6

Paysandisia archon: Taxonomy, Distribution, Biology, and Life Cycle

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6.1 Introduction

The intensive worldwide trade of plants and goods, along with increasing tourist traffic, has resulted in the quite common accidental introduction of exotic insects throughout Europe (Pellizzari, Dalla Montà, and Vacante 2005). Moreover, owing to the Mediterranean climate, several alien subtropical species have recently become established. The palm borer moth (PBM) *Paysandisia archon* (Burmeister) has become invasive in many European countries, representing a serious threat to palms. One of the main reasons for this situation is the insect’s confinement to the plant in almost all of its life stages, making observation and experimentation difficult, despite its large size. Moreover, information about the PBM, which was never a pest in its native range before settling in the Mediterranean Basin, is scarce, and many aspects of its biology, ecology, and ethology remain undetermined.

The present chapter reviews the current knowledge on the taxonomic position of the Castniidae family, and the current distribution, life cycle, and host range of the PBM. It also focuses on recent studies performed under European Mediterranean conditions.

6.2 Taxonomy of the Castniidae

The family Castniidae is considered to have originated in Gondwana as it is found in Australia (excluding Tasmania), Southeast Asia, and Central South America (Common 1990; Edwards *et al.* 1998). The taxonomic position of the Castniidae within the order Lepidoptera has changed over time. As previously speculated by Mosher (1916) and according to Miller (1986), the Castniidae has some similarities with the families Torticidae and Cossidae. Edwards *et al.* (1998), based on adult characteristics provided by Minet (1991) and Kozlov, Kuznetsov, and Stekolnikov (1998), placed the Castniidae together with the families Sesiidæ and Brachodidæ. Moreover, molecular analysis
showed phylogenetic affinity with the Cossidae as well as the Sesiidae (Regier et al. 2009). Currently, Castniidae has been placed in the superfamily Cossoidea (van Nieukerken et al. 2011).

Traditionally, this family has included the subfamilies Tascininae and Castniinae (Edwards et al. 1998). The Tascininae is a small subfamily with a single genus *Tascina* Westwood, including four described species that occur in Southeast Asia and the Indo-Malayan region (Fukuda 2000). The Castniinae subfamily contains three tribes. The Castniini and Gazerini tribes are found in the Neotropics. The Synemoniini tribe occurs in the Australian region with 24 species described and placed in the genus *Synemon* Doubleday (Miller 1995; Edwards et al. 1998).

The arrangement in tribes was proposed by Westwood (1877) based on some species (Gazerini) that are involved in mimetic complexes with Nymphalidae butterflies; the remaining species were included in Castniini (Strand 1913; Lamas 1995; Miller 1995). However, other species in Castniini may also be involved in mimetic complexes, and the mimetic relationship with butterflies is also a feature in Tascininae and Synemoniini (Moraes and Duarte 2014).

The tribes Castniini and Gazerini make up the most diverse and abundant group of Castniidae. However, taxonomy based exclusively on wing color pattern has generated an exaggerated number of genera and species (Moraes and Duarte 2014). As a consequence, this group has been revisited several times, including quite recently. Miller (1995) listed 134 species of Neotropical Castniidae (Castniini and Gazerini). Lamas (1995) reduced this number to 81 species assigned to 32 genera. More recent revisions have listed 88 species assigned to 31 genera (Pierre and Pierre-Baltu, 2003; Espinoza and González 2005; Miller 2007, 2008; Vinciguerra 2011). Previous authors’ hesitation to merge some genera is probably the result of the striking differences in wing pattern, contrasting with the similarities in other morphological traits (Moraes and Duarte 2014). The Neotropical species are currently included in only one tribe, Castniini, and the number of genera has been reduced from 31 to 16 (Moraes and Duarte 2014).

So far, *Paysandisia*, within the Castniini tribe, has been a monotypic genus, with the only species being *P. archon*. Moraes and Duarte (2014) observed that *Geyeria uruguayana* (Burmeister) has morphological attributes that are not related to the nominative genus, but to *Paysandisia*; therefore, based on the general morphological traits for males and females, they proposed a new combination: *Paysandisia uruguayana* (Burmeister) (*Geyeria*). The same authors believed that further morphological studies would show that the species included in genus *Paysandisia* are more closely related to other *Eupalamides* Hübner, and that the two genera could be synonymized (Moraes and Duarte 2014).

