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## BIOLOGY AND MANAGEMENT OF DYNASTID BEETLE PESTS

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**Abstract.** Two main species of dynastid or rhinoceros beetle, (Coleoptera: Scarabaeoidea: Scarabaeidae: Dynastinae: Tribe Oryctini) *Oryctes elegans* Prell, and subspecies of *Oryctes agamemnon* Burmeister, attack date palms causing significant documented damage. Adults of *O. elegans* bore into the stalks of inflorescences and fruit bunches to feed, and oviposit in leaf axils where the larvae develop and may invade the trunk. *O. agamemnon* larvae bore into frond bases, the trunk, and respiratory roots where their tunnelling may cause the palm to fall. It is difficult to distinguish the larvae of the 2 species in regions where both coexist. For control, annual servicing of palms includes cutting off old fronds at their bases using the correct technique which enables removal of larvae and their breeding places, and this may be integrated with light trapping for catching adults. Quarantine measures may hinder these pests' spread to uninfested areas. In India adults of a third species, *Oryctes rhinoceros* have been noted boring into the soft tissue of the growing point, this species has also been reported from Yemen. Pheromone trapping is available for *O. elegans* but for effectiveness it requires the addition of fresh date palm tissue to the traps as a synergist. No pheromone has been identified for *O. agamemnon*. The entomopathogens *Metarhizium anisopliae* fungus and the nematode *Rhabditis* sp. may have potential in integrated pest management but their possible natural occurrence in an area should be determined prior to propagation and release. The pathogen *Oryctes* Nudivirus, successful against *Oryctes rhinoceros* in lowering its populations and damage to coconut palms when introduced into areas where this virus did not previously exist, should be tested against date palm dynastids. *Oryctes agamemnon* and *O. elegans* adults attacking date palms do not appear to bore into the heart or meristem causing V-cuts to unfurling fronds or the death of the palm, in contrast to attacks by *O. rhinoceros* on coconut and young oil palms. Also *O. rhinoceros* larvae are found only in dead decomposing wood or other organic material, whereas larvae of date palm pests *O. elegans* and *O. agamemnon* may tunnel in living tissue.

### 1. INTRODUCTION

Dynastid or rhinoceros beetles may cause serious damage to date palms. Adults attack fruit bunches or frond bases. Larvae may tunnel into frond bases, the trunk or the root mass causing the death or collapse of the palm. The main pests are two species of *Oryctes*, namely *Oryctes elegans* Prell, and subspecies of *Oryctes agamemnon* Burmeister (El-Shafie, 2012). In Iraq, there is evidence that adults of *Oryctes* spp. act as vectors of the fungal pathogen *Fusarium proliferatum*



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(Matsushima) Nirenberg ex Gerlach & Nirenberg which causes wilt disease symptoms in date palms (Khudhair et al., 2014b). Adults of the well-known pest of coconut and oil palms *Oryctes rhinoceros* L. have been noted as attacking date palms in India (Butani, 1974; 1975) and United Arab Emirates (UAE) (Gassouma, 1991) and have also been reported from Yemen (Al-Habshi et al., 2006).

Taxonomic studies, with illustrations and a key to adults of the species *Oryctes* Illiger (Tribe Oryctini) have been provided by Endrödi (1985) and Dechambre & Lachaume (2001). In the order Coleoptera, species of *Oryctes* are members of the superfamily Scarabaeoidea, family Scarabaeidae, subfamily Dynastinae, and tribe Oryctini. In the field three species mentioned above (Figures 1, 2, 3) can be separated from each other based on leg morphology (Al-Deeb, 2012). The apex of the hind tibia has two large fixed teeth in *O. rhinoceros*, while it has three fixed teeth in *O. agamemnon* and *O. elegans*. In turn these two species can be separated based on the presence of a fixed tooth on the underside of the front tibia in *O. elegans* and its absence in *O. agamemnon*. A description and illustrations of these features has been provided for *O. elegans* (Hurpin & Fresneau, 1969).



Figure 1. *Oryctes elegans* adult male (Dechambre & Lachaume, 2001; with permission from Hillside Books, Canterbury, UK)



Figure 2. *Oryctes rhinoceros*: male (left and middle), female (right) (Dechambre & Lachaume, 2001; with permission from Hillside Books, Canterbury, UK)



Figure 3. *Oryctes agamemnon arabicus* adult. Female (top left), female head with small tuber-like horn (top right), male (bottom left), and male head with big horn (bottom right) (Photo: Mohammad A. Al-Deeb)

Data on the larvae of *O. elegans* with illustrations were given by Hurpin & Fresneau (1969), and its larva together with eggs and pupa are shown here in Figure 4. The larva of *O. agamemnon arabicus* and eggs are shown in Figure 5.



Figure 4. *Oryctes elegans*: egg; larva; pupa (left to right) (Photo: Kazem Mohammadpour)

However, a full descriptions of the larvae of *O. elegans* and *O. agamemnon* using the method of Ritcher (1966), and a key for differentiating them, are not available, causing difficulty in distinguishing larvae of each in regions where the two species coexist i.e. are sympatric. A full description of the larva of *O. rhinoceros* is available (Bedford, 1974).



Figure 5. *Oryctes agagemnon arabicus* larva (left), larval head showing big mandibles (top right), and eggs in dissected abdomen of female in dorsal view (bottom right) (Photo: Mohammad A. Al-Deeb)

## 2. DISTRIBUTION

*Oryctes elegans* is endemic in Iran and Iraq (Buxton, 1920; Endrödi, 1985; Rochat et al., 2004; Payandeh & Dehghan, 2010); Northern Pakistan (Ratcliffe & Ahmed, 2010); Saudi Arabia (Al-Deghairi, 2007), UAE, Bahrain and Qatar (El-Haidari & Al-Hafidh, 1986; Gassouma, 1991). In Iran, locations where *O. elegans* has been reported (Gharib, 1970; Endrödi & Petrovitz, 1974; Kazem Mohammadpour - unpublished) are shown in Figure 6. The distribution of *Oryctes* species in Iraq is shown in Figure 7.

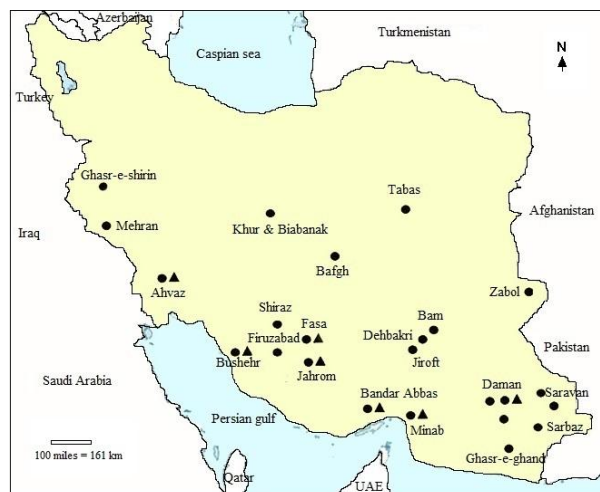


Figure 6. Distribution of *Oryctes elegans* (●) and *Oryctes agagemnon* (▲) in Iran (Kazem Mohammadpour; adapted from Google Maps)

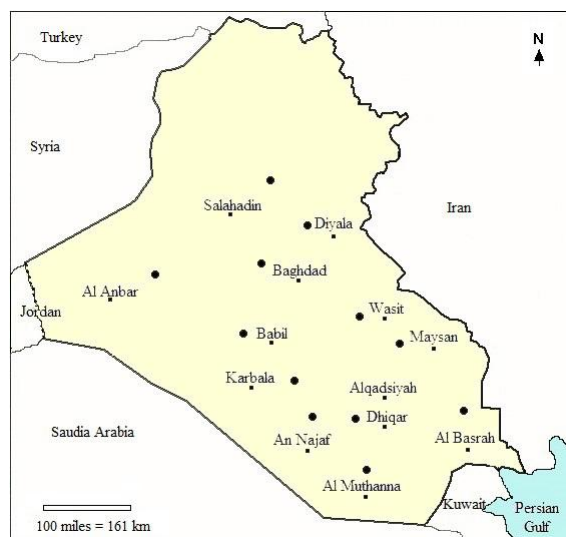


Figure 7. Distribution of *Oryctes* species in Iraq (indicated by black spots) (Mohammed Z. Khalaf; adapted from Google Maps)

Various subspecies of *O. agamemnon* are reported as attacking the date palm. In the Arabian Peninsula, *O. agamemnon arabicus* Fairmaire is endemic in Saudi Arabia (Endrödi, 1985), Oman (Al-Sayed & Al-Tamiemi, 1999) and in the eastern part of UAE in the Al-Ain Region, it is the only species of *Oryctes* found (Gassouma, 1991; Al-Deeb et al., 2012a) (Figure 8). In Iraq, it coexists with *O. elegans* (Buxton, 1920; Khalaf et al., 2013a,b) (Figure 7). Subsequent research has clarified that the material referred to as *O. elegans* in Khalaf et al. (2010; 2011; 2012) is now identified as *O. agamemnon arabicus* (Mohammed Z. Khalaf - personal communication, 2015), and the adjustment applies throughout this chapter.

