Arthropod pests of date palm and their management

H. A. F. El-Shafie[1,2]*, B. M. A. Abdel-Banat[1,2] and M. R. Al-Hajhoj[1]

Address: [1] Date Palm Center of Research Excellence, King Faisal University, Al-Hofuf, 31982-Al-Hassa, Kingdom of Saudi Arabia. [2] Department of Crop Protection, Faculty of Agriculture, University of Khartoum, 13314-Shambat, Sudan.

***Correspondence:** Hamadttu Abdel Farag El-Shafie. Email: elshafie62@yahoo.com

Received: 12 October 2017
Accepted: 7 November 2017

doi: 10.1079/PAVSNNR201712049

The electronic version of this article is the definitive one. It is located here: http://www.cabi.org/cabreviews

Abstract

This review lists 132 species of insect and mite pests associated with date palm (*Phoenix dactylifera* L.) grown worldwide. These species are distributed among eight insect orders and 30 families, besides one order of mite comprising nine families. Most of the species (52) were reported on the leaf (frond), while 26 species were associated with the roots and trunk. Green fruits with their stalks and stored dates hosted 27 species each. Coleoptera represented 41% of the listed pest species, followed by Hemiptera (20%), Acari (16%) and Lepidoptera (12%). Although the number of date palm pest species seems to be high, only a few species are considered major pests of economic importance. The major pests include the red palm weevil, (*Rhynchophorus ferrugineus*), old world date mite (*Oligonychus afrasiaticus*), lesser date moth (*Batrachedra amydraula*), Dubas date bug (*Ommatissus lybicus*), green pit scale (*Palmaspis phoenicis*), carob moth (*Ectomyelois ceratoniae*), date palm longhorn beetle (*Jebusaea hammerschmidti*), and almond moth (*Cadra cautella*). The review also lists 90 species of predators and parasitoids representing nine orders and 23 families, indicating their potential role in date palm pest management. The paper summarizes the current knowledge on management tactics including monitoring, agrotechnical measures, biological control, semiochemical-based control and chemical control. The implementation of integrated pest management strategies against major pests, based on the above-mentioned tactics, is discussed. The information gathered in this review indicates that strict quarantine, semiochemicals including pheromones and training and education of farmers are expected to play a central role in area-wide IPM of major date palm pests.

Keywords: Date palm, Arthropod pests, Natural enemies, Pest management, *Phoenix dactylifera*, Agrotechnical measures, Chemical control

Review Methodology: The CAB abstract database was searched for the following keywords: date palm, arthropod pests and pest management. Additionally, published works in recognized journals, books and book chapters were thoroughly reviewed for relevant information. Common names and taxonomic status of insects and mites and their natural enemies were selected according to the common names of Insect Database of Entomological Society of America [1] for species available in that database.

Introduction

The date palm, *Phoenix dactylifera* L. (Arecales: Arecaceae) is an important food and cash crop thriving well in hot arid regions of the world [2]. It is believed to have originated in Mesopotamia (Iraq) where it has been cultivated some 6000 years ago [3]. Date palm had played a significant role in the economy of some date-producing countries, and the global production has increased from 1.8 million tons in 1962 to about 8 million tons in 2012 [4, 5]. Of this yield, 88% is produced in the Middle East and North African countries namely, Egypt, Iran, Saudi Arabia, Pakistan, Iraq, Algeria, United Arab Emirates, Sudan, Oman and Morocco. Date Palm is also found in Australia, Mexico, Namibia, Peru, South Africa, Spain and USA [6]. Pakistan and India also cultivate date palm despite the heavy monsoon rains that coincide with the ripening of dates [2]. The date palm has been carried out from Mesopotamia to other parts of the world [6]. Factors such as monoculture of date palm, global warming, unrestricted application of insecticides and global movement of date palm planting materials have influenced the pest complex and its natural enemies [5]. A good

example of this change is the red palm weevil, which has invaded the Middle East in 1985. The weevil, a pest of coconut, is originally from the warm humid South and Southeast Asia has been now a major pest of date palm in the arid hot regions of the Middle East. Being evergreen with a unique morphology, the date palm provides shelter and food for a wide array of arthropod pests and their natural enemies. Diseases and pests that account for 30% loss in yield [7] are the main biotic constraints that hamper date palm cultivation and production. The nature and severity of the problems, however, vary with cultivar, location, weather and cultural practices [8, 9]. Date palm has a wide genetic diversity, and approximately 3000 cultivars exist in the world [10]. However, many pests and diseases threaten this genetic variability unless proper management is undertaken. Buxton [11] reviewed the insect pests of date palm in Mesopotamia (Iraq). The literature contains concise reports and lists of date palm pests from Oman, Jordon, Libya, Egypt, Qatar, Kuwait, Bahrain, UAE, Yemen, Sudan, Pakistan, Tunisia, Palestine, and the USA. Carpenter and Elmer [8] who listed 54 arthropod pests of date palm gave the first worldwide review on date palm pest. A comprehensive review on date palm pests in Israel listed 16 major and 15 minor insect and mite pests [12], which could give an overview of the pest complex of date palm in neighbouring countries. It has been reported that the arthropod fauna of date palm in the different countries of the Middle East and Gulf regions are not isolated from each other [12, 13]. El-Shafie [14] listed 112 insect and mites pests associated with date palm worldwide as well as 45 predators and parasitoids. The main damaging taxonomic groups on date palm are Coleoptera, Lepidoptera and Hemiptera from insects and Acari from mites. This review is devoted to arthropod pests (insects and mites) of the date palm and non-arthropod pests such as birds, flying bats, rodents, nematodes, mollusks, pathogenic fungi, bacteria and viruses are not included. The review enlists most arthropods pests of date palm worldwide available in the literature with emphasis on the management of species of economic importance including the role of their natural enemies.

Insect and Mite Pests Associated with Date Palm

In this review, 132 species of insects and mites have been reported to be associated with date palm (Tables 1–4). These species were classified according to the preferred part they attack on date palm. Species that attack more than one part of the date palm were classified according to the part on which it inflicts the most economical damage.

Although the number of insect and mite pests on date palm seems to be high, only a few species specialized for development on date palm i.e. exhibit a high degree of specificity to date palm. These species include the greater date moth, the issid bug, the lesser date moth, the dubas bug and the longhorned stem borer and the date stone beetle [12, 74–76]. The rest of the species are generalist feeders that exploit date palm as a resource such as the red palm weevil, *Rhynchophorus ferrugineus* that has been reported to attack 40 palm species worldwide including date palm [77]. The carob moth, *Ectomyelois ceratoniae* is an opportunistic feeder and has 43 hosts from 18 plant families [61].

Feeding Behaviour, Nature of Damage and Economic Importance

The feeding patterns of date palm arthropod pests could be broadly classified into three main categories; sap feeders, defoliators and borers. (I) The sap feeders have piercing-sucking or rasping mouthparts that suck the sap causing chlorotic spots and discoloration on the affected parts. This group comprises the tiny phytophagous mites, thrips, scale insects, mealy bugs, issid bugs and dubas bug. They are found outside the date palm at the crown regions where soft and succulent tissues exist [78]. Mites are found on either the leaf blade or developing fruits where they may cause 100% loss in yield. The date dust mite, *Oligonychus afrasiaticus* and the lesser date moth, *Batrachedra amydraula* are by far the most important pests damaging date palm developing fruits [14]. (II) Date palm defoliators are insects characterized by having chewing mouthparts. They include grasshopper, locusts, some beetles from the family Buprestidae, and caterpillars of some moths. Locusts can be a serious and devastating pest on date palm during the plague and huge swarms where complete defoliation of the crown could occur resulting in checking productivity of the palm for at least 3 years [12]. (III) Borers of economic importance on date palm include the invasive red palm weevil, the longhorn date palm stem borer, rhinoceros beetles and frond borers. They feed inside the palm trunk, frond and fruit bunch stalk by excavating tunnels and galleries in the internal tissues of the palm. Severe infestation by this group, particularly the red palm weevil and the longhorn borer, eventually lead to the collapse and death of the palm. The damage on date palm by one species may depend on the damage by another species. For example, the larvae of almond moth, *Cadra cautella* [8], readily infest dates damaged by the oriental wasp, *Vespa orientalis* [29, 51]. The damage of stone beetle on date fruits predispose them to subsequent attack by the sap beetle [12]. Among the listed date palm arthropod pests, a few were reported to vector diseases. The date palm fruit bunch borer, *Oryctes elegans* has been reported to transmit *Fusarium proliferatum*, the causal agent of wilt and dieback disease in date palm [79]. The date palm leafhopper, *Cicadulina bipunctata* (Melichar), Cicadellidae is reported to be a vector of a phytoplasma causing Al-Wajam disease in Saudi Arabia [38]. Recent quantitative data on the economic losses on date palm due to arthropod pests is scant, however, the annual losses in the Gulf region of the Middle East caused by eradication of date palms infested by the red palm weevil ranged from US$1.74 to 8.69 million at infestation levels of 1 and 5%, respectively [80]. The damage

Table 1 List of insect pests associated with date palm roots, bases and stem (trunk)

Scientific name	Common name	Order/family	References
Roots			
Oryctes agamemnon arabicus Burmeister	Fruitstalk or stem borer	Col., Scarabaeidae	[15, 16]
Oryctes rhinoceros	Rhinoceros beetle	Col., Scarabaeidae	[15]
Aspongopus viduatus F.	Water melon bug	Hem., Pentatomidae	[17]
Gryllotalpa gryllotalpa L.	Mole cricket	Orth., Gryllotalpidae	[17]
Base and stem (trunk)			
Rhynchophorus ferrugineus Oliv.	Red palm weevil	Col., Curculionidae	[18–20]
Rhynchophorus phoenicis Fabricius	African palm weevil	Col., Curculionidae	[9]
Sphenophorus parampunctatus	Date palm beetle	Col., Curculionidae	[9]
Xyleborus perforans	Bark beetle	Col., Curculionidae	[17]
Jebusaea hammerschmidti Reiche	Stem borer	Col., Cerambycidae	[14, 21]
Macrotoma palmata F.	Sunt borer	Col., Cerambycidae	[22]
Apatophysis barbara (Lucas)	Date palm borer	Col., Cerambycidae	[23]
Elaphidion villosum	Stalk borer	Col., Cerambycidae	[17]
Strategus julianus Burmeister	Young date palm borer	Col., Scarabaeidae	[17]
Paysandisia archon Burmeister	The palm borer moth	Lep., Castniidae	[24, 25]
Odontotermis smeathmani Ful.	Termites	Isopt., Termitidae	[26]
Odontotermis sudanensis Sjöstedt	Termites	Isopt., Termitidae	[27]
Odontotermis obesus Rambur	Termites	Isopt., Termitidae	[28]
Microcerotermes diversus Silvestri	Small waxy termites	Isopt., Termitidae	[29]
Amitermes stephensoni Harris	Termites	Isopt., Termitidae	[17]
Amitermes desertorum (Desneux)	Termites	Isopt., Termitidae	[30]
Psammotermes hypostoma (Desneux)	Sand termites	Isopt., Rhinotermitidae	[31]
Heterotermes aethiopicus (Sjostedt)	Termites	Isopt., Rhinotermitidae	[32]
Microtermes najdansis	Termites	Isopt., Termitidae	[17]
Anacanthotermes orchraceus (Burmeister)	Harvester termites	Isopt., Hodotermitidae	[32]
Anacanthotermes ubachi (Navas)	Termites	Isopt., Hodotermitidae	[32]
Acanthophorus arabicus Thomson	Cerambycid beetle	Col., Cerambycidae	[21]

by the carob moth can reach 40% to the harvestable crop each year [61], while the lesser date moth may cause a total loss of yield especially in neglected orchards with poor agronomic practices [81].

Infestation Status of Economically Important Pests

Infestation status of date palm pests is dynamic and changes with variation in prevailing climatic conditions and agronomic factors. A good example is the green pit scale insect, *Palmaspis phoenicis* which is considered a pest of less importance in the Middle East, but becomes a major pest in Sudan after being introduced in the country in 1987 [82]. Blumberg [12] classified pests of date palm according to their occurrence as major pests (frequent occurrence) and minor or accidental pests (rare occurrence). The major date palm pests worldwide are the red palm weevil, date dust mite, dubas bug, lesser date moth, longhorn stem borer, almond moth and carob moth [14]. Comprehensive reviews on the taxonomic status, distribution, biology, ecology and possible management measures are available in the literature [5, 8, 12, 78, 83–86].

