based on the exactunderstanding of abiotic and biotic causes responsible for the expression of the disease.

3.2.4. Host range

Date palm (*Phoenix dactilyfera* L.) data and no data on other possible hosts are available, for example, on ornamental palms and crops associated with date palm in oasis ecosystems.

3.2.5. Damage and economic importance

The Brittle leaves disease has affected or killed up to 40,000 date palm trees in the Djerid region of southern Tunisia since the 1980s (Takrouni et al., 1988; Triki et al., 2003). The incidence and intensity of disease in Tunisia depend on the regions and date palm varieties.

3.2.6. Biology

The MFC disease attracted attention during the 1980s. Suddenly, it spread epidemically and it affected many more trees than before. In affected plantations, the spread was reported to be occurring from affected trees to neighboring trees, and, in hitherto healthy gardens, newly affected trees were seen to appear. Symptoms resemble those of manganese deficiency, but it appeared that this deficiency in the leaves was a consequence of the expression of the disease and not the original cause. Mineral soil analysis could not reveal any differences between diseased and healthy plots. Leaflets from MFC-affected palm trees have been shown to contain MFC-specific RNAs (MFC-RNAs). Dot-blot hybridization analysis, using a bifunctional DNA probe that detects the MFC-RNAs, gave positive signals with all preparations from adult symptomatic leaflets collected from diseased symptomatic trees in the affected oases. As mentioned above, further research on disease etiology should be carried out in order to reveal the abiotic and biotic causes responsible for the expression of the disease and in order to develop efficient control methods of this disease.

3.2.7. Management

Given the current state of information on the etiology of the disease, quarantine measures seem to be the only means of limiting the spread of the disease by applying phytosanitary measures of prevention and of limiting further introductions and spreading into the contaminated country and between countries. However, the following and available methods of control may be recommended:

a. Cultural control

- Possible limitation of the extension of outbreaks of infection by eradication and burning of diseased trees.

- Since manganese is deficient in unhealthy palms, this nutrient could be brought to these palms either by spraying or by injection.

b. Host plant resistance

The disease has been reported on most Tunisian cultivars, including Deglet Nour, Tozeur Zaid, Akhouat Alig, Ammari, Besser, Kinta, as well as on seedling trees (*Khalt*) and Pollinator trees. The cultivar Kintichi seems to be relatively tolerant.

c. Chemical control

No chemical product has been developed and applied.

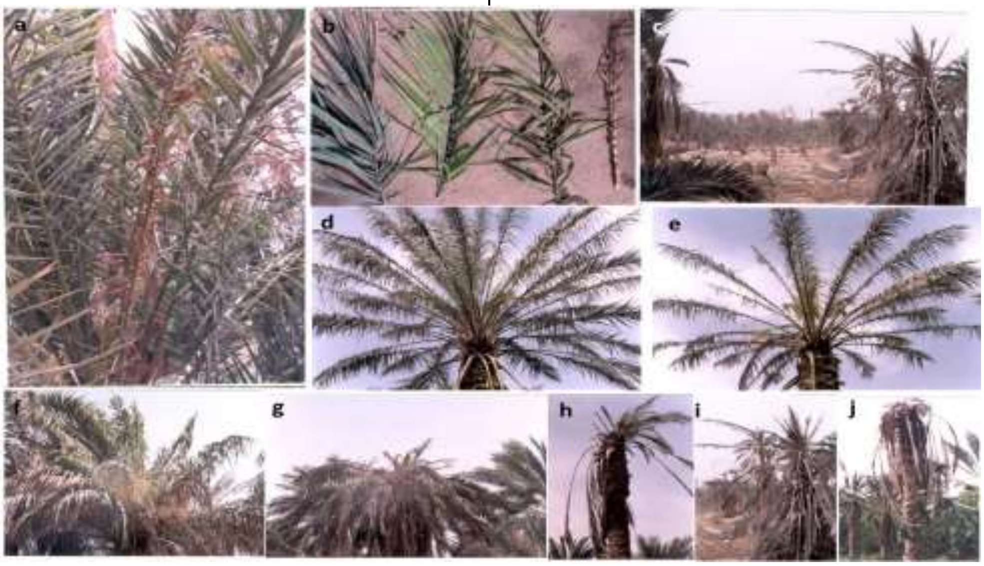

Fig.1. Symptoms of the brittle leaves disease on date palm. Necrotic streaks on the pinnae that become brittle, twisted, frizzled, and shriveled (a,b), different steps of symptoms evolution on leaf and leaflets from the left to right (b), focus of the disease in oasis of Nefta (Tunisia) (c), different steps of symptoms evolution on trees from the left to right: Symptomatic fronds appear on the inner part of the crown, the middle part and the outer part, then many fronds acquire a jagged appearance resulting from wind damage to weakened leaflets and at the end only frond midribs without leaflets remain (d,e,f,g,h,i,j). Sources of all photos: Sedra My.H.