In Tunisia, *O. agamemnon arabicus* was accidentally introduced into the oasis of Mrah Lahouar in the Djerid zone (Figure 9) from the UAE in the late 1970's. The pest was concealed in offshoots, which was the part of the date palm involved in varietal exchange of material between the two countries (Soltani, 2009). Lack of knowledge of this new species both by farmers and plant protection services, and the confusion of its larval stages, with larvae of other species of scarab beetles as no key was available, permitted its establishment and proliferation. The development of date palm cultivation in the oases of Djerid, with many immature young palms and offshoots also facilitated its establishment (Soltani, 2009; 2010). The first recognition of its presence in Tunisia, and its potential as a threat to date palms, was in 1995 after the sudden falling over of productive trees in Mrah Lahouar (Khoualdia et al., 1997; Soltani et al., 2008a,b; Soltani, 2004; 2009). As monoculture of the date palm is common in the oases, with which the beetle is closely linked, this association facilitates the beetle's survival and proliferation (Soltani, 2009).



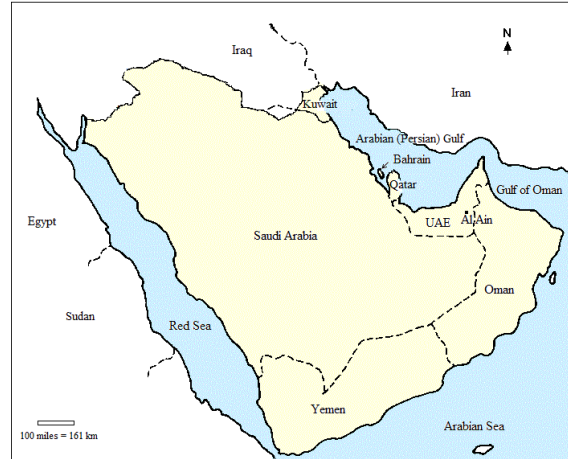


Figure 8. Map of the Arabian Peninsula. For countries where date palms are subject to attack by *Oryctes* species, see the text (adapted from Google Maps)

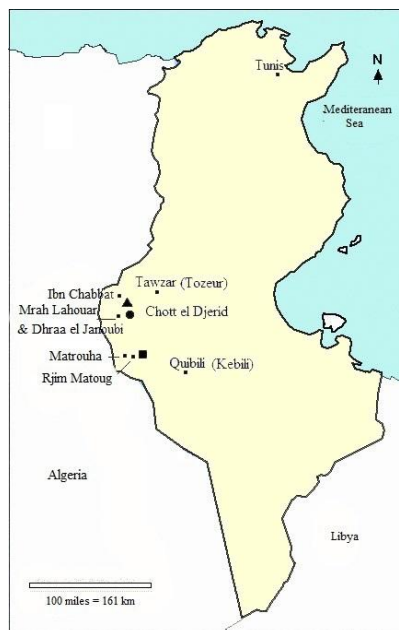


Figure 9. Geographical distribution of *Oryctes agamemnon arabicus* in Southwest Tunisia. The main foci of infestation are the oases of Mrah Lahouar (●), Ibn Chabbat (▲) and Rjim Matoug (■) (Rasmi Soltani; adapted from Google Maps)

During the initial years after its introduction, the infestation was limited to the northern edge of Chott El Djerid particularly in Mrah Lahouar (387 ha) and Dhraa El Janoubi (200 ha) oases. In 1987, with the emergence of date palm cultivation in

the zone and the lack of offshoots, farmers used plants originating from these infested areas for new plantations in Ibn Chabbat oasis located to the north of Mrah Lahouar and in the southern edge of Chott El Gharsa. This allowed the insect to spread and develop here, as the importance of sanitary and quarantine measures had been overlooked (Soltani, 2010).

At the beginning of the 1990's, in offshoots originating from Ibn Chabbat, the pest reached the oases of Rjim Matoug on the southern edge of Chott El Djerid and presently covers the entire border zone except eastern Matrouha oases (Soltani, 2009; 2010). As the habits of this pest were not fully understood at that time it was able to spread mainly through offshoots, as well as by flying adult beetles (Soltani, 2010).

Analysis of DNA markers in *O. agamemnon arabicus* populations in Tunisia showed no significant differences in relation to location or host plant varieties, suggesting a limited number of genotypes would have been present at the start of the invasion. Substantial gene flow was revealed among populations, confirming the belief that much of the pest's spread is the result of transfer of planting material for propagation (Abdallah et al., 2012; 2013).

*Oryctes agamemnon matthiesseni* Reitter is reported from Southern Iran (Endrödi & Petrovitz, 1974; Endrödi, 1985; Kazem Mohammadpour - unpublished) and Iraq (Mohammed Z. Khalaf - unpublished), however, there is no information about its biology from these countries. It also occurs in Southern Afghanistan and North West Pakistan (Endrödi, 1985). Another form of *O. agamemnon*, subspecies unknown, has been reported from Iraq (Mohammed Z. Khalaf - unpublished).

### 3. BIOLOGY

#### 3.1. ORYCTES ELEGANS PRELL

The adult bores a tunnel into the living parts of the palm such as the midrib (rachis) and leaf bases (petioles) of fronds, causing them to break off during wind, and into the stems of inflorescences, and stalks of fruit bunches (Buxton, 1920; Hussain, 1963; Mohammadpour, 2002).

Males produce a semiochemical, a male aggregation pheromone which attracts both sexes. It is 4-methyloctanoic acid (Figure 10), and its attractiveness is strongly enhanced by the presence of odor from fresh date palm tissue (Rochat et al., 2004). The laboratory protocols for the synthesis of these pheromones are reported (Ragoussis et al., 2007; Tabrizian et al., 2009; Sultanov et al., 2013).

The larvae are found in the axils of fronds and at the junction of dead and living tissue in crowns (Hussain, 1963; Rochat et al., 2004) and may tunnel toward the growing point (Buxton, 1920). Groups of larvae may tunnel in moist tissues inside dying or newly dead palm trunks forming a large hole (Gharib, 1970) which may topple the palm (Hussain, 1963).

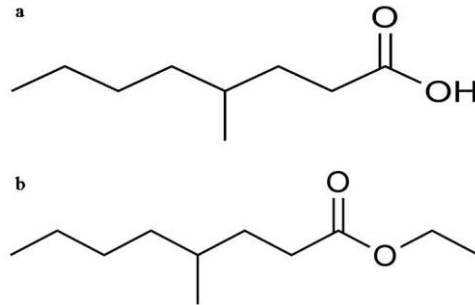


Figure 10. 4-methyloctanoic acid (4-MO) pheromone of *Oryctes elegans* (a), ethyl-4-methyloctanoate (E4-MO) (b) (Bedford, 2013; with permission from *Annual Review of Entomology* Volume 58 © 2013 by Annual Reviews)

In laboratory studies where larvae were reared on a food mixture of decayed wood or compost, and cow dung, at 28-30°C, the average duration of development was: egg, 10 days; larva, 91 days (three instars); prepupa, 7 days and pupa, 31 days (Hurpin & Fresneau, 1969). Larvae were also able to feed on living plant material e.g. apple, but development time was longer and the resulting adults were smaller sized (Hurpin, 1970). In another laboratory study, at 27°C, somewhat longer development times were observed, with mortalities of 5, 23 and 3% recorded for the egg, larval and pupal stages, respectively (Payandeh & Dehghan, 2010).

Adult life span was about four months, and egg-laying began 2 -3 weeks after individuals were brought together as couples, with an average of 60 eggs laid by a single female per life cycle (Hurpin & Fresneau, 1969).

### 3.2. ORYCTES AGAMEMNON ARABICUS BURMEISTER

In Tunisia, no attacks by adults on the inflorescence and green fronds were registered and little sign of feeding was found under laboratory rearing conditions (Soltani et al., 2008a,b; Soltani, 2009; 2010). However, in Saudi Arabia, adults attacked fruit bunch stalks and the rachis of fronds (Al-Sayed & Al-Tamiemi, 1999).

In Tunisia, the larvae are found feeding in the dead respiratory roots around the base of date palm trunks (Soltani et al., 2008b), but no attacks on the inflorescences and green fronds by larvae were reported (Soltani et al., 2008a,b; Soltani, 2009; 2010). In Tunisia, Saudi Arabia and Oman, it breeds in dead dry bark, dry frond petioles, fiber masses in axils, and offshoots (Khoualdia et al., 1997; Al-Sayed & Al-Tamiemi., 1999; Soltani et al., 2008a,b), while in Iraq they occur in debris in the bases of lower fronds and in tunnels in dead frond bases, where there may be up to 12-13 larvae per tree (Khalaf et al., 2010).