Integrated Pest Management (IPM) in Date Palm Agroecosystem

A new paradigm for management of date palm pests using a holistic approach and area-wide IPM strategy to replace the small-scale control strategy is urgently needed. In this respect, synchronization of control measures among farmers is an important step to save time and effort devoted to management operations. Additionally, simultaneous management of many date palm pests usually results in a reduction of pesticides and encouragement of natural enemies.

An IPM strategy has resulted in successful control of Parlatoria scale in Israel [87] where insect population was reduced from 96.6 to 0.02 scales/cm^2 in 10 years and the white scale changed from a key pest to an unimportant one [12]. An IPM in date palm includes phytosanitation, technical, technological methods, biological control, and chemical control and training of farmers [12]. These methods should be carried out in harmony in such a way to control the date palm pests without deleterious effects on human health and the environment. Different components (tactics) of integrated management of major date palm pests are reviewed in the following paragraphs.

Monitoring and Sampling of Date Palm Pests

Pest populations may change due to climatic factors [88–91], adverse effect on their natural enemies caused by the unwise use of pesticides [92] and transportation by a human to the new environment [93]. Thus, pest monitoring and sampling are essential for setting economic threshold levels upon which IPM decision-making is made [94, 95].

Table 2 Insect and mite pests associated with date palm leaves (pinnae, rachises and bases)

Scientific name	Common name	Order/family	References
Leave (frond) pinnae			
Ommatissus lybicus de Bergevin	Date palm Dubas bug	Hem., Tropiduchidae	[33–36]
Palmaspis phoenicis Ram.-Rao	Green pit scale	Hem., Asterolecaniidae	[37]
Parlatoria blanchardii Targioni-Tozetti	White scale	Hem., Diaspididae	[29]
Chrysomphalus aonidum L.	Florida red scale	Hem., Diaspididae	[29]
Parlatoria oleae (Colvee)	Olive scale	Hem., Diaspididae	[29]
Aonidiella orientalis	Oriental yellow scale	Hem., Diaspididae	[29]
Aonidiella aurantii (Mask)	Red scale	Hem., Diaspididae	[29]
Aspidiotus destructor Signoret	Coconut scale	Hem., Diaspididae	[23]
Aspidiotus camelliae Sign.	Armed scale	Hem., Diaspididae	[23]
Aspidiotus cyanophylli Sign.	Armed scale	Hem., Diaspididae	[23]
Aspidiotus hederae (Vall.)	Armed scale	Hem., Diaspididae	[23]
Fiorinia phoenicis (Newstead)	Brown flat scale	Hem., Diaspididae	[17]
Fiorinia lindereae	Date palm scale insect	Hem., Diaspididae	[17]
Fiorinia fioriniae (Targ.Tozz.)	Armed scale	Hem., Diaspididae	[23]
Cicadulina bipunctata (Melichar)	Date palm leafhopper	Hem., Cicadellidae	[38]
Asarcopus palmarum Horvath	Issid bug	Hem., Issidae	[39]
Icerya aegyptiaca (Dougl.)	Margarodid scale	Hem., Margarodidae	[23]
Eucalymnatus tessellatus (Sign.)	Tessellated scale	Hem., Coccidae	[23]
Maconellicoccus hirsutus (Green)	Mealy bug	Hem., Pseudococcidae	[9]
Dysmicoccus brevipes	Pineapple mealy bug	Hem., Pseudococcidae	[40]
Nipaecoccus viridis (Newstead)	Spherical mealy bug	Hem., Pseudococcidae	[23]
Planococcus citri Risso	Citrus mealy bug	Hem., Pseudococcidae	[41]
Pseudococcus adonidum (L.)	Mealy bug	Hem., Pseudococcidae	[23]
Pseudococcus nipae	Mealy bug	Hem., Pseudococcidae	[23]
Mackiella phoenicis K.	Palm bud mite	Acari, Eriophyidae	[42]
Tenuipalus eriophyides Baker	False spider mite	Acari, Eriophyidae	[42]
Tumescoptes trachycarpi Keifer	Leaf curl mite	Acari, Eriophyidae	[42]
Colopalpus eriophyiodes	Date palm false mite	Acari, Eriophyidae	[42]
Raoiella indica Hirst	Leave scarlet mite or frond crimson mite	Acari, Tenuipalpidae	[26, 43]
Brevipalpus californicus (Banks)	False red mite	Acari, Tenuipalpidae	[29]
Eutetranychus orientalis (Klein)	Oriental red mite	Acari, Tetranychidae	[29]
Eutetranychus banksi	Texas citrus mite	Acari, Tetranychidae	[42]
Eutetranychus bredini Baker & Pritchard	Tetranychid mite	Acari, Tetranychidae	[42]
Phyllotetranychus aegyptiacus Sayed	The flat mite	Acari, Tetranychidae	[44]
Polyphagotarsonemus latus (Banks)	The broad mite	Acari, Tarsonemidae	[45]
Steneotarsonemus spirifex (Marchal)	Tarsonemid mite	Acari, Tarsonemidae	[45]
Schistocerca gregaria Föskal	Desert locust	Oth., Acrididae	[11]
Anacridium aegyptium L.	Egyptian locust	Oth., Acrididae	[17]
Zonocerus variegatus Lesne	Variegated grasshopper	Oth., Acrididae	[23]
Julodis euphratica Castelnan & Gory	Sulfurous jewel beetle	Col., Bupredtidae	[46]
Julodis caillaudi	Metallic beetle	Col., Bupredtidae	[17]
Julodis spectablis Cast-Gory	Metallic beetle	Col., Bupredtidae	[17]
Sogatella sp.	Date palm leafhopper	Hem., Fulgoridae	[17]
Zophopetes dysmephila (Trimen)	Leaf skipper	Lep., Hesperiidae	[23]
Leave rachises			
Phonopate frontalis (Fahs.)	Frond borer	Col., Bostrichidae	[37]
Apate monachus F.	Black giant bostrychid	Col., Bostrichidae	[8, 23]
Enneadesmus trispinosus (Ol.)	Bostrychid beetle	Col., Bostrichidae	[23, 41]
Enneadesmus forficula (Fairm.)	Bostrychid beetle	Col., Bostrichidae	[23]
Dinoderus minutus F.	Bostrichid beetle	Col., Bostrichidae	[47]
Lyctus africanus Lesne	Bostrichid beetle	Col., Bostrichidae	[47]
Leave bases			
Phoenicoccus marlatti Cockerell	Pink or red palm scale	Hem., Diaspididae	[39]
Pseudospidoproctus hypheniacus	Giant mealy bug	Hem., Margarodidae	[48]

The unique morphology of date palm and the cryptic nature of many date palm pests, make a sampling of date palm pests' very complicated and difficult process. In spite of this, a sampling of date palm pests could be precisely defined and standardized [96]. Tables 5 and 6 illustrate monitoring tools, sampling unit and sampling size for the major date palm pests.

Field sampling plans and economic thresholds have not been developed for many major date palm pests [61, 68, 113]. However, sampling plans for red palm weevil, carob moth and dubas bug at research level have been developed [108–110]. Information about spatial distribution and economic thresholds of many date palm pests, which are essential for developing effective sampling plans

Table 3 List of insect and mite pests recorded on date palm inflorescence, fruit stalks, green and ripening fruits

Scientific name	Common name	Order/family	References
Pests of inflorescence			
Aphomia sabella Hampson	Greater date moth	Lep., Pyralidae	[29, 42, 49]
Derelomus sp	Inflorescence weevil	Col., Curculionidae	[29]
Antipa nigrocincta Lacordaire	Date inflorescence beetle	Col., Chrysomelidae	[21]
Macrocoma sp.	Inflorescence beetle	Col., Chrysomelidae	[50]
Adiheteothrips jambudvipae	Inflorescence thrips	Thys., Thripidae	[8]
Holarthrothrips josephi Bhatti	Flower thrips	Thys., Thripidae	[21]
Retithrips syriacus (Mayet)	Grape thrips	Thys., Thripidae	[29]
Prionus unipectinatus White	Flower chafer	Col., Cerambycidae	[21]
Palmiothrips palmae (Ramakrishna)	Flower thrips	Thys., Thripidae	[21]
Epicometis hirta (Poda)	Flower chafer	Col., Scarabaeidae	[29]
Potosia angustata Germar	Flower chafer	Col., Scarabaeidae	[51]
Pests of fruit stalks			
Oryctes elegans Prell	Fruitstalk borer	Col., Scarabaeidae	[52]
Platypleura arabica Myers	Arabian cicada	Hem., Cicadidae	[8]
Diceprocta apache (Davis)	Green-winged cicada	Hem., Cicadidae	[53]
Pests of green fruits			
Oligonychus afrasiaticus McGreg	Old world mite	Acari, Tetranychidae	[42, 54–56]
Oligonychus pratensis Banks	Banks grass mite	Acari, Tetranychidae	[8]
Oligonychus senegalensis	Spider mite	Acari, Tetranychidae	[8]
Eutetranychus palmatus Attiah	Red spider mite	Acari, Eutertanychidae	[57]
Coccotrypes dactyliperda Fab.	Date stone beetle	Col. Scolytidae	[8, 12, 29]
Batrachedra amydraula Meyer	Lesser date moth	Lep., Batrachedridae	[8, 12, 29, 42, 58]
Ripening fruits			
Polistes hebraeus F.	Yellow wasp	Hym., Vespidae	[29]
P. gallicus L.	Spotted yellow wasp	Hym., Vespidae	[29]
Vespa orientalis L.	Oriental wasp	Hym., Vespidae	[29, 51]
Drosophila melanogaster Meigen	Drosophila fly	Diptera, Drosophilidae	[17]
Ceratitis capitata Wied	Med. Fruit fly	Diptera, Tephritidae	[29]
Virachola livia Klug	Pomegranate butterfly	Lep., Nymphalidae	[23, 58]
Ectomyelois ceratoniae (Zeller)	Carob moth	Lep., Pyralidae	[59–61]

for their management is lacking. Recently, geographical information system (GIS) was used effectively for modelling the spatiotemporal patterns of dubas bug infestation in date palm [114]. Establishment of proper sampling plans for major date palm pests is the first step in decision-making rules for initiating date palm IPM.

Cultural and Agrotechnical Measures

The agronomic practices used in date palm to optimize yield include proper spacing, irrigation, fertilization, bunch covering or bagging, phytosanitary measures (pruning and removal of fallen fruits), early harvesting and soil cultivation. These operations should be carried out in such a way to favour growth, the yield of the crop and simultaneously manage arthropod pests.

Pruning and disposing of infested leaves as phytosanitary measures proved to be effective control of Parlatoria scale particularly against light infestations [115]. Pruning eliminates the sites for many date palm pests to hide, oviposit and feed. Additionally, it can also facilitate hand picking (physical control) of Oryctes and longhorn grubs [76, 116–118]. Pruning should, however, be carried out carefully to avoid overpruning that usually lead to a reduction of the photosynthetic surface area of the palm and provide entry points or wounds, in the palm trunk, for insect pests that cannot infest intact tissues on their own [119]. Removal of fruits in the axil of fronds and destruction of fallen fruits on the ground will help in the management of sap beetles, lesser date moth, almond moth [12, 120].

Dubas bug reaches high epidemic numbers only in densely spaced groves because of the ideal microclimate resulting in lower temperature coupled with high relative humidity. Sun scorching and desiccation in well-spaced groves usually kill the delicate newly hatched nymphs [121]. Shah *et al.* [122] recommended the removal of lower fronds rows (2–3) before egg hatching as part of IPM approach for the dubas management in Pakistan. Closely spaced and densely grown date palms, which are irrigated by flooding, are likely to be attacked by the red palm weevil, most probably due to increased humidity at the bases of these palms [123].