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Chapter VII

Field Operations in Date Palm and their Importance for Reducing Pest Infestation

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1. Introduction

Horticultural practices have a direct impact on fruit quality and quantity, consequently impacting the income of growers. Cultivation operations, if well conducted, can reduce pest infestation in date palm, ameliorate the health of date palm, and reduce the loss of date palm production up to 30-40%. In date palm, several field operations, including the choice of offshoots, spacing, fertilization irrigation, fruit thinning, leaf pruning, and harvesting are important field practices. Studies carried out in Saudi Arabia have shown that the date palm farming practices adopted, the variety planted, method of irrigation (flood/drip), palm density, crop and field sanitation, frond pruning, and offshoot removal, significantly impacted the establishment and subsequent infestation level due to red palm weevil, *Rhynchophorus ferrugineus* in date palm (Sallam et al., 2012). In order to manage the *Belaat* disease (*Phytophtora* spp.) in date palm, it is essential to adopt the best practices with regard to planting, fertilization, irrigation, and pruning (Sedra, 2015). The present chapter presents the importance of the above field practices in date palm and their role in managing pests.

2. Establishing date palm plantations

2.1. Choice and handling of offshoots

Micro-propagation of date palm has become easy and is now practiced by many laboratories. However, the main method of propagating date palm is still by offshoots. Date palm pests are known to prefer certain varieties. However, date palm varieties tolerant to pest attack are not always selected by the farmer over the most popular variety of the region, even though pest and disease tolerant varieties constitute the first line of defense in any pest management program. Therefore, host plant resistance is not well exploited to manage pests and diseases in date palm. Major infestations in date palm are known to originate through offshoots. Red palm weevil is a classic example in the way this pest has spread during the last three decades, locally within a country, regionally between neighboring countries, and internationally between continents. The spread of RPW has been rapid in the last three decades, mainly through infested offshoots for date palm farming and through larger palms for landscape gardening. It is therefore imperative to select offshoots and palms from pest free areas, besides imposing strict pre- and post-entry quarantine protocols to ensure that only weevil free planting material is transported. In this context, when establishing new date palm plantations, it is important to pay attention to the origin of offshoots. Offshoots must be at least four years of age weighing 15-20 kg (Nixon and Carpenter, 1978).

Planting material needs to be treated with the recommended pesticide and infested planting material needs to be removed and discarded. It is also essential to keep a close watch on newly planted offshoots and palms for any symptoms of pests and diseases.

Fungi are a serious problem in date palm offshoots. Cleaning and pruning offshoots can ameliorate their health and ensure better development. Offshoots must be treated twice a month with a broad spectrum of fungicides. Small offshoots weighing 5 kg or less, if needed, could also be used, but their survival potential will be much lower than that of larger offshoots. These offshoots should initially be looked after, for at least two years in a nursery, or mist bed in a greenhouse or a shaded net structure (Reuveni et al., 1972).

As the use of offshoots can enhance the spread of date palm diseases and pests between different regions of a country or between different countries, it is essential to ensure the control of pests and diseases by national programs and to facilitate easy and fast exchange of plant genetic material without the risk of spreading pests and diseases.

Offshoots have to be planted immediately after separation from the mother palm. If there is a delay (for no more than three days), offshoots have to be placed in shade, covered with jute bags and moistened from time to time to reduce dehydration of leaves and roots.

Care and skill are both important in order to cut and remove offshoots from the mother date palm. Roots should not be cut any closer than necessary, since most of the cut roots die and the newly emerging roots are susceptible to injuries (Zaid and de Wert, 2002). When possible, it is recommended to use pest and disease resistant varieties. This ensures that the palms have natural resistance to pests and diseases, minimizing the need for chemical control.

To ensure pest and disease free planting material growing of tissue cultured palms has been widely advocated.

2.2. Growth offshoots in nursery

When there is doubt that the offshoots may not be free of disease, then offshoots should be kept in a nursery for at least two years after removal, preferably in a greenhouse or under shade net. In order to ensure offshoots remain pest and disease free, they should be treated with a broad spectrum of insecticides immediately after removal from the mother date palm (El-Hamady et al., 1992).