The life cycle of *O. agamemnon arabicus* in Iraq is illustrated in Figure 11. Here at 25°C, the average durations of the stages are; eggs: 13 days; total larval stages: 196 days and pupae 29 days (Khalaf et al., 2014b). In Tunisia, laboratory



rearing at 23°C resulted in average durations of egg, first-, second-, third-instar larva, total larval stages, pupa, and total immature stages of 14, 35, 51, 141, 227, 24 and 266 days, respectively; at 27°C, 12, 35, 44, 118, 197, 22 and 231 days, respectively; and at 30°C, 9.5, 36, 45, 142, 223, 21 and 254 days, respectively (Soltani et al., 2008a; Soltani, 2012).

Males of *O. agamemnon arabicus* emitted a blend of four compounds: 1) ethyl 4-methyloctanoate, 2) 4-methyloctanoic acid, 3) 4-methyloctanyl acetate, and 4) 4-methyloctanol. Laboratory observations using an olfactometer showed that compounds 1 and 3 attracted both sexes but females were more attracted by compound 1, virgin females by compound 2, and males by compound 3. Field studies revealed that a mixture of compounds 1 and 2 with date palm core odor was the most effective in attracting both sexes, with females predominating (Saïd et al. (2015).



Figure 11. Life cycle of Arabian rhinoceros beetle, *Oryctes agamemnon arabicus*; 1: eggs, 2: larva, 3-4: pupae, 5: emerging adult, 6: adult female, 7: adult male (Photo: Mohammed Z. Khalaf)

## 4. SEASONAL INCIDENCE

In Iraq, adults of *O. elegans* are attracted to light from April to September, but especially during April and May (Buxton, 1920; Hussain, 1963). Light trapping in three orchards showed that flying activity of *O. agamemnon arabicus* started during April (Khalaf et al., 2013b) and peaked during July (82 individuals caught/trap/month). Population densities as measured by light trap captures then decreased dramatically in October (Khalaf et al., 2011; 2012).

In Iran, *O. elegans* is univoltine, having one generation per year. Here this species and *O. agamemnon matthiesseni* are sympatric; adults are nocturnal and attract towards light. Light trapping revealed that the adults emerged from March and April (spring) to late September, and were most abundant in June and July (summer) (Fasihi, 2011), and not found in late autumn. The female of *O. elegans* makes a small cavity and lays eggs individually in palm fiber in the axils of fronds and inflorescences, or living tissue where petioles join the trunk, or in damp dead half-rotten trunks. The larvae overwinter in their feeding sites in the palm, and each larva weaves a cocoon of fiber (6- x 2 cm). The pupal period in March and early April lasts for 3-4 weeks (Gharib, 1970). Pheromone trap catches also showed the population of *O. elegans* reached to a maximum during summer season (mid-July to mid-August) (Rochat et al., 2004).

In Oman, light trapping showed that *O. agamemnon* appeared from mid-April to early May, with maximum catches recorded from early June to early July i.e. the warmest and driest season, and then catches fall and cease from late August to early October (Al-Sayed & Al-Tamiemi, 1999).

In the Al-Ain region of the UAE, *O. agamemnon arabicus* adults were attracted to street lights and found crawling on the grass of gardens and parks under lights after sunset (Mohammad A. Al-Deeb - unpublished). In a two-year study using light-trapping in UAE, Al-Deeb et al. (2012a) found that *O. agamemnon arabicus* males and females appeared in the field around April and May and the population continued to build until maximum numbers were reached in mid-June. However, at the end of July and early August, the numbers declined sharply and no adults were found after the end of September. *Oryctes agamemnon arabicus* has one generation per year (Al-Deeb, 2012; Al-Deeb et al., 2012a) unlike the red palm weevil *Rhynchophorus ferrugineus* Olivier, which has several overlapping generations per year. In Saudi Arabia, Al-Deghairi (2007) reported that the highest activity of *O. elegans* occurred from April to July and the peak monthly activity was observed during June, and no beetle activity during January and February.

In Tunisia, light trapping showed a single peak - indicating that *O. agamemnon arabicus* has one generation per year (univoltine). The adults emerged from the date palm breeding sites in mid-June and flights continued to mid-October, with the peak flight activity between mid-July and mid-August, the warmest part of the year. The trap captures decreased afterwards, becoming rare in late September and early October, and then ceasing from mid-October until June of the following year. Adults spend most of their time within the green parts of the

palm, from where they emerge to seek breeding sites and disperse. In oases, both adult and immature stages also occur in compost heaps (Soltani, 2009).

In Yemen, when light traps were used to monitor the *O. rhinoceros* population, it appeared in March, increased in April, peaked in June, decreased to low numbers by September, and very low numbers were caught from October to February. The single peak of adult captures (sex ratio male: female 1:1.3) indicated there was one generation per year (Al-Habshi et al., 2006). In coconut-growing areas of the South Pacific, it is considered that *O. rhinoceros* is only occasionally attracted by light (Gressitt, 1953).

## 5. DAMAGE AND LOSSES

### 5.1. *Oryctes elegans*

When the adult bores into the stalk of the fruit bunch (Figure 12), they make a tunnel on one side of the stalk and the dates on that side of the bunch remain undersized, while on the other side of the bunch, fruit is of normal size. A heavily attacked stalk can cause all the dates on a bunch to shrivel, or the stalk breaks and the whole bunch falls. In Iraq, the stalks were attacked straight after fruit set in April, and in the early 1960's infestation of bunches was less than 2% so it was not regarded as a serious pest at that time (Hussain, 1963) whereas heavy damage to bunches was reported in 1918 (Buxton, 1920). Similar damage to fruit stalks occurs in Saudi Arabia (Al-Deghairi, 2007).

In Iran, *O. elegans* damage is more significant in young date palms (aged 10-20 years) than in old plantations, and more severe where planting distance between palms was less than 5 m (Latifian et al., 2012). The long feeding tunnels in the stalks of inflorescences (especially during the pollination period) and bunches, weaken them and cause them to break. They also feed on other living parts of the palm such as the base (petiole) and midrib (rachis) of fronds, causing them to break off during wind. In some areas the damage caused by *O. elegans* represents 5-20% of the total harvest (Gharib, 1970).



Figure 12. Damage from *Oryctes elegans* adults on base of fruit bunch (Photo: Kazem Mohammadpour)

The larval feeding sites of *O. elegans* may also serve as the egg deposition sites by *R. ferrugineus*, however only a weak correlation between the abundance of both these species was observed in sixteen date palm orchards of Saudi Arabia monitored from June 2007 to May 2008 (Al-Ayedh & Al Dhafer, 2015). In areas where both *O. elegans* and *O. agamemnon* (regardless of subspecies) coexist e.g. Iraq, at times there can not only be a difficulty in attributing damage to the larval or the adult stages, but also ascribing it to one or other of the species, moreover, the morphological differentiation of the larvae of both species is also difficult as no key is available. In Iran, *Oryctes* larvae live in the crown and trunk, feeding on petioles and rachis of fronds, and this injury may allow entry of fungi and secondary insect pests. When tunnelling in the trunk they may reach the central bud and kill the palm. They also attack the base of the palms to feed on sap.

## 5.2. *Oryctes agamemnon*

In Oman, adults were reported as attacking fruit bunch stalks and the rachis of fronds, and in Saudi Arabia fruit stalks and the rachis and bases of fronds (Al-Sayed & Al-Tamiemi, 1999).

In Iraq, all ages of date palm are infested by *O. agamemnon arabicus* larvae, but the trees aged over 30 years scored the highest level of infestation in comparison with middle age and young trees in all experimental date palm orchards in different provinces. However, infestation level varied among provinces as Wasit (Al-Nuaamniyah) (Figure 7) had the highest infestation level leading to breakdown of trunks especially during wind storms (Khalaf et al., 2013a,b; 2014a,b). In situations where *O. agamemnon arabicus* is clearly involved, it can infest most parts of the tree. In the young date palm it infests aerial roots at the base of the trunk due to the presence of frond bases that are close to the soil surface, leading to yellowing and drying of the crown (Khalaf et al., 2014a,b). However, this type of infestation does not occur in the middle aged and old trees. The lower part of the trunk (about 1 meter above the soil surface) is infested in palms of all ages. The insect infests the middle of the trunk in the middle-age and old palms (Khalaf et al., 2013a,b; 2014a,b). No infestation has been recorded in the upper part of the stem close to the crown region in the case of young trees, but severe infestation was recorded here on middle aged and old date palm trees. The upper crown, stalk, and frond have not been infested by this species on palms of all ages. The parts of the date palm that are attacked, in relation to the age of the palm, are summarized in Table 1.