Bagging of bunches just after pollination minimized the damage of the fruits and reduce the infestation of lesser date moth and carob moth [61, 120]. The use of 2×2 mm^2 mesh plastic nets to cover fruit bunches can protect these fruits from attacks by the fruit moth but not the sap beetle, which can penetrate through these, meshes [12]. In addition to protection from damages of birds, lizards, rodents, flying bats and insects, bunch covering also provide protection of date fruits against sunburn and excessive rains

Table 4 List of insect and mite pests attacking dates during harvest, storage and packinghouse processing

Scientific name	Common name	Order/family	References
Trogoderma granarium Ev.	Khapra beetle	Col., Dermestidae	[62]
Tribolium castaneum (Herbst)	Red flour beetle	Col.,Tenebrionidae	[63]
Tribolium confusum Jacquelin du Val.	Confused flour beetle	Col., Tenebrionidae	[63]
Cryptolestes ferrugineus (Stephens)	Rusty grain beetle	Col., Laemophloeidae	[8, 62]
*Oryzaephilus surinamensis (*L.*)*	Saw-toothed grain beetle	Col., Silvanidae	[8, 63]
Oryzaephilus mercator (Fauvel)	Merchant grain beetle	Col., Silvanidae	[8, 63]
Aphomia sabella Hampson	Greater date moth	Lep., Pyralidae	[64]
Plodia interpunctella (Hubn.)	Indian meal moth	Lep., Pyralidae	[8, 65]
Cadra cautella (Walker)	Almond moth	Lep., Pyralidae	[8, 66]
Cadra figulilella (Gregson)	Raisin moth	Lep.,Pyralidae	[11, 67]
Ephestia elutella Hübner	Tobacco moth	Lep., Pyralidae	[11, 63]
Ephestia kuehniella (Zeller)	Med. Flour moth	Lep., Pyralidae	[11, 62]
Ephestia dowsoniella Richard	Dowson moth	Lep., Pyralidae	[11, 62]
Ectomyelois ceratoniae (Zeller)	Carob moth	Lep., Pyralidae	[12, 61]
Ephestia calidella Günee	Currant moth	Lep., Pyralidae	[63]
Cotinis mutabilis Gary & Percheron	Fig beetle	Col., Scarabaeidae	[8, 29]
Carpoglyphus lactis L.	Mite on date palm	Acari, Carpoglyphidae	[68]
Blomia freemani Hughes	Mite	Acari, Glycyphagidae	[68]
Tyrophagus lintneri (Osborn)	The mushroom mite	Acari, Acaridae	[68]
T. putrescentiae Schrank	Grain mite	Acari, Acaridae	[69]
Carpophilus hemipterus (L.)	Dried fruit beetle	Col., Nitidulidae	[70, 71]
Carpophilus pepos	Dried fruit beetle	Col., Nitidulidae	[72]
Carpophilus mutilatus Erichson	Confused sap beetle	Col., Nitidulidae	[72, 73]
Carpophilus obsoletus	Sap beetle	Col., Nitidulidae	[72]
Urophorus humeralis (F.)	Pineapple beetle	Col., Nitidulidae	[72]
Epuraea luteola (Erichson)	Yellow nitidulid	Col., Nitidulidae	[72]
Lasioderma serricorne (F.)	Cigarette beetle	Col., Anobiidae	[50]

Table 5 Monitoring tools (techniques) for the major date palm pests

Common name	Scientific name	Monitoring tool	References
Red palm weevil	*Rhynchophorus ferrugineus*	Palm inspection, pheromone traps	[97]
Dynastid beetles	*Oryctes* spp.	Light and pheromone traps	[52, 98]
Longhorn borer	*Jebusaea hammerschmidti*	Light traps, palm inspection for adult exit holes	[76, 99, 100]
Lesser date moth	*Batrachedra amydraula*	Light and pheromone traps	[101]
Dubas bug	*Ommatissus lybicus*	Sticky traps, monitoring honey dew secretion by water sensitive paper (WSP)	[102, 103]
Sap beetles	*Carpophilus hemipterus*	Pheromone traps	[12]
White scale	*Parlatoria blanchardi*	Sticky traps for monitoring males	[104]
Carob moth	*Ectomyelois ceratoniae*	Pheromone traps	[61]
Raisin moth	*Cadra figulilella*	Pheromone traps	[61]
Old world mite	*Oligonychus afrasiaticus*	Counting mites on randomly selected date fruits	[56, 105]
Green pit scale	*Palmapsis phoenicis*	Counting scales insect per cm^2 per leaflet	[106]
Almond moth	*Cadra cautella*	Pheromone traps	[107]
Indian mea moth	*Plodia interpunctella*	Pheromone traps	[107]
Saw-toothed grain beetle	*Oryzaephilus surinamensis*	Floor food-baited traps	[107]

Table 6 Sampling units and sampling size for major date palm pests

Common & scientific name	Sampling unit	Sampling size	References
Caron moth, *Ectomyelois ceratoniae*	Date fruit	150 dates	[108]
Old world date mite, *Oligonychus afrasiaticus*	Fruit	100 fruits	[105]
	Pinnae	100 pinnae	
Red palm weevil, *Rhynchophorus ferrugineus*	Whole palm tree	100 Palms	[109]
Dubas bug, *Ommatissus binotatus*	Leaflet	40 leaflets (Counting eggs)	[110]
White scale insect, *Parlatoria blanchardi*	Leaflet	50 leaflets	[111]
Fiorinia date scale, *Fiorinia phoenicis*	Leaflet	80 leaflets	[112]
Green pit scale, *Palmapsis phoenicis*	Leaflet	48 leaflets	[106]
Lesser date moth, *Batrachedra amydraula*	Immature fruits	100 fruits on a bunch (25 fruits from each cardinal direction)	[101]

[8]. However, careful attention should be made when using paper covers on date bunches with green fruits to avoid damaging them by the increased humidity and sunburn due to intense heat under these covers.

Soil cultivation around infested date palms particularly the top 10 cm will help in the management of insect pests that pupate in the soil.

Different cultural practices adopted for the management of the lesser date moth, *Batrachedra amydraula* were evaluated using questionnaire data, which was subject first to correlation analysis then multiple regression analysis for management factors that had a significant correlation with pest infestation. The bunch remnant pruning and bunch covering significantly decreased the infestation by the pest [120]. In this respect, Al-Kindi *et al.* [124] applied the spatial statistical model to study the correlation between human-related practices and dubas bug infestation. They concluded that cultural practices such as palm spacing (less than 5×5 m^2), insecticide application, offshoots removal, fertilization and pruning significantly influenced the degree of dubas infestation on date palm in Oman.

Biological Control

Table 7 lists 90 species of predators and parasitoids from diverse groups of insects and mites reported from date palm ecosystem worldwide. Biological control of most date palm pests is not easy because their natural enemies are usually not host-specific and ineffective; however, Parlatoria scale was an exception when only insecticides are reduced to the minimum [12].

Predators have been recorded to provide up to 45% mortality in the white scale populations [158]. The general exotic coccinellid predator, *Chilocorus bipustulatus* introduced in Sudan in the 1980s against the white scale insect *Parlatoria blanchardi* however, it failed to establish its self against the green pit scale, *P. phoenicis* [26, 119]. The predator was introduced into Morocco in the 1970s and Oman in 1990s without successful establishment [9]. However, the release of the same predator into date palm groves in Mauritania, Niger and Tunisia provided a reasonable level of control against the white scale [16, 159, 160]. Recently, specialized egg parasitoid *Pseudoligosita babylonica* (Hymenoptera: Trichogrammatidae) was reported from Iraq and Yemen on dubas bug [42, 161].

Many species of foliage spiders were reported from date palm grown in Pakistan [162]. Although spiders are generalist predators and may tend to consume other beneficial insects and mites, their overall impact on date palm pest population may be positive [113]. Worldwide, the European strain of the phytoseiid predatory mite, *Neoseiulus californicus* Mc Gregor [68] and the egg parasitoids of the genus *Trichogramma* are commercially available and have been used in the field to manage insect pests [83, 85, 163]. Among the challenges that face the practical implementation of biological control are establishment and viability of the biocontrol agents in the field and their economic mass production [81]. A recent comprehensive review of the natural enemies of the red palm weevil including microbial pathogens is available in the literature [164, 165]. Despite the existence of many biocontrol agents of the red palm weevil, their role in biological control of this weevil, under field conditions, is minor.

Exploitation of Resistance/Tolerance among Date Palm Cultivars

Resistance to insect pests among date palm cultivars is well documented in the literature [166–168]. The date variety Ghasb was found to be more tolerant to infestation by the lesser date moth than Zahedi and Deyri varieties [169]. There seem to be differences among date palm cutlivars with regard to infestation by the green pit scale. Barakawi, a dominant variety in Sudan, is more susceptible to the green pit scale than other varieties particularly Meshrig Wad Laggi, which is relatively more resistant [49, 106]. It has been demonstrated that date palm cultivars with high sugar content are favoured by the red palm weevil for development while cultivars with high calcium content (hard tissue) inhibit development [97, 170]. Faleiro *et al.* [168] assessed the degree of preference by RPW in seven major date palm cultivars of Al-Ahsa *viz*. Khalas, Sheshi, Reziz, Khasab, Hatmi, Shahal and Gaar by determining the attraction of RPW to fresh palm volatiles emitted from date palm frond tissue through four-arm choice olfactometer assays. Their results revealed that the weevil was most attracted to the palm tissue volatiles of the cultivar Khalas that was statistically similar to the cultivars Reziz, Sheshi and Hatmi. The cultivars Khasab, Shahal and Gaar exhibited a high degree of non-preference (antixenosis). Date palm varieties with fragile textured fronds are preferred by *Oryctes* spp. compared with varieties with solid and hard textured fronds [116]. Thus, the resistance of some date palm varieties to infestations by arthropod pests can be an important component of IPM program [129]. Although many research studies provide evidence that resistance against date palm pests exists among date palm cultivars, it has not been fully exploited for the management of these pests under field conditions.

Chemical Control

Chemical insecticides should never be the only solution to date palm pests, especially those concealed inside the trunk or beneath palm tissues. Pesticides in such situation usually kill the natural enemies while the pests are protected. Several factors such as oviposition period, overlapping generations and constant infestation of axil and leaves beneath dry fibre may act alone or in

Table 7 List of predators and parasitoids associated with insect and mite pests of date palm