High density plantation


New plantation with good spacing

Fig.1. Different palm densities (spacing) in date palm

Fig. 2. Offshoots have to be removed from the mother palm

(Source: Date Palm project in GCC)

3. Planting density

Most traditional plantations in the Middle East and North Africa are not widely spaced and not planted in straight lines. The practice of removing offshoots from the mother palm is not always well-practiced. This complicates cultivation and protection intervention practices and facilitates establishment and infestation/infection by pests and diseases. As a standard practice, offshoots have to be removed from 3-4 years old mother palms in order to maintain one palm at each place.

The spacing and straightness of plantations can facilitate cultivation practices, mechanization, and the spraying pesticides to combat pests.

Modern farms prefer straight rows and it is recommended to maintain a minimum 8x8 m spacing, accommodating 156 palm trees per hectare in a square system of planting (Ben Salah, 1999). This will ensure penetration of sunlight in to the plantation and discourage pests like red palm weevil from establishing, which is known to prefer closely spaced palm grooves with high humidity (Sallam, et al., 2012).

Tissue culture-derived plants and young offshoots should be protected from harsh climatic conditions (sun and wind during the first summer and cold the following winter) and against some animals (goats, rabbits, etc.). The use of a shade net cover, *fibrilluim*, reed or date palm leaves is recommended (El Bekr, 1972).

4. Cultivation operations

4.1. Irrigation and fertilization

Irrigation is necessary in date palm to facilitate vegetative growth and ensure good fruit quality. An optimal quantity of irrigation water is necessary in many places, where the date palm is not tolerant to the salinity of the subsoil water. All surface irrigation techniques (flood method) can affect the date palm trunk and facilitate the establishment of pests. Flood irrigation is still carried out in most major plantations. This practice facilitates infestation by pests. High in-groove humidity due to open flood irrigation in date palm is known to facilitate red palm weevil establishment (Aldryhim and Al- Bukiri, 2003). In farms where excess water is supplied, the presence of green algae on the soil surface indicates waterlogging creating a favorable condition for pests surviving at the base of the date palm stem (Liebenberg and Zaid, 2002). On the other hand, in areas endemic to the apical drying of fronds caused by the fungi *Alternaria* sp. and *Phoma* sp., lack of irrigation water may cause spread of the disease (Sedra, 2003).

New techniques for irrigation such as drip irrigation reduce the date palm water requirement from 150 to 250 m^3 by flood irrigation to about 70 to 80 m^3 per tree. New sub-surface irrigation has been developed and is advantageous for maintaining the required water supply. Several subsurface techniques in date palm are currently under experimentation. Sub-subsurface irrigation can avoid the development of weeds at the base of the date palm and avoid the hibernation of pests, improving the date palm trunk health (Dewidar et *al*., 2016). In the case of red palm weevil, excessive weed growth around the palm base inhibits periodic inspection of palms essential to detect infestation by this lethal pest, besides hindering other pest control operations.

Fertilization is necessary for the date palm to improve over-all plant growth, to extend leaf longevity, and to improve date palm yield. Nutrient deficiency can affect date palm tree growth. It is advisable to apply organic and phosphate fertilizers in a single application deep in the soil. Nitrogen and potassium elements should be divided into 3-4 applications, starting at the beginning of the flowering season (January-February) and repeated every 2 months thereafter until the harvest. When adding mineral fertilizer, it is very important that fertilizers are mixed with the soil. Some farmers scatter fertilizer on the surface, leaving it without mixing, which results in the nutrients being lost through volatilization and percolation.

The amount of mineral fertilizers to be used depends on several factors. The major elements required are: nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. The minor elements are: boron, copper, iron, manganese, molybdenum, and zinc. Some estimations are: 200g of pure nitrogen and 100 g of phosphorus and potassium for each year of age of date palm.

Organic fertilizer is one of the most important sources of infection when is not thermally treated. Insect eggs can be carried by fertilizer. Organic fertilizer has to be thermally treated to ensure its safety from the pest's eggs, larvae, and other microbes. It is recommended to add 5-10 kg of well treated and decomposed organic manure per palm every year. This quantity can vary depending on soil fertility (Klein and Zaid, 2002).

Drip irrigation system

Sub-surface irrigation system

Fig.3. Irrigation systems in date palm Source: (Date Palm project in GCC)

5. Date palm crown operations

5.1. Pollination

Date palm trees are dioecious, having male and female inflorescence on separate plants. Artificial pollination is essential for the completion of fruit setting in date palm, which ensures optimum production. The male flower produces pollen, which is transferred to the inflorescence of the receptive female palm.