Table 1. Parts of the date palm infested by *Oryctes agamemnon arabicus* in Iraq

Date palm tree part	Young trees (4-10 years)	Middle age trees (10-20 years)	Old trees (over 30 years)
Stem base close to the root i.e. aerial roots at base of trunk	+	-	-
Lower stem or trunk, about 1 m above	+	+	+

soil			
Middle of the stem (Trunk)	-	+	+
Upper stem ( when the old fronds are present)	-	+	+
Lower crown	-	+	+
Upper crown	-	-	-
Fronds	-	-	-
Stalks (frond bases i.e. petioles)	-	-	-

(-) No infestation, (+) Infestation

In Tunisia, outbreaks of *O. agamemnon arabicus* develop inside plantations from those that are newly planted up to about 35 years old, with regular spacing between trees of  $9 \times 9$  m. This pest does not occur in plantations cultivated in the traditional system where palms are irregularly spaced and intercropped with other crops (Soltani, 2009). The feeding activity of larvae causes damage to offshoots, and to aerial roots and dry petioles of young palms beyond the offshoot stage (Soltani, 2009; 2010).

In offshoots eggs are laid in the mass of fibers in the axils of fronds, and here young larvae feed unnoticed until the third instar larvae bore into the heart. Most often, the attacked palms are killed in the first year after planting, and losses can reach up to 100% (Figure 13).



Figure 13. Damage caused to offshoot by a third instar *Oryctes agamemnon arabicus* larva (left), and offshoot death after larval attack (right) (Photo: Rasmi Soltani)

In palms that are past the offshoot stage, adults bore holes into the aerial root mass to oviposit, where damage is mostly due to the subsequent tunnelling by feeding larvae which produces cavities. These cavities provide access to subsequent generations of adults for entry and oviposition. Groups of adults, mainly ovipositing females, can coexist in these cavities, along with larvae, and the continuous feeding and tunneling activity by larvae (Figure 14) can lead to collapse of the palm after a few years (Figure 15) (Soltani, 2009).



Figure 14. Aerial roots attacked (left) and damage due to *Oryctes agamemnon arabicus* larvae (right) (Photo: Rasmi Soltani)

When eggs are laid in the mass of fiber in frond petioles, the early larval stages feed here, and the third instar larvae tunnel into the dry petioles, feeding on the soft wood and pupate at the end of the tunnels (Figure 16). Any attack to the trunk itself is less important as only external dead wood is affected (Soltani et al., 2008b; Soltani, 2009) (Figure 17).



Figure 15. Date palm highly liable to collapse following severe attack by *Oryctes agamemnon arabicus* larvae at the collar region (Photo: Rasmi Soltani)





Figure 16. Damage due to *Oryctes agamemnon arabicus* larvae and adults on dry petioles  
(Photo: Rasmi Soltani)



Figure 17. Attack by larvae of *Oryctes agamemnon arabicus* on fiber masses in axils and on bark of the trunk (Photo: Rasmi Soltani)

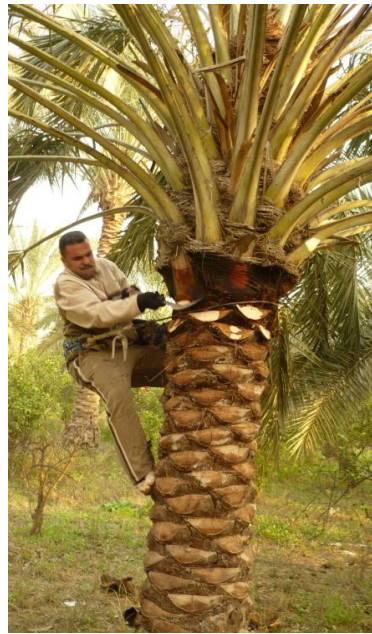
## 6. MANAGEMENT

### 6.1. Physical Control

This approach is very important in all date growing regions. Old and almost dried frond bases are pruned and removed from the palm trunk in an annual servicing by cutting them at a downward sloping 45 degree angle, the cut ends allowing the



farmer to climb the tree. Layers of fiber between fronds, frond thorns, and old dried bunch stalks are also removed (Figures 18, 19, 20). This eliminates sites for beetles to hide and oviposit, and for larvae to develop, and allows hand picking of any larvae found (Figures 21, 22). The number of larvae found later on serviced i.e. pruned palms was significantly less than the number present on unpruned control palms (Khalaf & Al-Abid, 2013). Pruning also reduces humidity around the trunk and frond bases so discouraging oviposition. Disinfecting any wounds on trees with approved pesticides may deter adults (Mohammadpour, 2002). Plantation sanitation is recommended to remove potential breeding sites such as dead palms or rotting trunks along with clippings and fronds after pruning, and to try to reduce excess humidity due to irrigation in palm groves (Gharib, 1970).



*Figure 18. A climbing harness being used in annual servicing of a middle-age date palm  
(Photo: Mohammed Z. Khalaf)*



*Figure 19. Young date palm showing a stage in annual servicing (Photo: Mohammed Z. Khalaf)*



*Figure 20. Previously pruned trunk showing frond bases cut off at the recommended 45 degree angle (Photo: Mohammed Z. Khalaf)*



*Figure 21. Larvae of Oryctes agagemnon detected in their tunnels in frond bases during important annual servicing in Iraq. Top right picture shows black tunnels (Photo: Mohammed Z. Khalaf)*



*Figure 22. Oryctes spp. larvae collected during annual servicing of date palms in Iraq (Photo: Mohammed Z. Khalaf)*

## 6.2. Trapping and Monitoring

### 6.2.1. Light Trapping

This has been used for monitoring the *O. elegans* and *O. agamemnon* populations in Iran (Fasihi, 2011), *O. agamemnon arabicus* in Iraq (Khalaf et al., 2010; 2011; 2012), UAE (Al-Deeb et al., 2012a) and Oman (Al-Sayed & Al-Tamiemi, 1999), *O. elegans* in Saudi Arabia (Al-Deghairi, 2007), and *O. rhinoceros* in Yemen (Al-Habshi et al., 2006). Where electricity supply is not available light traps with solar panels can be used (Figure 23). In UAE and Saudi Arabia, light traps emitting white light from a mercury vapour bulb may be used for mass trapping (Al-Deghairi, 2007; Al-Deeb et al., 2012a).



Figure 23. Solar light trap (Magna Trap with lamp of 320-420 nm wavelength, Russell IPM Limited, UK) used for monitoring and controlling *Oryctes* spp. in date palm orchards in Iraq (Photo: Mohammed Z. Khalaf)

In Iraq, the light traps, in conjunction with hand removal of larvae, have proven very efficient as a control method against *Oryctes* attacks, reducing beetle numbers by 90% (Khalaf et al., 2011). In fields where hand picking of immature stages from old frond bases is neglected, the subsequent catch of adults by light traps was found to be high.

Moonlight affected the light trap catches of adult beetles. During the nights of bright moon light, adult captures (considered to be *O. agamemnon arabicus*) decreased compared to nights with less moon light (Khalaf et al., 2011). A similar trend was also suggested by the data collected using coconut wood traps (i.e. non-light traps) for monitoring *O. rhinoceros* in New Britain (Bedford, 1975).

### 6.2.2. Pheromone Trapping

In Iran, monitoring of population fluctuations of *O. elegans* was conducted for 25 weeks in the Saravan Region between April and September, 2002. Ten traps baited with a piece of date palm core and the male aggregation pheromone 4-

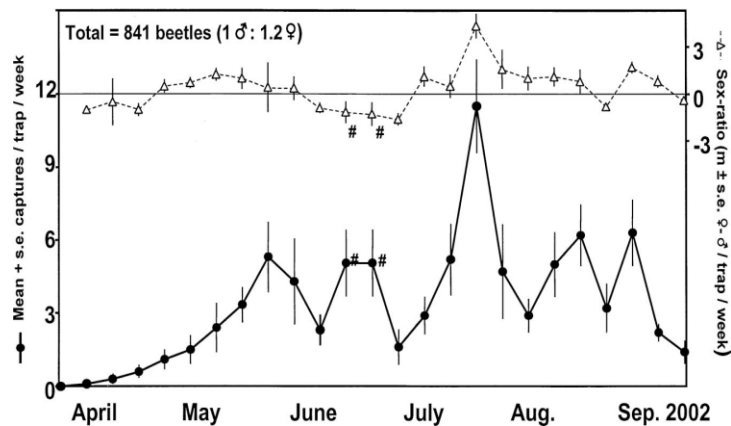


methyloctanoic acid were placed about 5 m above the ground on trunks of date palms in groves. The traps consisted of 24 litre plastic buckets with lids perforated by eight radial 8 x 5 cm openings (Figure 24).

Weekly captures of *O. elegans* between April and September increased gradually from mid-April until the beginning of June ( $5.3 \pm 1.4$  beetles per trap), reaching a peak in mid-July to early August ( $11.5 \pm 1.9$  beetles per trap), then the catch fell (Figure 25).