Order/Family/Species	Common name	Target pest	References
Coleoptera: Coccinellidae (predators)			
Coccinella undecimpunctata	Lady bird beetle	Parlatoria date scale	[125]
Coccinella quinquepunctata	Lady bird beetle	Parlatoria date scale	[125]
Cocinella septempunctata	Lady bird beetle	Parlatoria date scale	[125]
Chilocorus bipustulatus	Lady bird beetle	green pit scale	[26]
Scymnus bipunctata Kugelann	Lady bird beetle	Parlatoria date scale	[126]
Scymnus pictus Gorhan	Lady bird beetle	pineapple mealy bug	[12]
Scymnus punetillum Weise	Lady bird beetle	red date palm scale	[127]
Pharoscymnus anchorago F.	Lady bird beetle	red date scale	[39]
Pharoscymnus numidicus Pic.	Lady bird beetle	green pit scale	[26]
Pharoscymnus setulosus Chevrolat	Lady bird beetle	Parlatoria date scale	[128]
Pharoscymnus ovoideus Sicard	Lady bird beetle	Parlatoria date scale	[128]
Pharoscymnus pharoides Marseu	Lady bird beetle	Parlatoria date scale	[128]
Pharoscymnus horni	Lady bird beetle	Parlatoria date scale	[129]
Pharoscymnus varius (Kirsch)	Lady bird beetle	red date palm scale	[127]
Rhyzobius lophanthae	Lady bird beetle	Parlatoria date scale	[130]
Stethorus gilvifrons Mulsant	Lady bird beetle	old world dust mite	[131]
Parstethorus spp.	Lady bird beetle	old world dust mite	[131]
Exochomus nigripennis (Erichson)	Lady bird beetle	dubas bug	[121]
Cheilomenes propinqua	Lady bird beetle	dubas bug	[132]
Coleoptera: Cybocephalidae (Predators)			
Cybocephalus nigriceps nigriceps	Lady bird beetle	Parlatoria scale	[126]
Cybocephalus aegyptiacus	Lady bird beetle	Parlatoria scale	[126]
Cybocephalus pullus Endrödy-Younga	Lady bird beetle	Parlatoria scale	[126]
Cybocephalus micans Reitter	Lady bird beetle	Parlatoria scale	[126]
Coleoptera: Staphylinidae (Predator)			
Atheta coriaria (Kraatz)	Staphylinid beetle	Eggs of nitidulids	[133]
Coleoptera: Histeridae (Predator)			
Teretrius pulex Fairmaire	Histerid beetle	date palm bostrichid	[47]
Hymenoptera: Braconidae (Parasitoids)			
Habrobracon hebetor (Say)	Braconid wasp	Almond moth larva and lesser date moth	[84, 134]
Habrobracon brevicornis Wesmael	Braconid wasp	carob and almond moths larva	[59]
Phanerotoma flavitestacae Fisch	Egg larval parasitoid	Egg-larva of carob moth	[59]
Phanerotoma ocularis Kohl	Braconid wasp	Larva of carob moth	[135]
Phanerotoma leucobasis Kreichbaumer	Braconid wasp	Larva of carob moth	[59]
Microctonus nitidulidis	Braconid wasp	Adult nitidulids	[12]
Brachyserphus abruptus Say	Braconid wasp	nitidulids Larvae	[12]
Psyttalia concolor (Szépligeti)	Braconid wasp	Medfly	[136]
Hymenoptera: Trichogrammatidae (Egg parasitoids)			
Trichogramma evanescens	Trichogramma wasp	Almond moth	[84, 137]
Trichogramma bourarachae	Trichogramma wasp	Almond moth	[137]
Trichogramma cacoeciae	Trichogramma wasp	Almond moth	[137]
Trichogramma oleae (Voegele & Pointel)	Trichogramma wasp	Carob moth	[137]
Trichogramma embryophagum Harty	Trichogramma wasp	Carob moth	[138]
Trichogramma cordubensis Vargas & Cabella	Trichogramma wasp	Carob moth	[139]
Pseudoligosita babylonica	Parasitic wasp	Dubas bug	[42]
Hymenoptera: Encyrtidae (Parasitoids)			
Leptomastix dactylopi Midwest	Parasitic wasp	Citrus mealybug	[124]
Metaphycus sp.	Parasitic wasp	Green pit scale	[26]
Zeteticontus utilis Noyes	Parasitic wasp	Sap beetle	[12]
Archenomus arabicus Ferriere	Parasitic wasp	Parlatoria scale	[128]
Hymenoptera: Aphelinidae (Parasitoids)			
Aphytis phoenicis	Aphelinid wasp	Parlatoria date scale	[140]
Ahytis mytilaspides (Le Baron)	Aphelinid wasp	Parlatoria scale	[140]
Encarsia citrina (Craw)	Aphelinid wasp	Parlatoria scale	[141]
Hymenoptera: Chalcididae (Parasitoids)			
Antrocephalus mitys (Walker)	Parasitic wasp	Almond moth pupa	[59]
Brachymeris aegyptiaca Masi	Parasitic wasp	Carob moth pupa	[59]
Hymenoptera: Bethylidae (Parasitoids)			
Parasierola swirskiana Argaman	Parasitic wasp	Lesser date moth	[142]
Goniozus gallicola Fouts	Parasitic wasp	Raisin moth	[143]
Hymenoptera: Formicidae (Predators)			
Crematogaster sp.	Predatory ant	Dubas bug	[132]
Pogonomyrmex californicus (Buckley)	Predatory ants	Larvae of carob moth	[144]
Hymenoptera: Scoliidae (Parasitoid)			
Scolia erratica (Smith)	Parasitic wasp	Larvae of red palm weevil	[19, 145]

Table 7 (Continued)

Order/Family/Species	Common name	Target pest	References
Hymenoptera: Ichneumonidae (Parasitoid)			
Venturia canescens (Gravenhorst)	Parasitic wasp	Raisin moth	[134]
Acari: Phytoseiidae (Predators)			
Neoseiulus californicus Mc Gregor	predatory mite	tetranychid mites	[68]
Neoseiulus barkeri Hughes	predatory mite	old world mite	[68]
Amblyseius largoensis Muma	predatory mite	red palm mite	[146]
Euseius citrifolius	predatory mite	Red and black mite	[68]
Cydnoseius negevi	predatory mite	Old world dust mite	[147]
Galendromus flumenis (Chant)	predatory mite	Banks grass mite	[148]
Acari: Ascidae (Egg predators)			
Blattisocius tarsalis (Belese)	predatory mite	Almond moth	[149]
Blattisocius keegani Fox	Predatory mite	Almond moth	[150]
Acari: Cheyletidae (predators and parasite)			
Cheyletus malaccensis Oudemans	Predatory mite	Egg of Almond moth	[150]
Acaropsis docta	Predatory mite	Scale insects	[151]
Neoacarapsis sp.	Predatory mite	Parlatoria scale	[136]
Eutogenes sp.	Parasitic mite	Longhorn beetle	[136]
Hemicheyletia sp.	Parasitic mite	Longhorn beetle	[136]
Acari: Pyemotidae			
Tetrapholypus rhynchophori	Parasitic mite	Red palm weevil	[152]
Pyemotes ventricosus Newport	Parasitic mite	Larvae of carob moth	[59]
Acari: Laelapidae			
Hypoaspis sp.	Parasitic mite	longhorned beetle	[42, 144]
Acari: Ameroseiidae			
Ameroseius sp.	Parasitic mite	longhorned beetle	[42, 144]
Acari: Anystidae			
Anysits agilis	Predatory mite	Dubas bug	[42]
Acari: Hemisarcoptidae			
Hemisacoptes coccophagus Meyer	Predacious mite	Parlatoria scale	[153]
Acari: Tydeidae			
Pronematus sp.	Predacious mite	Parlatoria scale	[136]
Tydeus sp.	Predacious mite	Parlatoria scale	[136]
Acari: Bdellidae			
Spinibdella sp.	Parasitic mite	Longhorn beetle	[136]
Acari: Diplogynidae			
Dendrolalps sp.	Parasitic mite	Longhorn beetle	[136]
Hemiptera: Anthocoridae (Predators)			
Xylocoris flavipes	Predatory bug	Almond moth	[150]
Orius insidiosus (Say)	Predatory bug	Banks grass mite	[68]
Hemiptera: Reduviidae (Predators)			
Platymeris laevicollis Distant	Predatory bug	Red palm weevil	[152]
Peregrinator biannulipes	Predatory bug	Nitidulid beetles	[154]
Dictyoptera: Mantidae			
Calidomantis savigny	Praying mantid	Predator on dubas bug	[132]
Sphodromantis bimaculata	Praying mantid	General predator	[155]
Neuroptera: Chrysopidae (Predator)			
Chrysoperla carnea	Lace wing	Dubas bug	[156]
Thysanoptera: Thripidae			
Scolothrips sexmaculatus	Predatory thrip	Banks grass mite	[68]
Dermaptera: Forficulidae			
Chelisoches morio F.	Earwig	Eggs young larvae of red palm weevil	[157]
Diptera: Sarcophagidae			
Sarcophaga fuscicauda Bottcher	Parasitic fly	Larvae of red palm weevil	[144]
Diptera: Tachanidae			
Microthalma disjuncta	Tachanid fly	Fruit stalk borer	[136]
Diptera: Phoridae			
Megaselia sp.	Parasitic fly	Longhorn beetle	[136]

combination to reduce the effectiveness of chemical control against the white scale [128].

The timing of chemical control is a determining factor in the success of control operation against date palm pests. For example, the fifth instar nymphs (2-weeks-old) of dubas bug should be targeted before they develop into adults [78]. Application of contact insecticides against green pit scale can be only effective when applied against the first instar nymphs before the crawlers settle on the leaflets of fruits [8]. The lesser date moth chemical control is more effective at the first instar stage where the newly hatched larvae contact deposit of the insecticide applied to the female date

clusters at the time of pollination [171]. In case of the date palm longhorn stem borer, the growing point of the palm and the base of the fronds are the preferred sites for insecticide application, which should be timed with the peak of the beetle's activity extending from May until August of each year in Saudi Arabia [76, 100]. Application of insecticides by April–June can effectively control the lesser date moth, date stone beetle and greater date moth [12]. Targeting many date palm pests with a single application of insecticide will lead to a reduction in number of chemical treatments and avoidance of the negative impact on the ecosystem.

In Oman, the Ministry of Agriculture is responsible for the chemical control of dubas and the organophosphate pesticide fenitrothion was applied by either using ground-based mist blowers or helicopters fitted with microNair spraying heads. The aerial applications were found to be more effective than ground spraying [103]. The problem of this bug is still growing, indicating that pesticides application is not the panacea for this insect pest. In the past, the commonly used insecticides belong to organophosphate, carbamate and synthetic pyrethroid groups. Recently, insecticides belonging to new generation groups of neo-nicotinoid (Imidacloprid) and phenylpyrazole (Fipronil) are now commonly used in preventive and curative treatments of date palm pests particularly the red palm weevil [172]. The application of these insecticides as soil treatment or injection in the date palm trunk proved to be effective against sap feeder [106]

Semiochemical-based Control

Semiochemicals (chemical cues) have a great role in IPM particularly for cryptic species [173, 174]. The pheromone-baited trap has many advantages including being species-specific, easily used by non-professionals, save time and labour in field scouting of insect pests [175]. Additionally, it can be used as different tactics including mass trapping, attract-and-kill, and mating disruption [175, 176]. Experimentally, pheromone interaction with entomopathogenic fungi has been used in an attract-and-infect to manage the red palm weevil in date palm [177].

The sex pheromones of the lesser date moth have been identified and can be used as bait in sticky traps for monitoring and control of this pest, either by mass trapping or mating disruption [178, 179]. The red palm weevil aggregation pheromone 4-methyl-5-nonanol (ferrugineol) discovered by Hallett *et al.* [180] is extensively used for monitoring and mass trapping of adult weevils (both sexes) in area-wide IPM programs [97]. GIS-based temporal spread sheet could be developed to ascertain the activity and spread of date palm pests based on pheromone traps capture data [181]. Recently, ISCA Technologies introduced HOOK RPW, a semiochemical formulation that attracts and kill RPW and does not need food baits or water and ISCA Smart traps that provide automated, real-time reports of the pest activity in the field [182].

Microbial Pesticides

These include products with fungi, bacteria and viruses as the active ingredients. Several commercial products based on the bacterium *Bacillus thuringiensis* Berliner (*Bt*) were found to be effective against *B. amydraula*, and they are used for control, mainly in organic plantations [183]. These products are used either in spraying or in dusting formulations. The latter offers the better capability of penetrating into the center of the date bunches [184]. The efficiency of *Bt* compounds is higher at the beginning of the season when a larva consumes more than one fruit to complete its development. The first generation of lesser date moth *Bactrachedra amydaula* was effectively controlled, in Saudi Arabia, by application of *Bacillus thuringiensis* kurstaki [185]. Good results were also obtained in Iraq with commercial formulations of Bt used as dust during pollination or spray 2 weeks after pollination (fruit setting) [83–84, 186, 187].

Botanical and Environmentally Safe Insecticides

Ahmed *et al.* [188] gave a comprehensive information on botanical insecticides for controlling insect pests of date palm in the tropics. Early instar nymphs of dubas bug were effectively controlled by spraying with 1% neem (azadirachtin) at a rate of 2–3 ml/l water or by mixing 1.5 ml of neem and 15 ml summer oil [85]. In this respect, azadirachtin in low concentrations is known to have mild or no effect on predators and parasitoids. This characteristic makes neem a suitable insecticide for IPM. Additionally, neem can play an important role in insect resistance management [189]. Argel (*Solenostemma argel*) and Usher (*Calotropis procera*) applied in the soil at a rate of 100 g powder/tree proved to be an effective treatment against green pit scale insect [190]. Clove oil and power were reported to have a residual effect in the soil against grubs of the root borer *Oryctes agamemnon* [191]. Other environmentally safe insecticides such as oxymatrine, agricultural soap and spinosad have shown great potential for the management of date palm pests [85, 186]. The botanical insecticides could be used safely for the management of pests attacking fruits and in organic farming systems as alternatives to synthetic pesticides, which are not allowed.