Pollen should be mature and free of pests, especially the inflorescence rot fungi caused by *Mauginiella scaetae* Mich. & Sabet., *Fusarium moniliforme* and *Thielaviopsis paradoxa.* If any infection or insects are noticed, the pollination should be stopped immediately and the collected pollen should be burned (ICARDA, 2016).

Traditional pollination is handled by workers and this requires climbing each palm during the pollination season to place the male flower into the female cluster. This operation needs to be repeated at least thrice in the season to guarantee good pollination.

Due to the scarcity of capable laborers and cost reduction, and for easy pollination of date palm, mechanical pollination is being developed to reduce the cost and substitute traditional manual pollination.

Dry and liquid pollination use hand and machine dusters or machine-operated spray from the ground without climbing the tree. Both techniques use extracted pollen (Ben Salah and El Marzooqi, 2000; Shabana et al., 1985). Extracting pollen from male bunches can reduce the potential infestation of bunches which in turn reduces the transfer of insects from the male (pollinator) to the female date palm tree. In dry pollination, pollen is mixed with talc or flour. In liquid pollination, pollen is mixed with water. Both methods can help to reduce the transfer and spread of pests and diseases that can lead to bunch infestation/infection.

The recently developed date palm liquid pollination has proved to be a good pollination technique for improving fruit setting, gaining time, reducing cost, and consequently improving the quality of dates. Using liquid pollination technology raises the following advantages of saving time and effort, reducing the quantity of pollen and labor costs, and reducing the risk of accidents for the climbing laborers. The economic evaluation of the liquid pollination shows a reduction of more than 50% of the cost of the operation. The technique is being successfully disseminated to all GCC countries within the ICARDA project (Ben Salah and Al-Raissi, 2016).

The other advantage of the liquid pollination is the use of pollen powder, reducing the risk of transmission of pests carried by the male bunch to the female date palm tree, especially the inflorescence rot caused by *Mauginiella scattae* Cav., *Fusarium moniliforme* and *Thielaviopsis paradoxa.* However, liquid pollination is still not well adopted because the mechanical pollen extraction device is expensive and unaffordable by small farmers. Furthermore, farmers resist in adopting this technique as they are accustomed with hand pollination (Dhehibi et al., 2017).

Traditional hand pollination

Dry pollination with hand duster

Fig. 4. Pollination methods in date palm (Source: Ben Salah, M. 1999)

Fig. 5. Date palm liquid pollination (Source: Date Palm project in GCC)

5.2. Covering bunches after pollination

Covering female bunches directly after pollination can avoid infestation by air. Cover bags have to be made of paper and should be removable when the fruit set is achieved (about one month after pollination). This cultivation operation is practiced in some regions (as in United Arab Emirates) and can avoid the major infestation of the inflorescences beetle, *Macrocoma* sp.

Fig. 6. Inflorescence covering just after pollination (Source: Date Palm project in GCC).

5.3. Fruit thinning

Fruit thinning is considered to be an important cultural operation for improving the quality of date fruits. The quality of dates is improved by increasing fruit weight and size and also by reducing the magnitude of the alternate bearing phenomenon, which is known in date palm. Fruit thinning is adopted about two weeks after pollination (after fruit set) and can be a good opportunity to check the health of bunches and to avoid infesting healthy bunches in case infestation/infection by pests and diseases (Shabana et *al*., 1999).

Fruit thinning results in better air circulation within the bunch and can also help reduce pests and diseases associated with date fruits. Removing the spikelets of the date palm bunch can help in providing good ventilation inside the bunch and in reducing the development of fungi and insects.

Fig. 7. Fruit thinning practice by spiklets length of number cutting, (Source: Date Palm project in GCC)

5.4. Pruning (leaf cutting)

Pruning date palms is the removal of dead or nearly dead fronds (leaves) and their bases when these also dry out. It is also possible to remove green but broken leaves and to also remove those attacked by serious pests, such as the frond and stalk borers.

Regular pruning of fronds and sanitation of date palm growing areas are critical in preventing pest infestation and disease infection. All dead fronds should be removed from the palms. In order to restrict entry points of pests and diseases, the pruned area should be treated with pesticides. Pruning tools should be kept clean and disinfected, as they can spread the fungal disease, such as black scorch. This disease affects the flower and fruit strands, which become deformed, and causes terminal bud and trunk rot. It can eventually kill the palms (Dowson, 1982).