*P. archon* was originally described in 1880 from Argentina as *Castnia archon* by Burmeister, although there is confusion in some publications, where the year is given as 1878 or 1879 (Lepesme 1947; Sarto i Monteys 2002). About 30 years later, it was described as *Castnia josepha* by Oberthür (1914). Houlbert (1918) placed the species *archon* in the now invalid genus *Orthia* Herrich-Schäffer and the species *josepha* in the genus *Paysandisia*. Later, a full 50 years after it was described by Burmeister, Jorgensen (1930) published the first images of the species *C. archon* to the scientific community. Although, in the past, some authors, like Bourquin (1930, 1933) and Breyer (1931), noticed that *C. archon* and *C. josepha* were actually the same species, the taxonomy of the PBM continued to be debated. Indeed, Miller (1986) retained *archon* Burmeister (1880), in the monotypic genus *Paysandisia* Houlbert, 1918, and provided
an accurate description of the genus. Later in the same year, Miller (1995) distinguished the Argentinian subspecies *archon archon* from the Uruguayan subspecies *archon josepha*, based only on their extremely sketchy knowledge of their distribution, while Lamas (1995), in his review of Neotropical Castniidae, considered *josepha* to be merely a synonym.

6.3 Distribution of *P. archon*

*P. archon* is a Neotropical species that is indigenous to South America: northeastern Argentina, Paraguay (Paraguayan Chaco), western Uruguay, and the southernmost state of Brazil, Rio Grande do Sul, all of which are located between the parallels 25° and 35°, just south of the Tropic of Capricorn. Here the moth inhabits extensive open areas where wild palms grow (Sarto i Monteys 2002). Its distribution is mainly scattered in local populations with low abundance levels (Montagud Alario 2004).

Although the moth is not a pest in its native areas, Houlbert (1918) gave a first indication that PBM larvae might cause damage to palm trees. Later, Bourquin (1933) reported severe damage to exotic palms in Paysandú (Uruguay). More recently, mainly in the province of Buenos Aires, where palms are not native, the PBM has become a pest of exotic palms introduced since 1998 for ornamental reasons (Sarto i Monteys and Aguilar 2005) (Fig. 6.1a).

The moth was probably accidentally introduced to Europe between 1992, when the first main import occurred, and 1998, with commodities, mostly *Butia yatay* (Martius) Beccari and *Trithrinax campestris* (Burmeister) Drude and Grisebach, imported from Argentina (Aguilar, Miller, and Sarto i Monteys 2001). The invaded area within Europe grew rapidly from the year 2000, after an initial delay for population establishment (EPPO 2008) (Fig. 6.1b). The presence of the moth was first reported in March 2001, in

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**Figure 6.1** Global distribution of *P. archon*: (a) South America; (b) Europe. Black circles: pest presence; gray circles: pest presence in only a few areas; white circles: pest eradicated; na: pest present but not actionable; ue: pest under eradication; nc: pest presence reported but not confirmed.
Catalonia, in the province of Girona, Spain (Aguilar, Miller, and Sarto i Monteys 2001) and soon after, in July 2001, in the Department of Var near Hyères, France (Drescher and Dufay 2001).

Once established, the moth’s spread followed the commercial routes of palms as well as natural local dispersal of adults. Since 2002, in Spain, the moth has been detected in several localities of the Valencian Community, the province of Castellón, Alicante, and Valencia, and in the Balearic Islands, Mallorca, and Menorca (EPPO RS 2003/157; 2004/049; Montagud Alario and Rodrigo Coll 2004). It is now present all along the Spanish Mediterranean coast from Girona to Alicante, and a few outbreaks have been reported from Madrid (EPPO RS 2010/058). In France, since 2002, it has also spread to the departments of Alpes-Maritimes, Aude, Bouches-du-Rhône, Gard, Gironde, Hérault, Pyrénées-Orientales, and Vaucluse (Drescher and Jaubert 2003; EPPO 2008; André and Tixier Malicorne 2013).

In November 2002, the moth was reported for the first time in Italy along the Salerno seafront (Campania) (Espinosa, Russo, and Di Muccio 2003). In the fall of 2003, in the province of Ascoli Piceno (Marche), damages were reported on palms due to “big white” larvae, and investigations revealed the presence of the moth in some nurseries in this province. The introduction was probably due to importation of infested trees from both Argentina and Spain (Riolo et al. 2004). The pest was then reported in other Italian regions: Puglia, Tuscany, and Sicily in 2004 (Colazza et al. 2005; Porcelli et al. 2005), Abruzzo in 2005 (CABI 2014), Liguria in 2008 (EPPO RS 2008/137; 2010/146), Emilia-Romagna (Bariselli and Vai 2009), Veneto and Friuli-Venezia Giulia in 2009 (EPPO RS 2009/109; 2010/054), Lazio and Lombardy in 2010 (EPPO RS 2010/098, 2010/207, 2011/150), Basilicata in 2011 (EPPO RS 2011/150), and Sardinia in 2012 (Ciampi 2012) (Fig. 6.2). At present, the moth is considered invasive in France, Italy, and Spain.