Legislative Control

Application of an effective and strict internal quarantine measures will help restrict the spread of the insect by human activities. Inspection of offshoots before transporting into new areas also restricts outbreaks. A very good and simple internal quarantine procedure contained the green

pit scale in its limited sites in Sudan. There are about 13 checkpoints to inspect vehicles carrying any date palm planting materials out of the infested areas. Moreover, around the main infested area of Al Ghaba (Sudan) there exist two natural barriers, which prevent any crawlers from crossing to un-infested areas. Two stretches of bare sand each about 4 kms wide to the north and to the south also act as natural barriers [50]. Organic fertilizers are attractive to females of *Oryctes* spp. and importation of these fertilizers should be regulated through quarantine measures to avoid infestation by these beetles [52]. In this respect, quarantine protocols are applied by plant protection services in Tunisia to stop the spread of date palm offshoots infested by *Oryctes agamemnon arabicus* [192]. As a quarantine protocol, scale insects can be controlled by subjecting infested offshoots detached for transplanting to a temperature of 50 °C for 65 h in an insulated room [8]. Al-Shawaf *et al*. [193] developed a quarantine protocol of dipping date palm offshoots in 0.004% fipronil for 30 min to kill all stages of the red palm weevil. However, a quarantine protocol for tall palms intended for production or landscape is lacking. Thus, regional and international cooperation among countries growing date palm is essential to curb the spread of series pests [194].

Training and Education of Farmers

Increasing the awareness of farmer, through training, education and extension is essential for the success of any area-wide IPM in date palm. Farmers should have to be able, at least, to differentiate between beneficial and harmful insects in their plantation. This is a minimum requirement for proper application of chemical pesticides and implementation of IPM approach. The correct identification of pests and beneficial agents is a key point for a successful pest management program. In Sudan, farmers were trained to differentiate between the indigenous Parlatoria and the exotic green pit scales in the field simply by passing pinnae between two fingers. The former scale has a flat scale while the latter has a hump-shaped scale [50]. In connection to this, farmers field schools and participatory research approach were successfully used in the establishment of the integrated management program for the green pit scale [106]. The socio-economic and extension factors, as they have a noticeable impact on date palm IPM, have been reviewed by Latifian [81].

Conclusions

The date palm arthropod pests' complex is changing due to many factors including climate change and introduction into new geographical areas. Understanding the factors underlying the population dynamic and seasonality of both pests and their natural enemies is essential for designing and implementing an IPM program for these pests. Chemical pesticides should not be relied upon as short-term solutions against date palm pests to avoid the risk of residues in fruits and to maintain the balance of the ecosystem. Integrated management strategies combining cultural practices, biological control, resistant cultivars and minimum use of selected pesticides can hold the populations of most date palm pests at levels below that cause economic damage. The use of these environmental friendly tactics can lead to a reduction of pesticides and preservation of natural enemies. Enforcement of strict quarantine measures on the movement of offshoots and palms is essential to avoid the spread of series pests. Future improvement of date palm IPM should include the use of GIS to monitor pest activity over large areas. Additionally, meteorological and geostatistical computer models can revolutionize forecasting and monitoring of date palm pests which, eventually improve decision-making for IPM. The use of automated smart traps in date palm plantations will provide spontaneous reports on the pest activity; therefore facilitate rapid and accurate decision-making regarding initiation of pest control measures. Novel tactics such as silencing of pest gene or RNA interference (RNAi) and endosymbionts hosted by insect pests could be used as potential new tools for future management of date palm pests. Above all, training and education of farmers represent the cornerstone for the establishment of solid and effective IPM program in date palm agroecosystem.

Acknowledgements

The authors acknowledge the support, during the preparation of this review, provided by the Deanship of Scientific Research (grant number 150221) and the Date Palm Research Center of Excellence (grant number DPRC-2-2015), King Faisal University.

References

1. ESA-Entomological Society of America. Common Names of Insects and Related Organisms. Entomological Society of America, Annapolis; 2017. Available from: URL: http://www.entsoc.org/common-names [cited 3 September 2017].
2. Chao CC, Krueger RR. The date palm (*Phoenix dactylifera* L.): overview of biology, uses, and cultivation. HortScience 2007;45:1077–82.
3. Johnson DV, Al-Khayri JM, Jain SM. Seedling date palms (*Phoenix dactylifera* L.) as genetic resources. Emirates Journal of Food and Agriculture 2013;25:809–30.
4. FAOSTAT-Food and Agricultural Commodities Production. 2012. Available from: URL: http://faostat.fao.org/site/567/default.aspx#ancor [Cited 2 October 2017].
5. Wakil W, Faleiro JR, Miller TA, Bedford GO, Krueger RR. Date palm production and pest management challenges. In: Wakil W, Faleiro JR, Miller TA, editors. Sustainable Pest Management in Date Palm: Current Status and Emerging

Challenges, Sustainability in Plant and Crop Protection. Springer International Publishing, Switzerland; 2015. p. 2–11.

6. Johnson DV. World wide dispersal of the date palm from its homeland. Acta Horticulturae 2010;882:369–75.
7. El-Juhany M, Loutfy I. Degradation of date palm trees and date production in Arab countries: causes and potential rehabilitation. Australian Journal of Basic and Applied Sciences 2010;4:3998–4010.
8. Carpenter JB, Elmer HS. Pests and Diseases of the Date Palm. Handbook No. 527 United States, Department of Agriculture, Washington, DC; 1978.
9. Zaid A, de Wet PF, Djerbi M, Oihabi A. Diseases and pests of date palm. In: Zaid A, editor. Date Palm Cultivation, FAO Plant production and protection paper no. 156, Rev. 1. FAO, Rome, Italy; 2002. p. 227–81.
10. Zaid A. (2002). Date Palm Cultivation (FAO Plant Production and Protection Paper No. 156, Revision 1). Food and Agriculture Organization of the United Nations, Rome.
11. Buxton BA. Insect pests of date and date palm in Mesopotamia and elsewhere. Bulletin of Entomological Research 1920;11:287–303.
12. Blumberg D. Review: date palm arthropod pests and their management in Israel. Phytoparasitica 2008;36:411–48.
13. El-Haideri HS, Al-Hafidh EMT. Palm and date palm arthropod pests in the Near East and North Africa (in Arabic). In: Regional Project for palm and dates researches in the Near East and North Africa, FAO Bulletin: Al-Watan Printing Press, Lebanon; 1986.
14. El-Shafie HAF. Review: list of arthropod pests and their natural enemies identified worldwide on date palm, *Phoenix dactylifera* L. Agriculture and Biology Journal of North America 2012;3:516–24.
15. Carpenter JB. Notes on date culture in the Arab Republic of Egypt, Israel and the People's Democratic Republic of Yemen. Date Growers' Inst. Rep. 1975;52:18–24.
16. Khoualdia O, Rhouma A, Marro JP, Brun J. Premieres observations sur Oryctes Agamemnon (Col., Scarabidae), nouveau ravageur du palmier dattier en Tunisie. Fruits 1997;52:111–5.
17. Hassan N, Thuraya A, Al-Buraidi FH. A list of Date palm pests and their economic importance in Saudi Arabia. In: Proceeding of the second Symposium on the date palm in Saudi Arabia; 1986 March 3–6 Date palm research center, King Faisal University, Al-Hassa, Mars Publishing house, Riyadh, Saudi Arabia; 1986. p. 345–56.
18. Brand E. Coconut red weevil. Some facts and fallacies. Tropical Agricultural Management of the Ceylon Agricultural Society 1917;49:22–4.
19. Nirula KK. Investigations on the pests of coconut palm. Part 4. *Rhynchophorus ferrugineus*. Indian Coconut Journal 1956;9:229–47.
20. Giblin-Davis RM. Borers of palms. In: Howard FW, Moore D, Giblin-Davis R, Abad RG, editors. Insects on Palms. CABI publishing, Wallingford, UK; 2001. p. 267–305.
21. Blumberg D. Date palm pests and their control measurement. In: Bernstein Z, editor. Date Growing in Israel. The Plant Production and Marketing Board, Tel-Aviv., Israel; 2004. p. 398–433.
22. Helal H, Eissa IS, Aldel-salam AL, El-Sebay Y. Some biological and toxicological studies on Macrotoma palmata F. (Coleoptera: Cerambycidae). In Proceedings of the Second Symposium on Date Palm; March 3–6, King Faisal University, Kingdom of Saudi Arabia; 1986. p. 431–40.
23. Gentry JW. Crop Insects of Northeast Africa-Southwest Asia. Agriculture Handbook No. 273. USDA, Washington, DC; 1965.
24. Gómez S. Plagas y enfermedades de la palmera datilera (*Phoenix dactylifera* L.) en España. Phytoma 1999;114:188–91.
25. Soroker V, Stefano C, editors. Handbook of Major Palm Pests: Biology and Management. 1st ed. John Wiley and Sons Ltd, UK; 2017.
26. Yousof DE, Mahmoud MEE, Mohamed AH. Prospects of biological control of date palm green pit scale insect *Asterolecanium phoenicis* Rao (Homoptera: Asterolecaniidae) in Sudan. Persian Gulf Crop Protection 2013;2:42–8.
27. Nixon RW. Date culture in Sudan. Date Growers' Inst. Rep., 1967;44:9–14.
28. Butani RK. Les insectses parasites Du palmier-Dattier en Inde et leur Controle. Fruits 1974;29:689–91.
29. Mashal M, Albeidat B. A survey on insect pests of date palm trees in Jordan (Research Note). Jordan Journal of Agricultural Science 2006;2:94–104 (In Arabic with English abstract).
30. Ahmed HM, Mohany KM. Field studies on the control of subterranean termite *Amitermes desertorum* (Desneux) (Isop. Termitidae) attacking date palm trees in Aswan Governorate, Assuit. Journal of Agricultural Science 2008;39(1):135–40.
31. Bitton S, Nakash Y, Soroker V, Blumberg D. Control trials of sap beetle in date plantation. Alon Hanotea 2007;62:974–7.
32. Kaakeh W. Identification, geographical distribution and hosts of subterranean termites in the United Arab Emirates Arid Ecosystem. Agricultural and Marine Sciences 2005;10(1):33–40.
33. Kranz J, Schmutterer H, Koch W, editors. Disease, Pest and Weeds in Tropical Crops. John Wiley & Sons, Chichester; 1978.
34. Klein M, Venezian A. The dubas date, Tropiduchid, *Ommatissus binotatus* lybicus, a threat to date palms in Israel. Phytoparasitica 1985;13:96–101.
35. Asche M, Wilson MR. The palm-feeding plant hopper genus Ommatissus (Homoptera: Fulgoroidea: Tropiduchidae). Systematic Entomology 1989;14:127–47.
36. Mokhtar AM, Al Nabhani SS. Temperature-dependent development of dubas bug, *Ommatissus lybicus* (Hemiptera: Tropiduchidae), an endemic pest of date palm, Phoenix dactylifera. European Journal of Entomology 2010;107:681–5.
37. Hussain AA. Notes on borers of date palms in Iraq. Bulletin of Entomological Research 1963b;54:345–48.
38. Alhudaib K, Arocha M, Wilson M, Jones P. Al-Wijam, a new Phytoplasma disease of date palm in Saudi Arabia. Bulletin of Insectology 2007;60:285–6.
39. Stickney FA, Barres DF, Simmons P. Date palm insects in the United States. United States Department of Agriculture, Washington, DC; 1950. Circular 846, 52 pp.
40. Ben-Dov Y, Miller DR. ScaleNet, a systemic database of the scale insects of the world; 2007. Available from: URL: https://data.nal.usda.gov/dataset/

scalenet-scale-insects-coccoidea-database_136 [cited 2017 September 27].

41. Bitaw AA, Ben Saad AA. Survey of date palm tree insect pests in Libya. Arab Journal of Plant Protection 1990b;8:72–6.

42. Al-Jboory IJ. Survey and identification of the biotic factors in the date palm environment and its application for designing IPM-program of date palm pests in Iraq. In: Proceedings of the 4th Symposium On date palm; May 5–8, College of Agricultural and Food Sciences, King Faisal University, Saudi Arabia; 2007. p. 1110–65.

43. Gerson O, Venezian A, Blumberg D. Phytophagous mites on date palms in Israel. Fruits 1983;38:133–5.

44. Zaher MA, Wafa AK, Yousef AA. Biological studies on *Raoiella indica* Hirst and *Phyllotetranychus aegyptiacus* Sayed infesting date palm trees in the U.A.R. (Acarina: Tenuipalpidae). Zeitschrift für Angewandte Entomologie 1969;63:406–11.