Figure 24. Plastic bucket pheromone trap for trapping *Oryctes elegans* (Photo: Kazem Mohammadpour)



Considering the mean captures per trap calculated on monthly basis, the population reached a maximum in summer (mid-July to mid-August:  $5.9 \pm 0.8$  beetles). Both sexes seemed to be emerged simultaneously in spring and were reported until the temperature dropped in late autumn. The sex ratio of catches fluctuated through the trial, being approximately balanced in spring and then showing an excess of females through summer, especially in August. The female excess recorded in summer may reflect a shorter life span of the males or a greater mobility of females (Rochat et al., 2004). Furthermore, a trial with traps using 4-methyloctanoic acid and the odor from fresh date palm tissue as synergist in Saravan caught more than 4000 *O. elegans* over the two trapping seasons during which the synthetic pheromone was evaluated. The captures averaged 6.3 beetles/trap/week. (Rochat et al., 2004).

Monitoring by traps could be integrated with insecticide application at the time of leaf-pruning around fruit bunches, and could reduce the beetle population and hence the need for insecticide use.

Experiments on the possibility of co-mass trapping of red palm weevil, *R. ferrugineus* and *O. elegans*, using pheromone traps, were carried out in infested date palm groves of the Saravan Region in the Sistan and Baluchistan Province of Iran during 2004-2005. Results showed that the traps baited with separate dispensers of aggregation pheromones of the two insects, when compared with traps that were baited with pheromone mix (50:50) in one dispenser, attracted significantly more *O. elegans*. But all forms of the baits were equally attractive for *R. ferrugineus*. Also in this trial there was no significant difference in the number of *O. elegans* caught by traps placed at different heights i.e. at ground level, or 1.5 or 4 m above, but the traps placed on the ground attracted significantly more *R. ferrugineus* weevils in comparison with traps placed about 1.5 and 4 m above ground. So placement of traps on the ground is convenient for catching both species (Mohammadpour & Avand-Faghieh, 2008), though placing traps at a higher level (4 m) gave a higher catch for *O. elegans* if this is the main target (Rochat et al., 2004). A similar benefit i.e. improved catch by elevating the trap, has been noted in the pheromone trapping of *O. rhinoceros* in young oil palm plantations (Bedford, 2014). The effect of date palm core tissue ageing on the catch of *O. elegans* and *R. ferrugineus* was similar. Captures in traps where replacement of date palm core tissue was done every week, were significantly greater than in traps where replacement of date palm core was done every 2-3 weeks. So increasing age of the date palm core decreased captures in traps. These results indicated that pheromone traps with separate dispensers of pheromone of *R. ferrugineus* and *O. elegans*, and placed on the ground can be used for co-mass trapping of these beetles (Mohammadpour & Avand-Faghieh, 2008). Pheromone traps may also be used against *O. elegans* in Iraq.

To date, neither *O. agamemnon matthiesseni* in Iran nor *O. agamemnon arabicus* in Iraq were reported to be attracted to traps using the *O. elegans* pheromone (Mohammed Z. Khalaf & Kazem Mohammadpour - unpublished).

### 6.3. Host Plant Resistance

Different varieties of date palm have varying susceptibility to *Oryctes* attack. In Iran, *O. elegans* damage is more prominent in young date palms (10-20 years) and on short varieties (Mozafati) than in old plantations and tall varieties (Halili, Krout and Mordarsang) (Gharib,1970). No other plant species are reported as hosts (Mohammadpour, 2002).

In Iraq the date varieties Brem and Ustaomran (Umrani) were the most susceptible to attack and infestation by *O. agamemnon arabicus*, and 10 and 9 larvae per tree, respectively, were found in the parts exposed during the annual frond pruning of palms (Khalaf et al., 2011; 2014b). Date palm varieties show much difference in their morphological characters e.g. length and orientation of leaves, type of growth and shape of frond etc. In Iraq, a study on the characteristics of the dried base of fronds for different commercial date palm varieties in relation to borer infestation showed that varieties having fragile textured fronds are preferred by *Oryctes* compared to the varieties with solid and hard textured fronds (Khalaf et al., 2010).

#### 6.4. Quarantine Measures

Females of *Oryctes* spp. are attracted to the odors of animal manure or organic compost for oviposition. In the UAE organic fertilizer in bags or loose piles on the farm can serve as good breeding sites. They were found to chew holes in the fertilizer bags to enter and lay eggs. Therefore, proper storage and handling of the organic fertilizer on the date palm farm is very important to reduce infestation. In addition, importing organic fertilizer from countries infested with *Oryctes* beetles can serve as a new source of infestation. Thus, it is not recommended to bring in organic fertilizers from infested farms or countries. In this regard, internal and national quarantine procedures are a legislative method to prevent the spread of *Oryctes* infestation by helping in examination, detention, treatment or disposal of infested organic fertilizers.

In Tunisia, after defining infested areas, quarantine protocols were applied by plant protection services and law enforcement authorities at checkpoints to prevent the spread of infested offshoots (Soltani, 2010).

#### 6.5. Biological Control

##### 6.5.1. Entomopathogenic fungus

In Iran, laboratory studies using *Metarhizium anisopliae* (Metschnikoff) Sorokin showed that it killed *O. elegans* adults 6-11 days post-infection (LT50 values), additionally, the adults fed less and females laid fewer eggs compared to untreated insects (Latifian & Rad, 2012). It is the second most frequently found entomopathogenic fungus in Iraq, occurring in 18% of soil samples collected from date and date/citrus orchard sites (Khudhair et al., 2014a), and it infects *Oryctes* under laboratory conditions (Figure 26).





Figure 26. Adult of *Oryctes* infected by *Metarhizium anisopliae* fungus under laboratory conditions (Photo: Mohammed Z. Khalaf)

Spraying of spore suspensions against larvae, or light traps allowing auto-infection then release of the contaminated adults, may have potential for incorporating the fungus in future IPM (Integrated Pest Management) programs against *Oryctes* spp. in the date palm environment.

#### 6.5.2. Nematodes

In the UAE infective juveniles of the entomopathogenic nematode *Steinernema riobrave* Cabanillas at various concentrations caused 44-100% mortality in third instar larvae of *O. agamemnon* under laboratory conditions, and 33-78% mortality when applied to soil of a fig orchard (Abbas & Mahmoud, 2009). *Rhabditis* sp. has been isolated in Southern Iraq from *Oryctes* larvae which had developed an abnormal brown color. It is being propagated and investigated for its possible potential in pest control (Mohammed Z. Khalaf - unpublished). *Rhabditis* spp. and *Heterorhabditis* spp. Poinar in Iran (Kazem Mohammadpour - unpublished) are potential candidates as biological control agents, however, there is no data on their natural incidence in the field.

#### 6.5.3. *Oryctes Nudivirus*

This non-endemic virus was introduced into Oman and significantly lowered the damage caused by *O. rhinoceros* to fronds of coconut palms (Kinawy, 2004; Bedford, 2013). It is not known if *O. elegans* or *O. agamemnon* are susceptible to this pathogen, but its introduction into Oman means it is now present in the Arabian Peninsula, and free to disseminate.

#### 6.5.4. Mites

In the UAE, *O. elegans* adults often carry a large load of the phoretic mites *Sancassania* sp. and *Hypoaspis rhinocerotis* Oudemans on the body and under the elytra (Figure 27) (Al-Deeb & Enan, 2010; Al-Deeb et al., 2012b) but it is not established if they have a harmful effect on the pest, or are only phoretic.

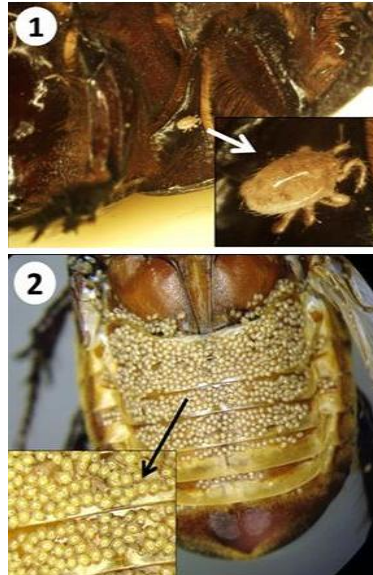


Figure 27. Mites on *Oryctes agamemnon* adult in UAE; 1: *Hypoaspis* sp. Adult, 2: *Sancassania* sp. deutonymphs on abdominal tergites (Photo: Mohammad A. Al-Deeb)

The same is true for *Hypoaspis* sp. in Iraq (Figure 28, 29).



Figure 28. *Hypoaspis* sp. mite (Photo: Mohammed Z. Khalaf)



Figure 29. Hypoaspis mites on adult *Oryctes* (to left of base of front legs) (Photo: Mohammed Z. Khalaf)

#### 6.5.5. Vertebrates

In Iran a species of squirrel, *Funambulus palmarum* L. inhabits the palm groves of Baluchistan Region (its local name is Herdak) and feeds on larvae of *O. elegans*. The average body length is 142 mm, general color of the body is gray with three strips of bright yellow color on the back while the abdomen is yellowish white (Gharib, 1970). However, its effect on the population of the pest is unknown.