Over the years, the moth has been reported in other European countries due to infested palms imported from Italy and Spain (EPPO 2014). In the UK, after two single isolated records in 2002 in Northern Ireland and southern England (Patton and Perry 2002; EPPO RS 2003/121), two recordings were made in May and July 2007 in Kent and north London (Reid 2008). All affected palms were destroyed and the moth is now considered eradicated (EPPO RS 2009/142). The first record in Greece dates back to 2006 from two areas, Crete and Attica (Vassarmidaki, Thymakis, and Kontodimas 2006). In 2008, the moth was found for the first time in Slovenia (EPPO RS 2009/050), where it is now present in only one area, the community of Izola (EFSA PLH Panel 2014). In 2009, Bulgaria and Cyprus Island announced finding the moth (EU 2009a; Vassiliou et al. 2009). At present in those countries, PBM is considered under eradication in only a few areas (EFSA PLH Panel 2014). The same year, Denmark also reported its first finding of the moth indoors (Larsen 2009); today, it is considered eradicated (EFSA PLH Panel 2014). In 2010, in Switzerland, the moth’s presence was first reported in a few occurrences and is now eradicated (EPPO RS 2010/145). In 2011, the Czech Republic announced the first record of the moth (EPPO RS 2011/137), now considered eradicated (EFSA PLH Panel 2014). The latest reports date back to 2011 in Portugal (Corley et al. 2012; EPPO 2014) and to 2012 in Croatia (Milek and Simala 2012). Finally, in Belgium, there were reports of adults in two locations in 2011 and 2012; there the moth is now considered transient but not actionable (EFSA PLH Panel 2014).

The accidental introduction and subsequent spread of PBM occurred by three pathways: (1) the commercial import of palms (Areccaceae) originating from areas where the
pest occurs, (2) the movement of palm trees from a contaminated area to one that is free of the pest, and (3) natural adult spread. The first pathway acts at the international level and is probably the main pathway by which the pest spreads over large distances, as it can often go undetected. The second one acts at the national level, as a consequence of not only commercial movement of plants but also of citizens’ individual actions. The third pathway acts at the local level, depending on the flight abilities of the moth.

Today, the moth is listed as a quarantine pest in EPPO member countries (EPPO 2008), and the European Community, with Commission Decision of 10/02/2009 no 2009/7/EC, has established protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community (EU 2009b). Thus, the risk of new introduction or spread of the insect within the EC by internal trade or natural spread is low. However, the southern part of the EPPO region (Mediterranean countries and Macaronesia) is most at risk.

### 6.4 Morphology of *P. archon* Stages

The *P. archon* egg is a typical fusiform Castniid egg, resembling a rice grain and bearing six to eight raised longitudinal ridges, which have associated aeropyles along their length, and the micropyle at one end of the long axis. When freshly laid, it is
creamy pink or light brown, becoming rosy brown as the days pass. Its length averages 4.69 ± 0.37 mm, with most measuring between 4.4 and 5.2 mm. Its width at the widest section averages 1.56 ± 0.11 mm, with most measuring between 1.50 and 1.60 mm (Sarto i Monteys et al. 2005) (Fig. 6.3a).