45. El-Sanady MA, Mohamed AA. Biodiversity and seasonal abundance of mites associated with two varieties of date palm in Giza and Sohag governorates, Egypt. Acarines 2013;7:57–62.

46. Almansoori TA, Al-Khalifa MA, Mohammed AMA. Date palm status and perspective in Bahrain. In: Al-Khayri JM, Jain SM, Johnson DV, editors. Date Palm Genetic Resources and Utilization. Volume 2. Asia and Europe. Springer, Dordrecht; 2015. p. 353–86.

47. Borowski J, Mazur S. Contribution to the knowledge of the Bostrichidae and associated Histeridae of Morocco (Insecta, Coleoptera). IL Naturalista valtellinese Atti Del Museco Civico Di Storia Naturale Di Morbegno 2001;12:69–75.

48. Elwan AA. Survey of the insect and mite pests associated with date palm trees in Al-Dakhliya region, Sultanate of Oman. Egyptian Journal of Agricultural Research 2000;78:653–64.

49. Talhouk AS. On the management of the date palm and its arthropod enemies in the Arabian Peninsula. Journal of Applied Entomology 1991;111:514–20.

50. Gassouma MS. *Palmaspis phoenicis*, Asterolecaniidae, Coccoidea, Homoptera, Insect; 2003. Available from: URL: http://ecoport.org/ep?SearchType=slideshowView&slideshowId=137 [Cited 27 September 2017].

51. Izhar Y, Wysoki M, Blumberg D, Swieski E. The flower chafer Potosia angustata Germar (Coleoptera: Scarabaeidae), a pest of Lchee, pear, avocado and date palm in Isreal. Alon Hanotea 1997;51:60–2 (In Hebrew with English abstract).

52. Bedford GO, Al-Deeb MA, Khalaf MZ, Mohammadpour K, Soltani R. Dynastid beetle pests. In: Wakil W, Faleiro JR, Miller TA, editors. Sustainable Pest Management in Date Palm: Current status and Emerging Challenges, Sustainability in Plant and Crop Protection. Springer International Publishing, Switzerland; 2015. p. 73–108.

53. Elmer HS. Protection of dates from injury caused by the Apache cicada in California. Journal of Economic Entomology 1963;56:875–6.

54. Lepesme P. Les Insects Des Palmiers. Editions P. lechevalier, Paris, France; 1947.

55. Calcat A. Diseases and pests of date palm in the Sahara and North Africa. Bulletin of Entomological Research 1959;11:287–303.

56. Palevsky E, Borochov-Neori H, Gerson U. Population dynamics of *Oligonychus afrasiaticus* in the southern Arava Valley of Isreal in relation to date fruit characteristics and climatic conditions. Agricultural and Forest Entomology 2005;7:283–90.

57. Attiah HH. The genus Eutetranychus in the U.A.R, with description of three new species (Acarina: Tetranychidae). Bulletin of Entomological Society of Egypt 1967;51:11–6.

58. Eissa IS, Helal H, El-Malki KG. Biological and control studies on Batrachedra amydraula Meyr. and Virachola livia Klug as date insect pests in Egypt. In: Proceedings of the second symposium on date palm; 1986 March 3–6; King Faisal University, Kingdom of Saudi Arabia; 1986. p. 411–8.

59. Gothilf S. Natural enemies of the carob moth *Ectomyelois ceratoniae* (Zeller). Entomophaga. 1969;14:195–202.

60. Navarro S, Donahaye E, Calderon M. Development of the carob moth, *Spectrobates ceratoniae*, on stored almond. Phytoparasitica 1986;13:177–86.

61. Perring TM, El-Shafie HAF, Waqas W. Carob moth, lesser date moth, and raisin moth. In: Wakil W, Faleiro JR, Miller TA, editors. Sustainable Pest Management in Date Palm: Current Status and Emerging Challenges, Sustainability in Plant and Crop Protection. Springer International Publishing, Switzerland; 2015. p. 109–67.

62. Hussain AA. Date Palms and Dates with their Pests in Iraq. Ministry of Higher education and scientific research, University of Baghdad, Baghdad, Iraq; 1974. 166 pp.

63. Mohammed MZ, Al-Giat SI, Logma HI, Dhafran HA, Al-Abdelsalam KS, editors. Important Diseases and Pests of Date Palm and their Integrated Control in the Kingdom of Saudi Arabia. Al-Asr Printing Press, Riyadh, Saudi Arabia; 2002. 369 p. (in Arabic).

64. Burks CS, Yasin M, El-Shafie HAF, Waqas W. Pests of stored dates. In: Wakil W, Faleiro JR, Miller TA, editors. Sustainable Pest Management in Date Palm: Current Status and Emerging Challenges, Sustainability in Plant and Crop Protection. Springer International Publishing, Switzerland; 2015. p. 237–86.

65. Donahaye E, Calderon GH. Survey of insects infesting dates in storage in Israel. Israel Journal of Agricultural Research 1964;14:97–100.

66. Moore D. Insects of palm flowers and fruits. In: Howard FW, Moore D, Giblin-Davis R, Abad RG, editors. Insects on Palms. CABI Publishing, Wallingford, UK; 2001. p. 233–66.

67. Abou El-Ghar MR, El-Rafie MS. Control measures of date pests in Egypt. Bulletin of the Entomological Society of Egypt 1964;48:291–301.

68. Negm MW, De Moraes GJ, Perring TM. Mite pests of date palms. In: Wakil W, Faleiro JR, Miller TA, editors. Sustainable Pest Management in Date Palm: Current Status and Emerging Challenges, Sustainability in Plant and Crop Protection. Springer International Publishing, Switzerland; 2015. p. 63–72.

69. Saleh SM, Abdel-Hamid MM, Yacout GA. Seasonal variations in soil mite populations under date palm tree at Rashid district. In: Proceedings of the third symposium on date palm; 1993 January 17–20; King Faisal University, Kingdom of Saudi Arabia; 1993. p. 221–7.

70. El-Haidari HS. Report on Insect Pests of Date Palms in Sultanate of Oman. Ministry of Agriculture and Fisheries in Oman and Islamic Development Bank, Oman; 1993.

71. Al-Zadjali T, Abd-Allah FF, El-Haidari HS. Insect pests attacking date palms and dates in Sultanate of Oman. The Egyptian Journal of Agricultural Research 2006;84:51–8.

72. Bartelt RJ, Vetter RS, Carlson DG, Baker TC. Responses to aggregation pheromones for five Carpophilus species (Coleoptera: Nitidulidae) in a California date garden. Environmental Entomology 1994b;23:1534–43.

73. Najla MZ, Kerra HM, Edongali EA, Abogila OS. Population dynamics of the sap beetles (Nitidulidae) associated with date palm trees in coastal regions of Libya. Egyptian Journal of Agricultural Research 2005;83:1343–53.

74. Gassouma MS. Pests of date palm (*Phoenix dactylifera* L.). In: Proceedings of the regional workshop on date palm development in Arabian Peninsula, Abu Dhabi, UAE; 2004. Available from: URL: http://www.icarda.cgiar.org/ARP/Datepalm/Tropics/Pest/Pest.htm.pes [cited 2017 September 27].

75. Howard FW, Moore D, Giblin-Davis RM, Abad RG. Insects on Palms. CAB International, Wallingford, UK; 2001.

76. El-Shafie HAF. Biology, ecology, and management of the Longhorn Date Palm Stem Borer *Jebusaea hammerschmidti* (Coleoptera: Cerambycidae). Outlooks on Pest Management 2015;26:20–3.

77. Anonymous. Save Algarve palms; 2013. Available from: URL: http://www.savealgarvepalms.com/en/weevil-facts/host-palm-trees [Cited 2017 September 27].

78. El-Shafie HAF, Peña JE, Khalaf MZ. Major hemipteran pests. In: Wakil W, Faleiro JR, Miller TA, editors. Sustainable Pest Management in Date Palm: Current Status and Emerging Challenges, Sustainability in Plant and Crop Protection. Springer International Publishing, Switzerland; 2015. p. 169–204.

79. Khudhair MW, Aboud HM, Khalaf MZ, Shbar AK. *Oryctes elegans*, a vector of *Fusarium proliferatum* causing wilt disease symptoms of date palm. International Journal of Phytopathology 2014;3:67–72.

80. El-Sabea AMR, Faleiro JR, Abo El Saad MM. The threat of red palm weevil *Rhynchophorus ferrugineus* to date plantations of the Gulf region of the Middle East: an economic perspective. Outlook on Pest Management 2009;20:131–4.

81. Latifian M. Integrated pest management of date palm fruit pests: a review. Journal of Entomology 2017;14:112–21.

82. Ali AA. Studies on *Astrolecanium phoenicis* (Rao). A date palm scale insect in El-Golid area [MSc. Thesis]. Faculty of Agriculture, University of Khartoum; 1989.

83. Ali A-SA, Mohammad JK. Potentials of utilizing biological measures for the management of lesser date moth *Batrachedra amydraula* in Iraq. In: Proceedings of the Fifth International Date Palm Conference; March 16–18, Abu-Dhabi, UAE; 2014. p. 299–304.

84. Mohammad JK, Al-Jassani RF, Ali A-SA, El-Bouhssini M. Efficiency of some biological control agents on lesser date moth *Batrachedra amydraula* Meyrick in central Iraq. Arab Journal of Plant Protection 2014;32(3):219–25.

85. Ali A-SA, Hama NN. Integrated management for major date palm pests in Iraq. Emirate Journal of Food and Agriculture 2016;28(1):24–33.

86. Khalaf MZ, Alrubiae HF. Impact of date palm borer's species in Iraqi agro-ecosystem. Emirates Journal of Food and Agriculture 2016;28(1):52–7.

87. Kehat M, Blumberg D, Greenberg S. Fruit drop and damage in dates: the role of *Coccotrypes dactyliperda* F. and nitidulid beetles, and prevention by mechanical measures. Phytoparasitica 1976;4:93–9.

88. Yamamura K, Kiritani K. A simple method to estimate the potential increase in the number of generations under global warming in temperate zones. Applied Entomology and Zoology 1998;33:289–98.

89. Ali A-SA. The future visions and the influence of climatic factors on the special and temporal distribution of dubas bug Ommatissus lybicus (de Bergevin) on date palm trees in Iraq. Proceedings of the 4th International Date Palm Conference. Acta. Horticulturae 2010;(ISHS)882:929–35.

90. Ali A-SA. 2011. Influence of climatic factors on the recent spread of dubas bug *Ommatissus lybicus* (Debergevin) on date palm trees in some Upper Euphrates regions of Al-Anbar Province. Journal of Agricultural Science and Technology (A) 2011;1:544–49.

91. Khalaf MZ, Khudhair MW. Spatial distribution of dubas *Ommatissus lybicus* (Homoptera: Tropiduchidae) in date palm frond rows. International Journal of Entomological Research 2015;3(1):9–13.

92. Desneux N, Decourtye A, Delpuech JM. The sublethal effects of pesticides on beneficial arthropods. Annual Review of Entomology 2007;52:81–106.

93. Faleiro JR, Ben Abdallah A, El Bellaj M, Al Ajlan AM, Oihabi A. Threat of red palm weevil, *Rhynchophorus ferrugineus* (Olivier) to date plantations of the Maghreb region in North Africa. Arab Journal of Plant Protection 2012;30:274–80.

94. Binns MR, Nyrop JP. Sampling insect populations for the purpose of IMP decision making. Annual Review of Entomology 1992;37:427–53.

95. Stubbins FL, Seiter NJ, Greene JK, Reay-Jones FPF. Developing sampling plans for the invasive *Megacopta cribraria* (Hemiptera: Plataspidae) in soybean. Journal of Economic Entomology 2014;107:2213–21.

96. Al-Shayeb SM, Seaward MRD. Sampling standardization of date palm, *Phoenix dactylifera* L. leaflets as a biomonitor of metal pollutants in arid environment. Asian Journal of Chemistry 2000;12:977–89.

97. Faleiro JR. A review of the issues and management of the red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Rhynchophoridae) in coconut and date palm during the last one hundred years. International Journal of Tropical Insect Science 2006;26:135–54.