#### 6.6. Chemical Control

In Iran, as the adult beetles were usually active in the inflorescence of palm trees, chemical control of this pest was difficult and expensive. In areas where control measures consisted of insecticides against the lesser date moth, *Batrachedra amydraula* Meyrick and the dubas bug, *Ommatissus lybicus* De Bergevin Ashe & Wilson, adult beetles of *O. elegans* that were active and flying in this season, may also be eliminated. Placing a bran bait with insecticide in the crowns was recommended in the past (Gharib, 1970). In Tunisia, again, chemical control was difficult due to the concealed behavior of the pest, the cost and high quantities of pesticide that would be needed, and the risk of pollution. However, treatment by dipping of offshoots in insecticide solution for 5 minutes is recommended to kill larvae, prior to the transfer of the offshoots to new areas (Soltani, 2010). In Iraq, a trial comparing three insecticides and a control showed spraying was not effective against *Oryctes* larvae in their concealed habitat (ICARDA, 2011). In the UAE, chemical control was not recommended as a major control method however, the use of chemical control can be applicable in certain situations: (1) soil insecticides can be used on infested farms where light traps are not available, (2) animal manure or organic compost could be treated with soil insecticides as a pre- or post-application treatment, and (3) insecticides can be applied to treat the root systems of infested trees.

### 6.7. Integrated Pest Management

Combining hand picking of larvae and light trapping of adults in orchards south of Baghdad (Iraq) from 2009 till 2012 compared to control orchards (without integrated control) reduced adult numbers caught in the location by about 90% and increased yield by about 28 and 31% in 2011 and 2012, respectively (Table 2) (Khalaf & Al-Abid, 2013; Khalaf et al., 2011; 2013a,b; 2014a,b).

Table 2. Effect of IPM program against *Oryctes* on yield of date palms

Treatment	No. of bunches per tree		Yield (kg per tree) (from Barhee variety)	
	2011	2012	2011	2012
Control (no hand collection of larvae)	10.91	10.7	104.00	106.00
Almost complete control, with hand collection of larvae and light traps	11.27	11.1	133.36	139.00
Yield/bunch increase (quantity)	0.36	0.40	29.36	33.00
% Yield increase	3.3	3.74	28.20	31.13

### 6.8. Comparison of *Oryctes* spp. on date palms with *Oryctes rhinoceros* on coconut and oil palms

It is of interest to compare the biology and damage caused by the two species of *Oryctes* on date palms, with that caused by the well-known pest *O. rhinoceros* on coconut (*Cocos nucifera* L.) and oil palms (*Elaeis guineensis* Jacquin). Adults of *O. elegans* bore into fruit bunch stalks of the date palm to feed, while *O. agamemnon* adults apparently feed little if at all. On coconut or oil palms *O. rhinoceros* adults crawl down frond axils to bore into the heart or meristem feeding on sap as they go. This tunnelling damages the still immature fronds which as a result display V-shaped cuts when they unfurl (Figure 30).



Figure 30. Coconut palm in Fiji showing damaged V-cut fronds resulting from *Oryctes rhinoceros* adults boring into the immature fronds (Bedford, 2013; with permission from *Annual Review of Entomology* Volume 58 © 2013 by Annual Reviews)

Such attacks by adult *O. rhinoceros* if continued and repeated, kill the growing point and the coconut palm dies (Figure 31).



Figure 31. Coconut palms killed and reduced to poles due to repeated heavy attacks by *Oryctes rhinoceros* at Drauniivi, Fiji. Breeding is now taking place in the tops (Bedford, 2013; with permission from *Annual Review of Entomology* Volume 58 © 2013 by Annual Reviews)

Coconut palms of all ages may be attacked and killed, while young oil palms in particular may be thus killed while older oil palms seem less affected. This type of damage is not reported in the case of date palms attacked by *Oryctes* spp. However, *O. rhinoceros* boring into young oil palms can cause the rachis of fronds

adults to break and the upper section of the frond to hang down, as has been noted with *Oryctes* spp. damage in date palms.

In date palms *Oryctes* spp. oviposit in leaf axils, or debris or fiber therein, and from here the larvae may penetrate into the leaf bases and trunk. Oviposition also occurs in the masses of respiratory roots at the base of the trunk. These attacks occur in the living date palm.

*Oryctes rhinoceros* only oviposits, and the larvae only develop in, dead wood e.g. the tops of dead standing coconut poles (often those killed by attacks by the adults) (Figure 31), decaying coconut logs and stumps, shredded pulverised oil palm trunk material, and a variety of other breeding sites of various types of decaying organic matter (Bedford, 2013). But it has been reported as breeding in debris in coconut palm leaf axils in Guam (University of Guam, 2010 [http://www.biologynews.net/archives/2010/06/21/unusual\\_rhino\\_beetle\\_behavior\\_discovered.html](http://www.biologynews.net/archives/2010/06/21/unusual_rhino_beetle_behavior_discovered.html)), perhaps similar to *O. elegans*.

Adults of subspecies of *Scapanes australis* Sternberg in Melanesia attack only young low coconut and oil palms, but in a manner similar to *O. rhinoceros*. Its breeding sites are at soil level under decaying bush logs or in decaying tree roots. Larvae are not found in living coconut or oil palms (Bedford, 1980; 2013).

## 7. FUTURE RESEARCH

A full description of the larvae of *O. elegans* and *O. agamemnon* and its subspecies, with a key to identify them, would be very useful so they can be reliably distinguished in locations where both species coexist.

The virus *Oryctes* Nudivirus (OrNV) has been successful in lowering populations and damage by *O. rhinoceros* to coconut palms in a number of countries where this virus did not exist prior to its introduction (summarised in Bedford, 1980; 2013). It kills larvae and adults, and infected adults act as vectors spreading it before they succumb. It would be of interest to test whether larvae or adults of *O. elegans* and *O. agamemnon* are susceptible to this virus. If found susceptible, prior to any release it would be important to observe samples of larvae and adults taken from the field to see if any other endemic viruses already exist in their natural habitat. As regards the Arabian Peninsula, it would be important to note that this virus has now been introduced and established in Oman (Kinawy, 2004) to lower damage by *O. rhinoceros* on coconut palms, and from here it is free to self-disseminate elsewhere, and would be available for introduction into locations where this species is attacking date palms.

The fungus *M. anisopliae* is ubiquitous so it would be important to observe samples of field-collected date dynastid larvae and adults for its presence to obtain data on its natural incidence in an area, prior to wide scale release against date palm dynastids. This would provide a base line from which the effect of releases may be assessed. Possibly light traps may be adapted to auto-infect adults with the fungus then release them to disseminate it. A pheromone trap has been developed for *O. rhinoceros* for trial use in oil palm plantations (Ramle et al., 2011). Perhaps pheromone traps for *O. elegans*, or light traps for *O. elegans* and *O. agamemnon*,

could be adapted for capture, infection of adults with *M. anisopliae*, then their release to disseminate the entomopathogen.

As the components of the male aggregation pheromone of *O. agamemnon arabicus* have now been identified (Saïd et al., 2015) as primarily a mix of 2 already known *Oryctes* spp. semiochemicals, ethyl 4-methyloctanoate and 4-methyloctanoic acid, can this discovery be developed for trapping and future use in an IPM programme (Vuts et al., 2014)? For *O. elegans*, the odor or volatiles from fresh date palm tissue, usually from shoots, is synergistic with the pheromone 4-methyloctanoic acid in traps, but as offshoots are sold for propagation, a cheap substitute for date palm offshoots is needed. So extraction and identification of date palm volatiles is needed, which might perhaps then be synthesized for adding to the pheromone so trapping can be more fully developed, enhanced and utilised. In locations where *O. rhinoceros* attacks date palms, use of the commercially available male aggregation pheromone ethyl 4-methyloctanoate for trapping may be applicable (Bedford, 2013).

Are there volatiles common to date, coconut and oil palms which attract *Oryctes* species e.g. *O. elegans* and *O. rhinoceros* to feed, or to oviposit in the case of *O. agamemnon*, and thus these *Oryctes* species are attracted to palms and not to other plants? Is it a similar question to that which applies to *O. rhinoceros* - do date palm volatiles attract date palm *Oryctes* spp. pests, and then the release of the male produced aggregation pheromone promotes intraspecific competition thence mating, and possibly subsequent oviposition?

While males of *O. elegans* confined in traps, or 4-methyloctanoic acid lures in traps, attract both sexes to traps (Rochat et al., 2004), there is lacking information or observations on where or when during their adult life span, males in the wild emit the pheromone, or both sexes respond (Vuts et al., 2014). Does this occur, with subsequent mating, in feeding sites, or breeding sites, or both? This question also applies to *O. agamemnon arabicus* where more than one key pheromone molecules are produced (Saïd et al., 2015).

A prior assessment of the natural incidence of entomopathogenic nematodes in an area would be advisable if their propagation and widespread release is envisaged.

## 8. SUMMARY

Adults of *O. elegans* cause damage to date palms by boring into the stalks of inflorescences, fruit bunches and frond bases. Their larvae bore into frond bases and trunks. Larvae of subspecies of *O. agamemnon* bore into frond bases thence trunks and into aerial root masses and may thus cause the palm to fall subsequently. Physical control measures such as pruning off old frond bases removes oviposition sites and hence ensuing damage by larvae.