The larva emerges by gently splitting the egg chorion along one of the longitudinal ridges. Immediately after hatching, the larva is pink, except for the head capsule, which is light brown. Moreover, chaetotaxy differs in the number and length of the setae, which are much longer than in subsequent larval stages, and cuticular spinules are not present. Through the first instar, the rosy color fades to whitish and the long straight-lined setae becoming shorter. After the first molt, the larva becomes ivory white, chaetotaxy changes and the setae become much shorter, and cuticular spinules appear. These new traits are retained throughout the remaining larval stages. Earlier instars show a blackish dorsum as a consequence of the blackish longitudinal dorsal vessel clearly seen from outside the body. Later instars turn to a more intense ivory white and the dorsal vessel is less obvious. Light-brown cuticular spinules on the dorsum of the prothoracic segment form an “M” mark, which is more obvious in mid- and later instars. From the first to last instar, the larvae of *P. archon* increase dramatically in size. After emergence, the body length is 7.3 ± 2.2 mm, the width of the head capsule at the widest part being 1.00 ± 0.10 mm. When full-grown, before entering the prepupal stage, the larva may reach a body length of 9 cm, a width of 1.5 cm at mid-length, with the widest part of the head capsule being 7.84 ± 0.34 mm (Miller 1986; Sarto i Monteys and Aguilar 2005) (Fig 6.3b, c).
At first, the pupa is pale yellow, turning to reddish brown after the pupal cuticle darkens and hardens. The size of the pupa is about 5.5 cm (Sartoi Monteys and Aguilar, 2005). Most of the abdominal segments of the pupa are furnished dorsally with transversal rows of short spines pointing backwards. In particular, two rows of dorsal spines are present on segments II–VIII in males and on segments II–VII in females, and only one row in the last abdominal segments (Riolo, unpublished). The pupa is protected by a palm-fiber cocoon within the burrow. Under laboratory conditions, pupation may occur without this cocoon (Beaudoin-Ollivier, unpublished). The cocoons are fusiform with an average length of 5.8 cm, and are stout, with the inner walls smoothly coated by a layer of silk and secretions. The outer walls are loosely covered by fragments of palm fibers which make cocoons inconspicuous (Sartoi Monteys and Aguilar 2005) (Fig 6.3d).

The adult is a big diurnal moth, with a large wingspan of 6–11 cm. The forewings are greenish-brown, with a blackish-brown median band. The hindwings are orange with a wide transverse black band containing five or six white cells. The antennae are clubbed with a typical apical hook. Females are generally larger than males and bear a long telescopic ovipositor (Miller 1986; Sarto i Monteys and Aguilar 2005) (Fig 6.3e). For extensive descriptions and images of antennal and ovipositor morphology and fine structure, see Chapter 7, this volume.

### 6.5 Biology

#### 6.5.1 Host Plants

*P. archon* seems to have a large range of genera within the monocotyledonous family of palms (Arecaceae) (Table 6.1).

In South America, Houlbert (1918) reported *Phoenix canariensis* Chabaud as a food plant for the moth in Paysandú (Uruguay). In the same area, Bourquin (1930, 1933) reported a list of host palm species, including *B. yatay*, *Chamaerops humilis* L., *Livistona chinensis* (Jacquin) Brown ex Martius, *P. canariensis*, and *T. campestris*. Lepesme (1947) reported *Latania* spp. in Argentina. In the state of Rio Grande do Sul (Brazil) (De Biezanko 1961) and in Uruguay (Ruffinelli 1967), *L. chinensis*, *P. canariensis*, and *Syagrus romanzoffiana* (Chamisso) Glassman were reported as host plants for *P. archon*. In the province of Buenos Aires, where palms are not native but have been introduced since 1998 for ornamental purposes, *B. yatay*, *Butia capitata* (Martius) Beccari, *P. canariensis*, and *T. campestris* were certainly affected (Sartoi Monteys and Aguilar 2005).

In Europe, the moth has a broad host range. In Spain (Catalonia, Valencian Community, and Balearic Islands), PBM infestation has been reported on *Brahea armata* Watson, *C. humilis*, a *Livistona* sp., *P. canariensis*, *Phoenix reclinata* Jacquin, *Phoenix roebelenii* O’Brien, a *Sabal* sp. (maybe *minor* (Jacquin) Persoon), *S. romanzoffiana*, *Trachycarpus fortunei* (Hooker) Wendland, *T. campestris*, *Washingtonia filifera* (Linden) Wendland, and *Washingtonia robusta* (Linden) Wendland (Sarto i Monteys and Aguilar, 2005).

Table 6.1 List and status of *P. archon* host plants.