98. Rochat D, Mohammadpour K, Malosse C, Avand-Faghih A, Lettere M, Beauhaire J, *et al.* Male aggregation pheromone of date palm fruit stalk borer *Oryctes elegans*. Journal of Chemical Ecology 2004;30:387–407.

99. Al-Deeb MA, Khalaf MZ. Longhorn stem borer and frond borer of date palm. In: Wakil W, Faleiro JR, Miller TA, editors. Sustainable Pest Management in Date Palm: Current Status and Emerging Challenges, Sustainability in Plant and Crop Protection. Springer International Publishing, Switzerland; 2015. p. 63–72.

100. El-Shafie HAF, Mohammed MEA. Description and quantification of damage incurred by the Longhorn Date Palm Stem Borer, *Jebusaea hammerschmidti* Reiche, 1877 (Coleoptera: Cerambycidae) on date palm (*Phoenix dactylifera* L., 1753). International Journal of Entomological Research 2016;4:55–65.

101. Kakar MK, Nizamani SM, Rustamani MA, Khuhro RD. Periodical lesser date moth infestation on intact and dropped fruits. Sarhad Journal of Agriculture 2010;26:393–6.

102. Mokhtar AM, Al-Mjeni AM, Salem HEM. An attempt to estimate honeydew production of different stages of *Ommatissus lybicus* De Berg. (Homoptera: Tropoduchidae) in vitro. Mansoura University Journal of Agricultural Science 2003;28:5669–77.

103. Thacker JRM, Al-Mahmooli HIS, Deadman ML. Population dynamics and control of the dubas bug *Ommatissus lybicus* in the Sultanate of Oman. In: The British Crop Protection Council, UK; 2003. p. 987–92.

104. Abd-El-Kareim AI. Swarming activity of the adult males of Parlatoria date scale in response to sex pheromone extracts and sticky color traps. Archives of Phytopathology and Plant Protection 1998;31:301–7.

105. Ben Chaaban S, Chermiti B, Kreiter S. *Oligonychus afrasiaticus* and phytoseiid predators' seasonal occurrence on date palm *Phoenix dactylifera* (Deglet Noor cultivar) in Tunisian oases. Bulletin of Insectology 2011;64:15–21.

106. Ahmed MA, Abdelbagi AO, El-Shafie AF, Fageer EA, Abass IA. Efficacy of imidacloprid (Confidor 200SL) and improved cultural practices in the control of the green date palm pit scale insect (*Astrolecanium phoenicis* Rao) (*Palmaspis phoenicis*) (Homoptera: Asterolecaniidae) in Northern Sudan. Scientific Research and Essays 2013;8:1752–8.

107. Toews MD, Nansen C. Trapping and interpreting captures of stored grain insects. In: Hagstrum DW, Phillips TW, Cuperus GW, editors. Stored Product Protection. Publication S156. Manhattan, Kansas State University; 2012. p. 243–61.

108. Park J, Perring TM. Development of a binomial sampling plan for the carob moth (Lepidoptera: Pyralidae), a pest of California dates. Journal of Economic Entomology 2010;103:1474–82.

109. Faleiro JR, Ben Abdallah A, Kumar JA, Shagagh A, Al Abdan S. Sequential sampling plan for area-wide management of *Rhynchophorus ferrugineus* (Olivier) in date palm Plantations of Saudi Arabia. International Journal of Tropical Insect Science 2010;30:145–53.

110. Payandeh A, Kamali K, Fathipour Y. Population structure and seasonal activity of *ommatissus lybicus* in bam region of Iran (Homoptera: Tropiduchidae). Munis Entomology and Zoology 2010;5:726–33.

111. Salama HS. On the population density and bionomics of *Parlatoria blanchardi* (Targ.) and *Mycetaspis personatus* (Comstock) (Homoptera-Coccoidea). Zeitschrift für Angewandte Entomologie 1972;70:403–7.

112. Elwan EA, El-Sayed MI, Serag AM. Seasonal activity of Fiorinia date scale, *Fiorinia phoenicis* Balachowsky (Hemiptera: Diaspididae) on date palm at Giza Governorate, Egypt. Egyptian Journal of Agricultural Research 2011;89:549–65.

113. Emekci M, Moore D. Sap beetles. In: Wakil W, Faleiro JR, Miller TA, editors. Sustainable Pest Management in Date Palm: Current Status and Emerging Challenges, Sustainability in Plant and Crop Protection. Springer International Publishing, Switzerland; 2015. p. 205–35.

114. Al-Kindi KM, Kwan P, Andrew N R, Welch M. Modelling spatiotemporal patterns of dubas bug infestations on date palms in northern Oman: a geographical information system case study. Crop Protection 2017;93:113–21.

115. Siddig SA. Field control of the scale insect *Parlatoria blanchardii* Targ. (Diaspididae) infesting date palm in the Sudan. Journal of Horticultural Science 1975;50:13–9.

116. Khalaf MZ, Naher FA, Ali AA. Population density of *Oryctes elegans* Prell (Coleoptera: Scarabaeidae) on some date palm varieties in south Baghdad orchards. Agriculture and Biology Journal of North America 2010;1(3):238–42.

117. Khalaf MZ, Al-Rubeae HF, Al -Taweel AA, Naher FH. First record of Arabian Rhinoceros beetle *Oryctes agamemnon arabicus* Fairmaire on date palm in Iraq. Agriculture and Biology Journal of North America 2013;4(3):349–51.

118. Khalaf MZ, Altaweel AA. Palm borers in Iraqi environment; species, damages, and method of control. In: The Blessed Tree (KIDPA); 2015. p. 54–64.

119. Ahmed MA. The efficacy of four systemic insecticides using two methods of application against the Green Date Palm Pit Scale Insect *Asterolecanium phoenicis* Rao.) (*Palmaspis phoenicis*) (Homoptera: Asterolecaniidae) in Northern Sudan. Acta Horticulturae 2007;736:369–89.

120. Latifian M. The effects of cultural management on the lesser date moth (*Batrachedra amydraula* Myer) infestation. Emirates Journal of Food and Agriculture 2012;24:224–9.

121. Talhouk AS. The present status of date palm pests in Saudi Arabia. In: Proceedings of the First Symposium on the date palm, Saudi Arabia, 23–25March 1982; 1983. p. 432–38.

122. Shah A, Ul-Mohsin A, Hafeez Z. Egg distribution behavior of dubas bug (*Ommatissus lybicus*: Homoptera: Tropiduchidae) in relation to seasons and some physico-morphic characters of date palm leaves. Journal of Insect Behavior 2013;26:371–86.

123. Sallam AA, El-Shafie HAF, Al-Abdan S. Influence of farming practices on infestation by red palm weevil *Rhynchophorus ferrugineus* (Olivier) in date palm: acase study. International Research Journal of Agricultural Sciences and Soil Sciences 2012;2:370–6.

124. Al-Kindi KM, Kwan P, Andrew NR, Welch M. Impacts of human-related practices on *Ommatissus lybicus* infestations of date palm in Oman. PLoS ONE 2017;12:e0171103. doi: 10.1371/journal.pone.0171103.

125. Bitaw AA, Ben Saad AA. Survey of natural enemies of date palm pests in Libya. Arab Journal of Plant Protection 1990a;8:12–5 (In Arabic with English Abstract).

126. Blumberg D. Survival capacity of *Cybocephalous* spp. (Coleoptera: Cybocephalidae) under temperature and humidity extremes. Entomologia Experimentalis Et Applicata 1971;14:434–40.

127. Moustafa M. Host plant, distribution and natural enemies of the red date scale insect *Phoenicococcus marlatti* (Hemiptera: Phoenicococcidae) and its infestation status in Egypt. Journal of Basic and Applied Zoology 2012;65:4–8.

128. Kehat M. Some notes on the life cycle of the date palm scale, Parlatoria blanchardi Targ. in Israel. Israel Journal of Agricultural Research 1967;17:175–9.

129. Swaminathan R, Verma SK. Studies on the incidence of date palm scale *Parlatoria blanchardi* (Targ.) in Western Rajasthan. Entomology 1991;16:217–21.

130. Gomez SV. Cŕa masiva de *Rhyzobius lophanthae* Blaisdell (Coleoptera: Coccinellidae) de predator de la Cochinilla roja de las palmeras (Phoenicococus marlatti Cockerell). Boletin de Sanidad Vegetal Plagas 2002;28:167–76.

131. McMurtry JA, Huffaker CB, van de Vrie M. Ecology of tetranychid mites and their natural enemies: a review. I. Tetranychid enemies: their biological characters and the impact of spray practices. Hilgardia 1970;40:331–90.

132. Hubaishan MA, Gamal SB, Ashour MA, Amjed B. Distribution and control of dubas date bug in Republic of Yemen. In: Proceedings of the 4th Symposium On date palm in Saudi Arabia; 5–8 May 2007; 2007. p. 1388–405.

133. Miller KV, Williams RN. Biology and host preference of *Atheta coriaria* (Coleoptera: Staphylinidae), an egg predator of nitidulidae and muscidae. Annals of the Entomological Society of America 1983;76:158–61.

134. Johnson JA, Valero KA, Hannel MM, Gill RF. Seasonal occurrence of postharvest dried fruit insects and their parasitoids in a culled fig warehouse. Journal of Economic Entomology 2000;93:1380–90.

135. Khoualdia O, R'Houma A, Marro JP, Brun J. Release of *Phanerotoma oculalis* Kohl to combat the carob moth *Ectomyelois ceratoniae* Zeller on dates in an experimental plot at Tozeur in Tunisia. Fruits 1996;51:129–32.

136. Alrubeai HF. Biological control of insect pests in Iraq: (1) an overview of parasitoids and predators research development. Academic Journal of Entomology 2017;10(2):10–8.

137. Ksentini I, Jardak T, Zeghal N. A laboratory comparison of four *Trichogramma* species (Hymenoptera: Trichogrammatidae) as potential biocontrol agents for the carob moth, *Ectomyelois ceratoniae* (Lepidoptera: Pyralidae). Biocontrol Science and Technology 2013;23:465–69.

138. Doumandji-Mitiche B, Doumandji S. Les ennemis naturels d'Ectomyelois ceratoniae Zeller dans les palmeries de Briskra. Bulletin de Zoologie Agricola 1982;4:1–10.

139. Idder MA, Doumandji-Mitiche B, Pintureau B. Biological control in Algerian palm groves. Acta Horticulturae (ISHS) 2013; 994:347–54. Available from: URL: http://www.actahort.org/books/994/994_35.htm [accessed 27 September 2017].

140. Laudeho Y. Aphites mytilaspides (Le Baron) Parasite de *Parlatoria blanchardi* Targ. Dans les Palmeraies de L'Adrar Mauritanien. Fruits 1968;23:271–5.

141. Abd-Rabou S, Hendawy AS. Parasitoids attacking date palm scale, *Parlatoria blanchardii* (Targ.) (Homoptera: Diaspididae) in Egypt. Journal of Agricultural Science, Mansoura University 2000;25:8217–22.

142. Argaman Q. *Parasierola swirskiana* n. sp. (Hymenoptera: Bethylidae) from the lesser date moth, *Batrachedra amydraula* Meyerick (Lepidoptera: Batracheridae). Israel Journal of Entomology 1991–1992;25–26:195–8.

143. Neunzig HH. Systematics of immature phycitines (Lepidoptera: Pyralidae) associated with Leguminous plant in the southern United States. In: United States Department of Agriculture, Agricutlture Research Service; 1979. Technical Bulletin No. 1589, Washington, DC, USA; 1979. 119 p.

144. Nay JE, Perring TM. Impact of ant predation and heat on carob moth (Lepidoptera: Pyralidae) mortality in California date gardens. Journal of Economic Entomology 2005;98:725–31.

145. Peter C. A note on the mites associated with the red palm weevil, *Rhynchophorus ferrugineus* Olivier in Tamil Nadu. Journal of Insect Science 1989;2:160–1.

146. Peña JE, Rodigues JC, Roda A, Carrillo D, Osborne LS. Predator-prey dynamics and strategies for control of the red palm mite (*Raoiella indica*) (Acari: Tenuipalpidae) in areas of invasion in the Neotropics. Integrated Control of Plant Feeding Mites. IOBC/wprs Bulletin 2009;50:69–79.

