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BS1847: Fruit-piercing moth, *Eudocima phalonia* (Linneaus 1763) review: biology, ecology and pest management with reference to kiwifruit

Chhagan A, McKenna C

March 2019















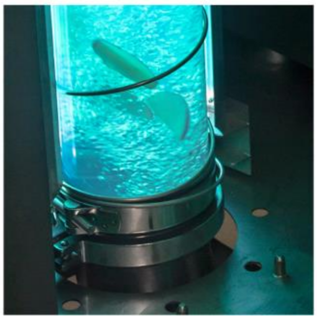


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EXECUTIVE SUMMARY

BS1847: Fruit-piercing moth, Eudocima phalonia (Linneaus 1763) review: biology, ecology and pest management with reference to kiwifruit

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Background

Eudocima phalonia (fruit–piercing moth; FPM) (Linnaeus 1763), is native to the Indo-Malaysian region of Asia, with an extensive distribution throughout Africa, Asia and Oceania. This invasive moth is a significant economic pest of ripening fruits, and is known to attack over 40 different types of fruit. Primary damage by *E. phalonia* is caused by adult feeding on the fruit, whereby adults of both sexes use their barbed proboscises to pierce the rind or skin of fruit and extract the juices. The pin-hole sized piercings are the initial external sign of an attack by *E. phalonia*. As a result of the piercing, fruit juice exudate can be seen surrounding the feeding holes, discolouring the skin of fruit. Internally, the damaged tissue becomes spongy and dry and the fruit can lose their market value. Damaged fruit can fall from the tree or vine within 3–4 days of feeding.

The *E. phalonia* life cycle consists of four main life-stages: egg, larva (5–6 instars), pupa and adult. The pest has overlapping generations throughout the year. Egg laying appears to peak in the wetter months when larval host plants are in abundance, and adult activity appears to be highest in the drier moths.

Unlike many Lepidoptera, it is the adult moth, not the larval stage, which causes damage to host crops. *E. phalonia* are nocturnal and moths feed on fruiting crops at night then subsequently return to surrounding bush. Hosts of adult *E. phalonia* include apple (*Malus* spp.), grape (*Vitis* sp.), kiwifruit (*Actinidia* spp.), mandarin (*Citrus reticulata*), orange (*Citrus sinensis*), peach (*Prunus* spp.), pear (*Pyrus* spp.), plum (*Prunus* spp.) persimmon (*Diospyros kaki*) and tomato (*Solanum lycopersicum*). *E. phalonia* larvae feed on the foliage of trees, vines and shrubs within the Menispermaceae and Fabaceae (Leguminosae). In regions other than the Pacific, larval host plants within the genus *Tinospora* (Menispermaceae) are preferred. However, in the Pacific, Guam and Papua New Guinea, larval *E. phalonia* attack *Erythrina* (Fabaceae) as well as Menispermaceae.

Eudocima phalonia management

Although *E. phalonia* is considered to be an economically significant pest, tools to reliably monitor and manage field populations require further development. Monitoring for *E. phalonia* has often relied on visual inspections of fruits to identify and monitor the presence of the pest. Fruit bait traps have also been used to monitor seasonal populations of *E. phalonia*, with banana baits the most commonly used. No commercial lure is currently available for monitoring *E. phalonia.* However, the development of attractants is an active area of research in Australia and New Caledonia.

There is a lack of available data concerning the chemical control of *E. phalonia. S*uccessful control of fruit-piercing moths such as *E. phalonia* may be difficult with conventional insecticide sprays as (a) the adult moth has insufficient contact time with the fruit affecting moth mortality, and (b) fruit are generally damaged late in the season, approaching harvest. Therefore, an appropriate withholding period may not be attained. However, chemical control of *E. phalonia* larvae on nearby host plants may be an option.

Numerous cultural methods have been trialled and/or implemented for the control of *E. phalonia,* including bagging of fruit, netting individual trees or blocks, early harvest of fruit, removal of larval host plants, block plantings and light barriers. Many of these methods may have potential for use in kiwifruit orchards. A number of natural enemies of *E. phalonia* have been identified and studied worldwide, and attempts have been made to introduce and establish biological control agents of *E. phalonia,* with varying success.

Damage to kiwifruit

Kiwifruit (*Actinidia* spp.) is recorded as a host of *E. phalonia.* Little information is available in relation to the degree or appearance of damage, but estimates of 30–40% fruit losses have been reported on *A. chinensis* var. *chinensis* 'Hort16A' grown in Queensland, Australia.

Management of *E. phalonia* on kiwifruit In New Zealand

Damage caused by *E. phalonia* to kiwifruit could result in significant production losses to the New Zealand kiwifruit industry. This review of the available literature concerning *E. phalonia* has identified significant gaps in the data concerning control options for the pest. If *E. phalonia* were to establish in New Zealand, control would require an integrated approach, encompassing a number of cultural methods, new technologies such as lure and kill, and biological control, with monitoring playing a crucial role to in determining population abundance and spread. Further research is required to address these knowledge gaps.