<table>
<thead>
<tr>
<th>Taxonomic position within Angiospermae, Monocotyledonae Clade: Commelinids Order: Arecales Family Arecaceae</th>
<th>Common name</th>
<th>Subfamily, genus and species</th>
<th>Main features</th>
<th>Infestation: Conditions and amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arecoideae</strong></td>
<td><em>Butia capitata</em> (Martius) Beccari</td>
<td>Jelly p.</td>
<td>South America Trop dry forest</td>
<td>Orn Cult</td>
</tr>
<tr>
<td></td>
<td><em>Butia yatay</em> (Martius) Beccari</td>
<td>Yatay p.</td>
<td>South America Trop dry forest</td>
<td>Orn</td>
</tr>
<tr>
<td></td>
<td><em>Elaeis guineensis</em> Jacquin</td>
<td>African oil p.</td>
<td>Africa panTrop</td>
<td>Cult</td>
</tr>
<tr>
<td></td>
<td><em>Howea forsteriana</em> Beccari</td>
<td>Kentia p., Thatch p.</td>
<td>Australia Trop moist forest</td>
<td>Orn H (Italy); H? (Portugal)</td>
</tr>
<tr>
<td></td>
<td><em>Syagrus romanzoffiana</em> (Chamisso) Glassman</td>
<td>Queen p., giriba p.</td>
<td>South America Trop dry forest</td>
<td>Orn</td>
</tr>
<tr>
<td>Coryphoideae</td>
<td>Watson</td>
<td>Mexican blue p., blue hesper p.</td>
<td>North and Central America</td>
<td>Desert and xeric shrubland</td>
</tr>
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<td>------------------------------------------------------------------------------</td>
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<tr>
<td><em>Brahea armata</em> Watson</td>
<td>Wendland</td>
<td>Guadalupe p.</td>
<td>North and Central America</td>
<td>Desert and xeric shrubland</td>
</tr>
<tr>
<td><em>Brahea edulis</em> Wendland</td>
<td></td>
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<td></td>
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<tr>
<td><em>Chamaerops humilis</em> L.</td>
<td>European fan p.</td>
<td>Med basin</td>
<td>Med forest and scrub</td>
<td>Pat Orn</td>
</tr>
<tr>
<td><em>Latania</em> spp.</td>
<td></td>
<td>Islands of Indian Ocean</td>
<td>Trop moist forest</td>
<td>Pat Orn</td>
</tr>
<tr>
<td><em>Livistona australis</em> (Brown) Martius</td>
<td></td>
<td>Cabbage-tree p.</td>
<td>Australia</td>
<td>Med forest and scrub</td>
</tr>
<tr>
<td><em>Livistona chinensis</em> (Jacquin) Brown ex Martius</td>
<td></td>
<td>Chinese fan p., fountain p.</td>
<td>Far East Asia</td>
<td>Med forest and scrub</td>
</tr>
<tr>
<td><em>Livistona decipiens</em> Beccari</td>
<td></td>
<td>Ribbon fan p.</td>
<td>Australia</td>
<td>Trop dry forest</td>
</tr>
<tr>
<td><em>Livistona saribus</em> (Loueiro) Merrill ex Chevalier</td>
<td></td>
<td>Taraw p.</td>
<td>Far East Asia</td>
<td>Trop moist forest</td>
</tr>
<tr>
<td><em>Phoenix canariensis</em> Chabaud</td>
<td></td>
<td>Canary p.</td>
<td>Canary Islands</td>
<td>Med forestland scrub</td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>Common name</th>
<th>Originating area</th>
<th>Originating climate and biotope</th>
<th>Economic value</th>
<th>Host and susceptibility status</th>
<th>Abundance</th>
<th>Infestation: Conditions and amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phoenix dactylifera L.</td>
<td>Asia Middle East</td>
<td>Med forestland scrub</td>
<td>Cult</td>
<td>H</td>
<td>+++</td>
<td>Positive development under natural conditions in invasion area (7)</td>
</tr>
<tr>
<td>Phoenix reclinata Jacquin</td>
<td>Africa</td>
<td>Trop dry forest</td>
<td>Orn Trad</td>
<td>H</td>
<td>r</td>
<td>Positive development under natural conditions in invasion area (6)</td>
</tr>
<tr>
<td>Phoenix roebelenii O’Brien</td>
<td>Far East Asia</td>
<td>Med forestland scrub</td>
<td>Orn</td>
<td>H</td>
<td>r</td>
<td>Positive development under natural conditions in invasion area (6)</td>
</tr>
<tr>
<td>Phoenix sylvestris (L.) Roxburgh</td>
<td>Silver date p. Sugar date p.</td>
<td>Asia</td>
<td>Med forestland scrub</td>
<td>Orn Trad</td>
<td>H</td>
<td>r</td>
</tr>
<tr>
<td>Phoenix theophrasti Greuter</td>
<td>Cretan date p.</td>
<td>Med basin Greece Turkey</td>
<td>Med forestland scrub</td>
<td>Pat</td>
<td>H</td>
<td>r</td>
</tr>
<tr>
<td>Sabal mexicana Martius</td>
<td>Mexican palmetto, Texas palmetto</td>
<td>North America</td>
<td>Med forestland scrub</td>
<td>Orn</td>
<td>H</td>
<td>r</td>
</tr>
<tr>
<td>Sabal minor (Jaquin) Persoon</td>
<td>Dwarf palmetto, Bush palmetto</td>
<td>North America</td>
<td>Med forestland scrub</td>
<td>Orn</td>
<td>H</td>
<td>r</td>
</tr>
<tr>
<td>Common names</td>
<td>Scientific name</td>
<td>Origin</td>
<td>Climate and Biotope</td>
<td>Economic/patrimonial value</td>
<td>Host and susceptibility status</td>
<td>Infestation</td>
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</table>