Light trapping enables monitoring of both species and may be used as a component of IPM. Pheromone trapping is also an important tool available in IPM for control of *O. elegans*. Various entomopathogens and other biological control agents may well be investigated as potential or possible components in IPM against these date palm pests.



The damage caused by adults of *O. rhinoceros* which bore into the heart of coconut and oil palms causing the emergence of typical V-cut fronds, and the death of the palm if repeated attacks destroy the meristem, does not seem to occur with the two species of *Oryctes* attacking date palms. *Oryctes rhinoceros* only breeds in dead decomposing woody or organic material whereas immature stages of date palm dynastids may tunnel into living date palm tissue.

#### REFERENCES

- Abbas, M.S.T., & Mahmoud, B. (2009). On the pathogenicity of the entomopathogenic nematode, *Steinernema riobravis* on some economic insect pests. *Egyptian Journal of Biological Pest Control*, 19(1), 49-53.
- Abdallah, Z., Mezghani-Khemkhem, M., Bouktila, D., Makni, H., & Makni, M. (2013). Genetic variation and invasion pattern of the Arabian rhinoceros beetle, *Oryctes agamemnon arabicus* (Burmeister) (Coleoptera: Scarabaeidae), in Tunisia, deduced from mitochondrial DNA sequences. *African Entomology*, 21(2), 362-367.
- Abdallah, Z., Mezghani-Khemkhem, M., Bouktila, D., Makni, H., & Makni, M. (2012). Genetic diversity of an invasive pest (*Oryctes agamemnon* Burmeister, Coleoptera: Scarabaeidae) of date palm in Tunisia, inferred from random amplified polymorphic DNA (RAPD) markers. *African Journal of Agricultural Research*, 7, 1170-1176.
- Al-Ayedh, H.Y., & Al Dhafer, H.M. (2015). Does *Oryctes elegans* (Coleoptera: Scarabaeidae) abundance determine future abundance of *Rhynchophorus ferrugineus* (Coleoptera: Rhynchophoridae) in the date palms of Saudi Arabia? *African Entomology*, 23, 43-47.
- Al-Deeb, M.A., Muzaffar, S., & Sharif, E.M. (2012b). Interactions between phoretic mites and the Arabian rhinoceros beetle, *Oryctes agamemnon arabicus*. *Journal of Insect Science*, 12, 128. DOI: 10.1673/031.012.12801.
- Al-Deeb, M.A. (2012). Date palm insect and mite pests and their management. In: Manickavasagan, A., Mohamed Essa, M., & Sukumar, E. (editors), Dates Production, Processing, Food, and Medicinal Values. Taylor and Francis Group, USA. 113-128 pp.
- Al-Deeb, M.A., & Enan, M.R. (2010). First record of a phoretic astigmatid mite *Sancassania* sp. (Acaridae: Astigmata) on *Oryctes agamemnon* (Coleoptera: Scarabaeidae) in UAE. *International Journal of Agriculture and Biology*, 12, 157-160.
- Al-Deeb, M.A., Mahmoud, S.T., & Sharif, E.M. (2012a). Use of light traps and differing light colour to investigate seasonal abundance of the date palm pest, *Oryctes agamemnon arabicus* (Coleoptera: Scarabaeidae). *Journal of Economic Entomology*, 105, 2062-2067.
- Al-Deghairi, M. (2007). Seasonal fluctuation of the date palm fruit stalk borer, *Oryctes elegans* Prell (Coleoptera: Scarabaeidae), in date palm plantations in Al-Qassim region, Saudi Arabia. *Agricultural and Marine Sciences*, 12, 67-70.
- Al-Habshi, K.A., Ba-Angood, S.A., & Al-Baiti, S.O. (2006). The occurrence of the date palm borer *Oryctes rhinoceros* (Linnaeus) in light traps in Wadi Hadramout in 2002. *University of Aden Journal of Natural and Applied Sciences*, 10(3), 419-426.
- Al-Sayed, A.E., & Al-Tamiemi, S.S. (1999). Seasonal activity of the fruit-stalk borer, *Oryctes agamemnon* (Burm.) (Coleoptera Scarabaeidae) in Sultanate of Oman. *Egyptian Journal of Agricultural Research*, 77, 1597-1605.
- Bedford, G.O. (1974). Descriptions of the larvae of some rhinoceros beetles (Col.: Scarabaeidae, Dynastinae) associated with coconut palms in New Guinea. *Bulletin of Entomological Research*, 63(3), 445-472.
- Bedford, G.O. (1975). Trap catches of the coconut rhinoceros beetle *Oryctes rhinoceros* (L.) (Coleoptera, Scarabaeidae, Dynastinae) in New Britain. *Bulletin of Entomological Research*, 65(3), 443-451.
- Bedford, G.O. (1980). Biology, ecology and control of palm rhinoceros beetles. *Annual Review of Entomology*, 25, 309-339.
- Bedford, G.O. (2013). Biology and management of palm dynastid beetles: Recent advances. *Annual Review of Entomology*, 58, 353-372.

- Bedford, G.O. (2014). Advances in the control of rhinoceros beetle, *Oryctes rhinoceros* in oil palm. *Journal of Oil Palm Research*, 26(3), 183-194.
- Butani, D.K. (1974). Les insectes parasites du palmier-dattier en Inde et leur controle. *Fruits*, 29, 689-691.
- Butani, D.K. (1975). Insect pests of fruit crops and their control - 15. Date Palm. *Pesticides*, 9, 40-42.
- Buxton, P.A. (1920). Insect pests of dates and the date palm in Mesopotamia and elsewhere. *Bulletin of Entomological Research*, 11, 287-303.
- Dechambre, R.-P., & Lachaume, G. (2001). Les Coléoptères du monde (Beetles of the world) - Dynastidae - Volume 27, *Oryctes*. Hillside Books, Canterbury, UK. 72 p.
- El-Haidari, H.S., & Al-Hafidh, E.M. (1986). Palm and date arthropod pests in the Near East and North Africa. Regional Project for Palm and Dates Research Center in the Near East and North Africa, Food and Agriculture Organization, Al-Watan Press, Baghdad, Iraq. 126 p.
- El-Shafie, H.A.F. (2012). Review: list of arthropod pests and their natural enemies identified worldwide on date palm, *Phoenix dactylifera* L. *Agriculture and Biology Journal of North America*, 3(12), 516-524.
- Endrödi S. (1985). The Dynastinae of the World. *Series Entomologica* 28, Junk, The Hague, The Netherlands. 800 p.
- Endrödi, S., & Petrovitz, R. (1974). Die Arten und Rassen der Gattung *Oryctes* Illiger in Iran. *Applied Entomology and Phytopathology*, 36, 4-19.
- Fasihi, M.T. (2011). A study on the population dynamism of sympatric species of *Oryctes agamemnon* and *O. elegans*. Annual report of project. Agricultural and Natural Resources Center. Bushehr, Iran. 11 p.
- Gassouma, M.S.S. (1991). Agricultural pests in the United Arab Emirates. Part 1. Fruit trees (In Arabic). Ministry of Agriculture and Fisheries, UAE. 148 p.
- Gharib, A. (1970). *Oryctes elegans* Prell. (Coleoptera-Dynastidae). *Applied Entomology and Phytopathology*, 29: 20-29. (Summary in *Review of Applied Entomology. A* (1971), 59, 879-880).
- Gressitt, J.L. (1953). The coconut rhinoceros beetle (*Oryctes rhinoceros*) with particular reference to the Palau Islands. *Bulletin of the Bernice P Bishop Museum No.*, 212, 157.
- Hurpin, B. (1970). Essais sur l'alimentation des larves d' *Oryctes* aux dépens de végétaux vivants. *Oleagineux*, 25, 657-660.
- Hurpin, B., & Fresneau, M. (1969). Contribution a l'étude de *Oryctes elegans* (Col. Dynastidae). *Annales de la Societe Entomologique de France (N.S.)*, 5(1), 595-612.
- Hussain, A.A. (1963). Notes on borers of date palms in Iraq. *Bulletin of Entomological Research*, 54, 345-348.
- ICARDA. (2011). Integrated control for stem borers of date palm in Iraq. In: Improved livelihoods of small farmers in Iraq through integrated pest management and organic fertilization. 4 p. Available at: [https://apps.icarda.org/wsInternet/wsInternet.aspx/DownloadFileToLocal?filePath=Research\\_publications\\_archive/Plant\\_protection\\_IPM/Stem\\_Borers.pdf&fileName=Stem\\_Borers.pdf](https://apps.icarda.org/wsInternet/wsInternet.aspx/DownloadFileToLocal?filePath=Research_publications_archive/Plant_protection_IPM/Stem_Borers.pdf&fileName=Stem_Borers.pdf); accessed on; April 17, 2015.
- Khalaf, M.Z., & Al-Abid, M. (2013). Photographical manual for annual regular practices for date palm trees and its efficiency on palm borers. Ministry of Science and Technology, Baghdad, Iraq. 23 p.
- Khalaf, M.Z., & Al-Taweel, A.A. (2014a). Palm borers in Iraqi environment: Species - Damages - Methods of Control. Manual - Agricultural Research Directorate, Ministry of Science and Technology, Republic of Iraq. 31 p.
- Khalaf, M.Z., Al-Derawie, M.M., Naher, F.H., Al-Rubeae, H.F., & Al-Zaidi, S. (2013a). Palm borers in the Iraqi environment. In: Abstract Book of 6<sup>th</sup> National Conference of Environment and Natural Resources, University of Basrah, Iraq. 26 p.
- Khalaf, M.Z., Alrubeae, H.F., Al-Taweel, A.A., & Naher, F.H. (2013b). First record of Arabian rhinoceros beetle, *Oryctes agamemnon arabicus* Fairmaire on date palm trees in Iraq. *Agriculture and Biology Journal of North America*, 4(3), 349-351.
- Khalaf, M.Z., Naher, F., Khudair, M.W., Hamood, J.B., & Khalaf, H.S. (2014b). Some biological and behavioural aspects of Arabian rhinoceros beetle, *Oryctes agamemnon arabicus* Fairmaire (Coleoptera: Scarabaeidae: Dynastinae) under Iraqi conditions. *Iraqi Journal of Agricultural Research (Special Issue)*, 19(2), 122-133.