147. Negm MW, Alatawi FJ, Aldryhim YN. Biology, predation and life table of *Cydnoseius negevi* and *Neoseiulus barkeri* (Acari: Phytoseiidae) on the old world date mite, *Oligonychus afrasiaticus* (Acari: Tetranychidae). Journal of Insect Science 2014;14:1–6.

148. Gispert C, Farrar C, Perring TM. Seasonal abundance and the banks grass mite *Oligonychus pratensis* (Banks) (Prostigmata: Tetranychidae) and a predatory mite, and their response to sulfur treatment on commercial date palms *Phoenix dactylifera* L. in Southern California. In: Halliday RB, Walter DE, Proctor HC, Norton RA, Colloff MJ, editors. Proceedings of the 10th International Congress of Acarology. CSIRO Publishing, Melbourne; 2001. p. 403–8.

149. Bitaw AA, Bin Saad AA, El-Mokhtar O. Natural enemies of date palm pests in Jamahiriya. Arab and Near East Plant Protection Newsletter 1988;7:26.

150. Arbogast RT, Chini SR. Abundance of *Plodia interpunctella* (Hübner) and *Cadra cautella* (Walker) infesting maize stored on South Carolina farms: seasonal and non-seasonal variation. Journal of Stored Products Research 2005;41:528–43.

151. Hammad SM, Kadous AA, Ramadan MM. Predators and parasites of date-palm insects in Al-Hassa and Al-Qatif regions, (eastern province, Saudi Arabia). In: Proceedings of the first symposium on the date palm; 23–25 March 1983; Kingdom of Saudi Arabia; 1982. p. 322–41.

152. Reginald C. Principal Insect Pests in Coconuts. Tropical Agriculture Series. Longmans, London, UK; 1973.

153. Gerson U, Smiley RL. Acarine Biocontrol Agents, an Illustrated Key and Manual. Chapman and Hall, London, UK; 1990.

154. Zipagan MB, Pacumbaba EP. *Peregrinator biannulipes* Montrouzier and Signoret, a reduviid predator of insect pests of copra. In 25th Pest Management Council of the Philippines, Inc. Anniversary and Annual Scientific Meeting, 3–6 May 1994, Cagayan de Oro City, Philippines; 1994.

155. Ali MA, Metwally MM, Hussain AE. Pest suppression of date palm insect populations and effects on yield as a component of sustainable development of El-Bahria oases. Egypt Bulletin of Entomological Society 2002;79:89–102.

156. Hussain AA. Biology and control of the Dubas bug, *Ommatissus binotatus* lybicus De Berg (Homoptera: Tropiduchidae) infesting date palm in Iraq. Bulletin of Entomological Research 1963a;53:737–45.

157. Abraham UA, Kurian C, Nayer NM. Chelisoches morio F. (Forficulidae, Dermaptera) a predator on eggs and early instar grubs of the red palm weevil, *Rhynchophorus ferrugineus*. Journal of Plantation Crops 1973;1:147–52.

158. Gharib A. *Parlatoria blanchardi* Targ. (Homoptera – Diaspididae). Entomologie et Phytopathologie Appliquées 1973;34:10–7.

159. Stansly PA. Introduction and evaluation of *Chilocorus bipustulatus* (Col.: Coccinellidae) for control of *Parlatoria blanchardi* (Hom. Diaspididae) in date palm groves of Niger. Entomophaga 1984;29:29–39.

160. Khoualdia O, Rhouma A, Hmidi MS. Contribution to the bio-ecological study of the white scale *Parlatoria blanchardi* Targ. (Homoptera, Diaspididae) of date palm in Djerid (southern Tunisia). Annales de l'Institut National de la Recherche Agronomique de Tunisie 1993;66:89–108.

161. Hubaishan MA, Bagwaigo AA. The effect of the egg parasitoid *Pseudoligosita babylonica* on dubas infestation in Doaan, Shichawi and Asid (Hudramout, Yemen). Acta Horticulturae 2010;882:451–5.

162. Mushtaq S, Hadait S, Ali L. Diversity and relative abundance of spiders of date palm groves. International Journal of Agriculture and Biology 2000;2:52–4.

163. Grieshop MJ, Flinn PW, Nechols JR, Campbell JF. Effects of shelf architecture and parasitoid release height on biological control of *Plodia interpunctella* (Lepidoptera: Pyralidae) eggs by *Trichogramma deion* (Hymenoptera: Trichogrammatidae). Journal of Economic Entomology 2006;99:2202–9.

164. Mazza G, Francardi V, Simoni S, Benvenuti C, Cervo R, Faleiro JR, *et al.* An overview on the natural enemies of Rhynchophorus palm weevil, with focus on *R. ferrugineus*. Biological Control 2014;77:83–92.

165. Yasin M, Wakil W, El-Shafie HAF, Bedford GO, Miller TA. Potential role of microbial pathogens in control of red palm weevil (*Rhynchophorus ferrugineus*) – a review. Entomological Research 2017;47:219–34.

166. Harhash M, Mourad AK, Hammad SM. Integrated crop management of the lesser date moth *Batrachedra amydraula* Meyr. (Lepidoptera: Cosmopteridae) infesting some date palm varieties in Egypt. Communications in Agriculture and Applied Biological Sciences 2003;68:209–21.

167. Khajehzadeh Y, Latifian M. Response of different date palm cultivars to lesser date moth (*Batrachedra amydraula* Myer.) under natural infestation in Behbahan. Seed and Plant Improvement Journal 2013;29:311–30.

168. Faleiro JR, El-Shafie HAF, Ajlan AM, Sallam AA. Screening date palm cultivars for resistance to red palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae). Florida Entomologist 2014;97:1529–36.

169. Shayesteh N, Marouf A, Amir-Maafi M. Some biological characteristics of the *Batrachedra amydraula* Meyrick (Lepidoptera: Batrachedridae) on main varieties of dry and semi-dry date palm of Iran. In: 10th international working conference on stored product protection. Julius-Kühn-Archiv 2010;425:151–4.

170. Al-Ayedh H. Evaluation of date palm cultivars for rearing the red palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae). Florida Entomologist 2008;91:353–8.

171. Al-Samarraie A, Al-Hafdh I, Abdul-Majed K, Basumy MA. The chemical control of the lesser date moth, *Batrachedra amydraula* Meyr, and residue levels of organophosphate insecticides in dates. Pesticide Science 1989;25:227–30.

172. Al-Shawaf AM, Al-Shagag AA, Al-Bagshi MM, Al-Saroj SA, Al-Badr SM, Al-Dandan AM, *et al.* Toxicity of some insecticides against red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae). Indian Journal of Plant Protection 2010;38:13–6.

173. Witzgall P, Kirsch P, Cork A. Sex pheromones and their impact on pest management. Journal of Chemical Ecology 2010;36:80–100.

174. El-Shafie HAF, Faleiro JR. Semiochemicals and their potential use in pest management. In: Shield VDC, editor. Biological Control of Pest and Vector Insects. InTech Publisher, Rijeka, Croatia; 2017. p. 3–22.

175. Harari AR, Sharon R, Weintraub PG. Manipulation of insect reproductive systems as a tool in pest management. In: Horowitz AR, Ishaaya I, editors. Advances in Insect Control and Resistance Management. Springer International Publishing, Switzerland; 2016. p. 93–119.

176. El-Shafie HAF, Faleiro JR. Optimizing components of pheromone-baited trap for the management of red palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) in date palm agro-ecosystem. Journal of Plant Diseases and Protection 2017;124:279–87.

177. Hajar MJ, Ajlan AM, Al-Ahmed MH. New approach of *Beauveria bassiana* to control the red palm weevil (Coleoptera: Curculionidae) by trapping technique. Journal of Economic Entomology 2015;108:425–32.

178. Levi-Zada A, Fefer D, Anshelevitch L, Litovsky A, Bengtsson M, Gindin G, *et al.* Identification of the sex pheromone of the lesser date moth, *Batrachedra amydraula*, using sequential SPME auto-sampling. Tetrahedron Letters 2011;52:4550–3.

179. Levi-Zada A, Sandusky A, Dobrinin S, David M, Ticuchinski T, Fefer D, *et al.* Reevaluation of the sex pheromone of the lesser date moth, *Batrachedra amydraula*, using autosampling SPME-GC/MS and field bioassays. Chemoecology 2013;23:13–20.

180. Hallett RH, Gries G, Borden JH, Czyzewska E, Oehlschlager AC, Pierce HD, *et al.* Aggregation pheromones of two Asian palm weevils, *Rhynchophorus ferrugineus* and *R. vulneratus*. Naturwissenschaften 1993;80:328–31.

181. Massoud MA, Sallam AA, Faleiro JR, Al-Abdan A. Geographic information system-based study to ascertain the spatial and temporal spread of the red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) in date plantations. International Journal of Tropical Insect Science 2012;32:108–15.

182. Faleiro JR, Abdallah B, Aldawood A, El-Shafie HA, Al Homaidi S, AboHassan Y, *et al.* Hook RPW and ISCA smart traps: Revolutionary new tools for the management of the red palm weevil in Gulf countries. In: Entomological Society of America (ESA) Meeting, 15–18 November 2015, Minneapolis, MN, USA; 2015.

183. Navon A, Nakashe Y, Blumberg D, Levski S, Gan-Mor S, Bechar A, *et al.* The effectiveness of *Bacillus thuringiensis* in granular feeding baits for use against the lesser date moth, *Batrachedra amydraula* in date palms, in comparison with chemical and biological control agents (1995–1999). Alon Hanotea 1999;53:484–9.

184. Blumberg D, Navon A, Kehat M, Eliahu M, Levski S, Nakash J. Date palm pests in Israel at the beginning of the third millennium. Alon Hanotea 2001;55:42–8.

185. Habib DM, Essaadi SH. Biocontrol of the lesser date moth *Batrachedra amydraula* Meyrick (Cosmopteridae= Batrachedridae) on date palm trees. Acta Horticulturae 2007;736:391–97.

186. Mohammad JK, Al-Jassany RF, Ali A-SA, El-Bouhssaini M. The efficacy of the biological insecticides *Bacillus thuringiensis* Berliner and Spinosad against the lesser date moth. Iraqi Journal of Agricultural Science 2013;44(2):220–5.

187. Ali A-SA, Hama NN. Integrated pest management for major date palm pest in Iraq. In: Harmonized Support for Agriculture Development (HSAD) Manual; 2014. p. 22.

188. Ahmed IA, Umma M, Kutama AS, Hassan KY. Insect pests of date palm (*Phoenix dactylifera* L.) and potentials of botanical insecticides for their control in the tropics: a review. Global Advanced Research Journal of Agricultural Science 2015;4(7):275–79.

189. Mordue (Luntz) AJ, Nisbet AJ. Azadirachtin from the neem tree *Azadirachta indica*: its action against insects. Anais da Sociedade Entomológica do Brasil 2000;29(4):615–32.

190. Eldoush KOAM, Taha AK, Idris TSIM, Sidahmed OAA, Musa FEA, Mardi HG. Application of plant based extracts for the control of the green pit scale insect (*Asterolecanium phoenicis* Rao.) with yield enhancement on date palm. Emirates Journal of Food and Agriculture 2011;23(5):404–12.

191. Ibrahim RA, Alahmadi SS. Effect of *Syzygium aromaticum* cloves on larvae of the thinoceros beetle, *Oryctes agamemnon* (Coleoptera: Scarabaeidae). African Entomology 2015;23(2):458–66.

192. Soltani R. The rhinoceros beetle *Oryctes agamemnon arabicus* in Tunisia: current challenge and future management perspectives. Tunisian Journal of Plant Protection 2010;5:179–94.

193. Al-Shawaf AM, Al-Shagag A, Al-Bagshi M, Al-Saroj S, Al-Bather S, Al-Dandan AM, *et al.* A quarantine protocol against red palm weevil *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) in date palm. Journal of Plant Protection Research 2013;53:409–15.

194. Al-Dosary NMN, Al-dobai S, Faleiro JR. Review on the management of red palm weevil *Rhynchophorus ferrugineus* Olivier in date palm *Phoenix dactylifera* L. Emirates Journal of Food and Agriculture 2016;28:34–44.