Common names: p., palm.
Climate and Biotope: Med, Mediterranean; Trop, Tropical.
Economic/patrimonial value: Cult, cultivated for fruits; Orn, ornamental; Pat, patrimonial for biodiversity as locally native in one of the EU territories; Trad, traditional use (beverage, sugar...).
Host and susceptibility status: H<sub>n</sub>, host in neotropics; H+, host in invading area with high susceptibility (high economic impact); H-, host in invading area with low susceptibility compared to abundance; H, host in invading area with insufficient data to establish degree of susceptibility; H?, host in invading area with unconfirmed record; PH, potential host (development possible under laboratory conditions).
Abundance in Mediterranean area and EU: ++++, highly abundant and widely distributed; ++, locally abundant as avenue or park trees but much less than +++; r, rare and scattered in parks and gardens as compared to ++; 0, absent or extremely rare, essentially in greenhouses.
Infestation: Conditions and amplitude: The number refers to the reference in the reference list below.
have been observed on palm leaves of the genus *Jubaea* Kunth (INRA 2014), which is also listed in the legislation addressing PBM (EU 2009b).

In the Marche region of Italy, high plant mortality of up to 90% in ornamental palm nurseries has been recorded for *C. humilis*, *P. canariensis*, *T. fortunei*, and *Washingtonia* spp. Wendland (Riolo et al. 2004). No other PBM host palm species were subsequently recorded in other Italian regions or in other European countries, except for three single reports. Indeed, in Sicily in 2014, an attack was observed on a *Howea forsteriana* Beccari plant that was cultivated in a nursery where several *C. humilis* plants were seriously damaged (Suma, personal observation). Signs of a possible infestation on two *H. forsteriana* trees were also reported in Portugal, but this record remains unconfirmed (EPPO 2014). Moreover, in 2012, the first infestation by the moth on Cretan palm trees *Phoenix theophrasti* Greuter, an endemic species in Greece, was reported (Psirofonia and Niamouris 2013).

Although *P. archon* has not been reported to be a significant pest in South America, with the exception of reports from Buenos Aires (Sarto i Monteys and Aguilar 2005), and rarely kills date palms (*P. dactylifera*) or Canary palms (*P. canariensis*), it has been the cause of serious damage and plant mortalities in France, Italy, and Spain. Moreover, the native Mediterranean fan palm, *C. humilis*, which is endemic in natural Euro-Atlantic landscapes, is very susceptible to PBM attack (Riolo et al. 2004). Finally, a preliminary laboratory study established *Elaeis guineensis* Jacq as a possible host for PBM (Beaudoin-Ollivier et al. 2014). Recent research under the Palm Protect project has aimed to determine the host palm tree range under European environmental conditions.

In France, observation of oviposition choice in field condition shows that mated females are capable of distinguishing palm species, preferring *P. canariensis* for oviposition when available. The mated ovipositing female moth did not avoid it, although less preferred than other palm species. Little damage has been reported on *W. robusta*, suggesting an antibiosis mechanism of resistance against this pest as observed also for RPW (Dembilio, Jacas, and Llácer 2009). Moreover, ovipositing females do not avoid palms with previously laid eggs (Frérot, personal communication and Beaudoin-Ollivier, unpublished). A significant choice for *W. filifera* that had been damaged the year before was observed compared to healthy palms of the same species (Beaudoin-Ollivier, unpublished). Oviposition observations in a wind tunnel showed that the orientation behavior of mated females is characteristic of a chemically mediated attraction and follows a chemo-anemotactic process (Frérot, personal communication).