- Khalaf, M.Z., Naher, F.H., & Abdul-Sattar A.A. (2010). Population density of *Oryctes elegans* Prell (Coleoptera: Scarabaeidae) on some date palm varieties in South Baghdad orchards. *Agriculture and Biology Journal of North America*, 1(3), 238-242.
- Khalaf, M.Z., Shbar, A.K., Al-Seria, M.H., Sami, R.A., & Naher, F.H. (2011). Some aspects of biology and control methods of Fruit Stalk Borer, *Oryctes elegans* Prell (Coleoptera: Scarabaeidae). *Journal of Agricultural Science and Technology*, A1, 142-147.
- Khalaf, M.Z., Shbar, A.K., Naher, F.H., Jabo, N.F. Abdulhamza, B.H., & Sami, R.A. (2012). Activity of insect fauna during the night in palm orchards of central Iraq. *Journal of Food Science and Engineering*, 2, 277-282.
- Khoualdia, O., Rhouma A., Marro, J.P., & Brun, J. (1997). First observations on the date palm pest *Oryctes agamemnon* in Tunisia. *Fruits*, 52, 111-115.
- Khudhair, M.W., Aboud, H.M., Khalaf, M.Z., & Shbar, A.K. (2014b). *Oryctes elegans*, a vector of *Fusarium proliferatum* causing wilt disease symptoms of date palm. *International Journal of Phytopathology*, 3(2), 67-72.
- Khudhair, M.W., Al Rubeai, H.F., Khalaf, M.Z., Shbar, A.K., Hamad, B.S., & Khalaf, H.S. (2014a). Occurrence and distribution of entomopathogenic fungi in Iraqi agro-ecosystems. *International Journal of Entomological Research*, 2(2), 117-124.
- Kinawy, M.M. (2004). Biological control of the coconut palm rhinoceros beetle (*Oryctes rhinoceros* L. Coleoptera: Scarabaeidae) by using *Rhabdionvirus oryctes* Hüger in Sultanate of Oman. *Egyptian Journal of Biological Pest Control*, 14, 113-118.
- Latifian, M., & Rad, B. (2012). Pathogenicity of the entomopathogenic fungi *Beauveria bassiana* (Balsamo) Vuillmin, *Beauveria brogniartii* Saccardo and *Metarhizium anisopliae* Metsch. to adult *Oryctes elegans* Prell, and effects on feeding and mortality. *International Journal of Agriculture and Crop Sciences*, 4(14), 1026-1032.
- Latifian, M., Rahnama, A.A., & Sharifnezhad, H. (2012). Effects of planting pattern on major date palm pests and diseases injury severity. *International Journal of Agriculture and Crop Sciences*, 4(19), 1443-1451.
- Mohammadpour, K. (2002). Investigation on development of control methods of Date palm fruit stalk borer, *Oryctes elegans* Prell., by semiochemicals. MSc Thesis, Faculty of Agriculture, Ahvaz Shahid Chamran University, Iran. 81 p. (In Persian with English Summary).
- Mohammadpour, K., & Avand-Faghhih, A. (2008). Investigation on the possibility of co-mass trapping of the populations of red palm weevil, *Rhynchophorus ferrugineus* and date palm fruit stalk borer *Oryctes elegans* using pheromone traps. *Applied Entomology and Phytopathology*, 75, 39-53.
- Payandeh, A., & Dehghan, A. (2010). Demography of date palm fruit stalk borer, *Oryctes elegans* (Col.: Scarabaeidae), on date palm under laboratory conditions. *Plant Protection Journal*, 2, 255-263.
- Ragoussis, V., Giannikopoulos, A., Skoka, E., & Grivas, P. (2007). Efficient synthesis of (+/-)-4-methyloctanoic acid, aggregation pheromone of rhinoceros beetles of the genus *Oryctes* (Coleoptera: Dynastidae: Scarabaeidae). *Journal of Agricultural and Food Chemistry*, 55(913), 5050-5052.
- Ramle, M., Norman, K., & Mohd, B.W. (2011). Trap for the auto dissemination of *Metarhizium anisopliae* in the management of rhinoceros beetle *Oryctes rhinoceros*. *Journal of Oil Palm Research*, 23, 1011-1017.
- Ratcliffe, B.C., & Ahmed, Z. (2010). Additions to the distribution of Scarabaeidae (Insecta: Coleoptera) in northern Pakistan. *Pakistan Journal of Zoology*, 42(6), 827-830.
- Ritcher, P.O. (1966). White grubs and their allies. Oregon State University Press, Corvallis, USA. 219 p.
- Rochat, D., Mohammadpour, K., Malosse, C., Avand-Faghhih, A., Lettere, M., Beauhaire, J., Morin, J.P., Pezier, A., Renou, M., & Abdollahi, G.A. (2004). Male aggregation pheromone of date palm fruit stalk borer *Oryctes elegans*. *Journal of Chemical Ecology*, 30, 387-407.
- Säid, I., Hasni, N., Abdallah, Z., Couzi, P., Ouhichi, M., Renou, M., & Rochat, D. (2015). Identification of the aggregation pheromone of the date palm root borer *Oryctes agamemnon*. *Journal of Chemical Ecology*, 41, 446-457.
- Soltani, R. (2004). *Oryctes agamemnon* Burmeister (Coleoptera: Scarabaeidae): Contribution à l'étude de sa biologie et des dégâts occasionnés dans les oasis du Djérid au Sud Ouest Tunisien. Diplôme d'Etudes Approfondies. Ecole Supérieure d'Horticulture et d'Elevage de Chott Marien, Tunisie. 81 p.

- Soltani, R. (2009). *Oryctes agamemnon arabicus* Fairmaire (1896): Etude bioécologique et éthologique dans les oasis de Rjim Maâtoug au sud ouest Tunisien. Thèse de Doctorat, Institut des Sciences Agronomique, Chott Mariem, Tunisia. 181 p.
- Soltani, R. (2010). The rhinoceros beetle *Oryctes agamemnon arabicus* in Tunisia: current challenge and future management perspectives. *Tunisian Journal of Plant Protection*, 5, 179-194.
- Soltani, R. (2012). Laboratory rearing of immature stages of *Oryctes agamemnon arabicus* under three constant temperatures. *Tunisian Journal of Plant Protection*, 7, 35-43.
- Soltani, R., Chaieb, I., & Ben Hamouda, M. (2008a). The life cycle of the root borer, *Oryctes agamemnon*, under laboratory conditions. *Journal of Insect Science*, 8, 61.
- Soltani, R., Ikbel, C., & Ben Hamouda, M. (2008b). Descriptive study of damage caused by the rhinoceros beetle, *Oryctes agamemnon*, and its influence on date palm oases of Rjim Maatoug, Tunisia. *Journal of Insect Science*, 8, 57.
- Sultanov, R.M., Ismagilov, R.R., & Dzhemilev, U.M. (2013). One-step synthesis of racemic 4-methyloctanoic acid, a component of the aggregation pheromone of *Oryctes rhinoceros*. *Chemistry of Natural Compounds*, 48(6), 1122-1123.
- Tabrizian, M., Mohammadpour, K., & Tabak, S.N. (2009). Synthesis and field evaluation of aggregation pheromone of date palm fruit stalk borer *Oryctes elegans*. *Applied Entomology and Phytopathology* (Special Issue), 51-60.
- Vuts, J., Imrei, Z., Birkett, M.A., Pickett, J.A., Woodcock, C.M., & Tóth, M. (2014). Semiochemistry of the Scarabaeoidea. *Journal of Chemical Ecology*, 40, 190-210.