This operation of frond pruning also aims to facilitate several cultivation operations, such as pollination, fruit thinning, bunch bending, and harvesting (Hussain et *al*., 1984b).

Pruning of older, less productive, or dead fronds increases the fruit production capacity of the palm tree, whilst reducing the risk of date checking and black nose (very small cracks starting at the apex of the fruit which ultimately darkens). Dead fronds and frond bases growing up to the lower ends of the fruit bunch must be removed after harvest, as they do not drop off naturally. In case of the red palm weevil, it has been recommended (Sallam et al., 2012) to protect the injuries on frond bases immediately after frond pruning with insecticide in order to prevent attracting female weevils for oviposition. This is also recommended after offshoot removal.

Frond pruning is not practiced by many growers, due to the difficulty of climbing the date palm tree. Small mechanization is now developed that can help to adopt pruning without climbing date palm tree.

Date palm fronds have several uses. When fronds are transported from region to region, care should be taken not introduce new pests, such as the *Parlatoria* date scale, *Parlatoria blanchardi* L. (Dowson, 1982).

Fig.8. Use of date palm leaves in combatting desertification and in fencing of farms (Source: Ben Salah, M)

5.5. Bunch lowering and support

In the first few weeks after pollination, fruit stalks grow rapidly, are pliable, and bend easily. Once fully elongated, they become more brittle and can easily break. At this stage, bunches should be gently pulled downwards through the leaves (fronds) and supported by tying the fruit stalks to the midrib of one or two of the lower leaves. Bunch lowering also facilitates manual harvesting. This prevents fully laden bunches from breaking and allows easy access for thinning, bagging, and pesticide application (Aldawood, 2013).

5.6. Bagging bunches before maturation

Bunch bagging (netting) is done at the onset of fruit coloring. It is important to remove dried fruits manually before netting.

Bunches should be covered with bags to protect the fruit against physical damage, such as scarring from strong winds, bird attacks and damage caused by insects and dust mites

Oligonychus afrasiaticus (McGregor). Netting also facilitates bunch harvest and prevents any detached fruit from falling to the ground (Dowson, 1982).

Fig.9. Bunch bagging (Source: Ben Salah, M. Date Palm project in GCC)

6. Harvesting of dates

Some of dates ripen at the “Rutab” stage for fresh consumption, whilst in other cultivars fruits are consumed at the “Tamr” stage. For the former, growers must repeat harvesting in about one-two months.

Post-harvest fruit losses are considerable, which are caused by improper fruit handling, infestation/infection by pests and diseases, and/or inadequate marketing facilities and policy.

In order to minimize fruit losses and to enhance date palm profitability, it is recommended to use net bags to bag fruit bunches, to separate infested fruits, and to clean and dry the fruits. In order to preserve the natural fruit shape, one should observe the following (Baruch et al., 2002):

Open the bag clamp which encapsulates the bunch carefully and remove it from the bunch. Wash it with water in order not to contaminate the fruits during opening and closing, particularly in areas with a dusty atmosphere. Do not mix fruits with symptoms of insects, rot, or acidification with good fruits.

7. Sorting and drying dates

When harvest is done by dropping dates from the crown directly onto plastic mats or carpets, it is necessary to sort the fruits in the field. Infected/infested dates, immature and damaged dates have to be separated immediately and transported separately to the drying area in order to avoid infestation and loss of quality. Drying soft dates is necessary for storage and packing. Infestation by insects and birds is affecting the quality of dates, particularly in areas where the traditional practice of drying dates after harvest is not practiced.

Drying dates in polycarbonate chambers is a promising technology introduced by the Project Development of Sustainable Date Palm Production Systems in the GCC countries of the Arabian Peninsula. This is done with the aim of improving the quality of dried dates, accelerating the drying process and getting cleaner fruits, free from dust. This technology aims to reduce the cost of labor, gain time and improve the quality of the fruits. Assessments of the polycarbonate drying chamber reveal many advantages for the produced dates: (1) improving the quality of the fruits, especially in humid areas, (2) accelerating the drying rate, (3) reducing the loss rate and (4) avoiding the contamination of dates by insects, birds, dust, and rain (Dhehibi et *al*. 2017).

Sorting dates in the field

Drying dates in polycarbonate chambers

Fig.10. Sorting and drying of dates (Source: Ben Salah, M. Date Palm project in GCC)

In conclusion, date palm farming operations have a direct impact on date palm production, fruit quality, and date palm tree protection. Adopting the best practices with regard to propagation, pollination, fruit thinning, pruning, and harvesting can help to efficiently manage several pests and diseases in date palm.

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