Extensive periodic surveys were carried out in open fields in the Marche region: the highest degree of susceptibility to PBM was determined in *C. humilis*, followed in descending order by *T. fortunei*, *Washingtonia* spp., and *P. canariensis*. The highest level of infestation was observed on a 3.5 m tall *T. fortunei* palm tree, which harbored 20 specimens of PBM (larvae and pupae). Further surveys in a plantation of 3- to 10-year-old *T. fortunei* showed that 80% of the palms were infested. Infestation in nurseries on potted 2- to 3-year-old *C. humilis* was up to 95%. A semi field choice assay between palm species showed *W. robusta* and *T. fortunei* to be the most infested, followed in descending order by *C. humilis* and *P. canariensis*. The mean number of eggs and larvae in infested palms was higher in *P. canariensis*, although not significantly so (Riolo, personal observation). A similar choice assay carried out in the south of France revealed a preference for young *P. canariensis* seedlings for oviposition with a maximum of nine eggs per seedling. Then, *W. filifera* and *C. humilis* were chosen for oviposition, before *T. fortunei* and *E. guineensis* (Beaudoin-Ollivier, unpublished).
To locate a host plant, PBM can exploit volatile organic compounds emitted from the plants. The biological activity of some of these was evaluated by electrophysiological bioassays (EAG) (see Chapter 7, this volume). This investigation demonstrated that female and male moths, with higher sensitivity for the former, respond to linalool, one of the major compounds of palm volatiles, and to esters such as ethyl acetate, ethyl propionate, ethyl butyrate, ethyl isobutyrate, and ethyl lactate, produced by damaged and fermenting palm-tissue volatiles. Among the compounds tested, ethyl isobutyrate elicited the strongest antennal responses (Ruschioni et al. 2015).

6.5.2 Life Cycle

There is little information about *P. archon* from its native area due to the lack of economic importance. There is virtually no detailed information on its biology in Europe. Houlbert (1918) was the first to provide data on the biology and host plants of PBM. Later, Bourquin (1930, 1933, 1944) briefly described the moth stages and provided some biological data.

In Europe, adult moths are active during the hottest part of sunny days, from mid-May to September—October, with a peak in June—July. In contrast, adults are inactive under cloudy or rainy weather conditions (Riolo et al. 2004; Sarto i Monteys and Aguilar 2005; Liégeois, Tixier, and Beaudoin-Ollivier 2014). In Buenos Aires province, the occurrence of adults is reported from early November to early May; this is quite similar to the occurrence in the Northern hemisphere (Sarto i Monteys and Aguilar 2005).

The adult life span in the wild is unknown, although it is most likely to fall short of that found in captivity, where females live an average of 14.1 days and males 23.8 days, although there is information about the physiological status of the insects. Moreover, it was noticed that the adult life span could be significantly extended by refrigeration (Sarto i Monteys and Aguilar 2005). Observation in the Marche region, Italy, showed an adult life span ranging from a minimum of 3 days to a maximum of 20 days, with an average of 10.3 days (Riolo, Isidoro, and Nardi 2005), while mated caged males survived an average of 33 days (Riolo, personal observation). In France, under natural conditions, the mean life span of virgin encaged males was 21.0 ± 3.6 days (mean ± SD), whereas mated males survived 12.0 ± 2.0 days. Mated females lived 11.4 ± 2.3 days and virgin females 8.7 ± 3.4 days under natural conditions (Hamidi, personal observation). Despite their well-developed proboscis, adults have never been seen feeding in the wild or in captivity (Miller, 1986).

The times of the day at which adults emerge are quite numerous. Emergence may occur at night or in the morning, between 1000 and 1300 h (Sarto i Monteys and Aguilar 2005). Drescher and Jaubert (2003) reported emergences occurring early in the morning, before 0800 h, in the laboratory. The adults start to fly 1–2 h after emerging; they are strong flyers during the day and have a peak of flying activity between 1100 h and 1700 h in insect-proof tents (Drescher and Jaubert 2003). Dispersal capabilities of the adults have never been documented by tracking tagged individuals. Preliminary experiments to determine flight capability and conditions using a wind mill indicated a mean flight time of about 1 min, with maximum mean flight times of 2.76 and 4 min (♂ and ♀), maximum flight distances of 195 and 310 m (♂ and ♀), and a maximum speed of 6–7 km/h for virgin specimens of both sexes (Beaudoin-Ollivier, unpublished). Radio telemetry has been used to trace the movement of PBM under natural conditions. Results revealed high mobility for the females, which are responsible for the spread of
the species (>500 m), whereas the males were successfully tracked in a restricted area estimated at 4 ha (Liégeois, Tixier, and Beaudoin-Ollivier 2014).

Recent studies indicate that 73% of the adults are sexually mature 3 h after emergence (Delle Vedove et al. 2012). In outdoor experiments, mating peaks between 1400 h and 1500 h, and 87% of the females are fertilized and start laying eggs 1.25 (±1.14) days after mating (Delle Vedove et al. 2012). Riolo et al. (2014) reported that in semi field conditions mating occurred mainly in the morning from 0930 to 1130 h; mated moths were 1–2 days old. Under laboratory conditions, mating occurred in the afternoon, as soon as the cage with males and females was in the sun (Beaudoin-Ollivier, unpublished).

Females are generally monandrous, but nevertheless remain attractive after mating (Delle Vedove et al. 2012). PBM males are expected to mate more than once (Delle Vedove et al. 2012), as in most Lepidoptera (Rutowski 1982). For extensive data on PBM courtship and mating behavior, refer to Chapter 7, this volume.

Females lay eggs singly, sometimes in small clusters but not glued, within the plant fibers, close to or in the crown of the palm, at the base of the leaf, on the stem, or in the terminal bud. The average number of eggs laid in the wild is not known but could be around 140 on the basis of observations of female dissections by Sarto i Monteys and Aguilar (2005). Eggs are found from late May to mid-October. As for embryonic development, hatching occurs after 12 to 21 days, depending on the temperature (Drescher and Jaubert 2003; Sarto i Monteys and Aguilar 2005). Because the larvae do not eat the chorion after hatching, hatched eggs can be found at any time within the palm fiber webs where they are laid (Sarto i Monteys and Aguilar, 2005).

The larvae start looking for food immediately after hatching and bore into the host plants. The larvae are endophagous for most of their lives and are highly lucifugal, with only the first instar being partly or fully exophagous. They feed by tunneling long galleries in the succulent plant material of stems, leaves, and fruit and complete their preimaginal development in the plants. For an extensive description and images of symptoms, refer to Chapter 9, this volume.

The final larval instar seems to be the ninth, although in captivity pupation has also been observed after the seventh or eighth instar (Sarto i Monteys and Aguilar 2005). The larval stage is the longest and most complex developmental stage; it is the only one that overwinters. During the winter, nearly all larval instars can be found within the palms in the wild, including prepupal larvae (Riolo, Isidoro, and Nardi 2005; Sarto i Monteys and Aguilar 2005). Although the overwintering larval populations live protected, cold winters might increase their mortality. A measure of larval survivorship capacity indicated that development for the immature stages is optimum when the temperature is fluctuating during the cold period (Beaudoin-Ollivier, unpublished).

The larval stage, including the prepupal period, lasts from 10.5 months in larvae having a 1-year cycle to 18.5 months in larvae having an almost 2-year cycle. One-year-cycle larvae are fully grown at the end of the winter, building their cocoons from mid-March to mid-April and becoming adults in early summer. Under laboratory conditions, the prepupal stage might be observed 6–8 months after hatching (Beaudoin-Ollivier, unpublished). Otherwise, 1-year-cycle larvae reach their last instar in late spring and become adults in late summer. Larvae that overwinter twice build their cocoons at the end of the second winter and, in this case, adults emerge in May–June of the second year. The prepupal stage, characterized by full-grown larvae making their cocoons, is made up of two periods. The first includes the time spent by the larva making the cocoon; the second one starts after the cocoon has been built and includes time spent by the larva inside the
cocoon before conversion into a pupa. Its duration is very variable, from a few days to several weeks if lethargy occurs (Sarto i Monteys and Aguilar 2005).

The cocoons are always located near or on the surface of the trunk or leaf axillae, well camouflaged, at one end of the larval gallery. Cocoons with living pupae can be found from mid-March to mid-September, whereas empty cocoons can be found anytime as they remain on the palm after adult emergence. Sarto i Monteys and Aguilar (2005) reported that 43–66 days are necessary for pupae to complete their metamorphosis to adults, depending on when they formed; from 25 to 46 days have been reported in France (Beaudoin-Ollivier, unpublished). PBM pupae react to low temperatures by slowing down or halting their transformation into adults.

Overall, the PBM life cycle in Spain from egg to adult lasts from 12.8 months in specimens having a 1-year cycle to 22.1 months in specimens having a 2-year cycle (Sarto i Monteys and Aguilar 2005). In Europe, all stages of the pest (eggs, larvae, pupae, and adults) can be observed during the summer (Riolo et al. 2004).

6.6 Conclusion

*P. archon* has been able to successfully invade the Euro-Mediterranean area despite earlier actions and regulations. A review of available data, as a starting point, along with relevant new investigations, is therefore necessary to fill in the knowledge gaps in assessing host selectivity and its underlying mechanisms, dispersal capabilities of the pest, and the duration of its life cycle under Euro-Mediterranean conditions. The data will support decisions for risk assessment, improvement of monitoring, and control means for use by EU Plant Protection authorities and NPPOs, as well as regulation.

References


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