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1 BIOLOGY AND ECOLOGY

1.1 Classification and nomenclature

***Eudocima phalonia* (Linnaeus, 1763) (= *fullonia* Clerck, 1764)**

Class:	Insecta
Order:	Lepidoptera
Family:	Erebidae
Genus:	*Eudocima*
Species:	*E. phalonia*

Other scientific names

Phalaena phalonia (Linnaeus 1763), *Phalaena fullonia* (Clerck 1764), *Eudocima fullonica* (Clerck 1764), *Phalaena fullonica* (Linnaeus 1767), *Othreis fullonica* (Linnaeus 1767), *Noctua dioscoreae* (Fabricius 1775), *Phalaena pomona* (Cramer 1776), *Ophideres obliterans* (Walker 1858).

Common names

English:	Fruit-piercing moth, fruit-sucking moth, orange-piercing moth
French:	Papillons piqueurs de fruits

Eudocima phalonia is the scientific name given to a species of fruit-piercing moth (FPM), also known as the fruit-sucking moth or orange-piercing moth. *E. phalonia* was only recently reinstated as the species name and is often referred to as "*Eudocima fullonia*" or "*Othreis fullonia*" in scientific literature (Zilli & Hogenes 2002; Brou & Zilli 2016; Gilligan & Passoa 2016).

The genus *Eudocima* consists of numerous species, including a number of newly described species (Zilli & Hogenes 2002; Brou & Zilli 2016; Klem ; Zilli et al. 2017). Gilligan & Passoa (2016) noted that "the taxonomy of *Eudocima* is confusing and species are often misidentified". "Forewing patterns are variable for many species, contributing to misidentifications". "Any species-level identification of *Eudocima* should be confirmed by an expert."

A recent study sequenced and characterised the complete mitochondrial genome of *E. phalonia* (Sivasankaran et al. 2017).

1.2 Geographical distribution

1.2.1 Endemicity

The fruit-piercing moth (FPM; *Eudocima phalonia*) is native to the Indo-Malaysian region of Asia (Baptist 1944).

1.2.2 Global distribution

E. phalonia is widely distributed in Oceania, Asia and Africa (Waterhouse & Norris 1987; Davis et al. 2005; EPPO 2017) (Figure 1, Table 1). Although *E. phalonia* is present in Hawaii, it is not currently known to occur in the mainland states of the United States of America (Martin-Kessing & Mau 1993; Davis et al. 2005; Gilligan & Passoa 2016). According to Davis et al. (2005), analysis of the current worldwide distribution of *E. phalonia* indicates that the pest is primarily associated with the following biomes: temperate broadleaf and mixed forests, tropical and subtropical grasslands, savannas and shrubs; and subtropical and tropical moist broadleaf forests. Based on this, the authors predicted the likely areas of establishment within the continental USA (Figure 2). Areas of high risk included the north-eastern and mid-eastern states of the USA.

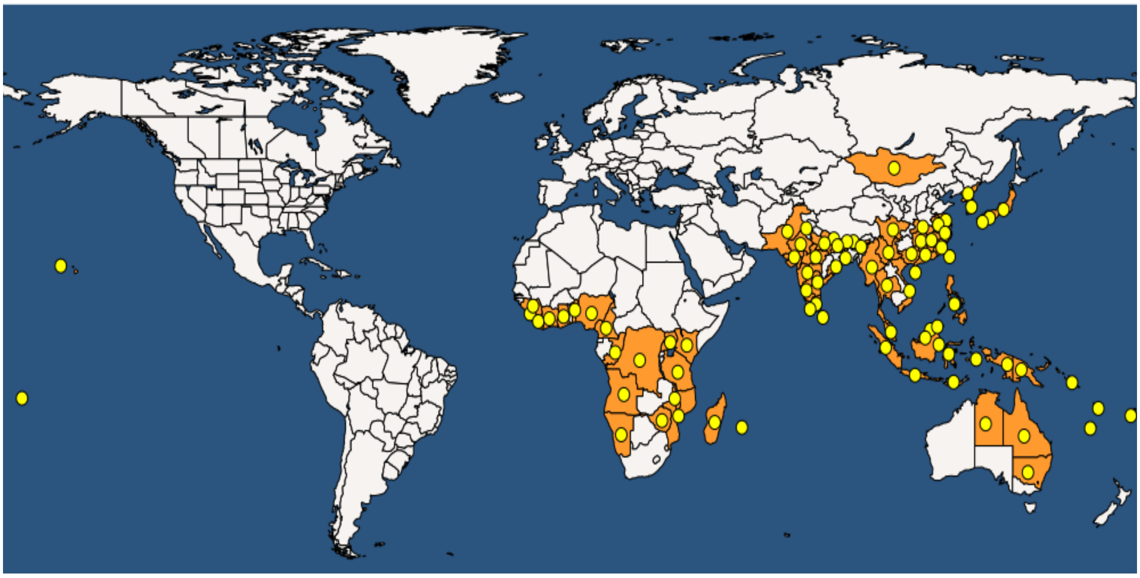


Figure 1. Global distribution of fruit-piercing moth, *Eudocima phalonia*. (Source EPPO Global Database, last updated 21 December 2017, [https://gd.eppo.int/taxon/EUDOFU/distribution)](https://gd.eppo.int/taxon/EUDOFU/distribution).

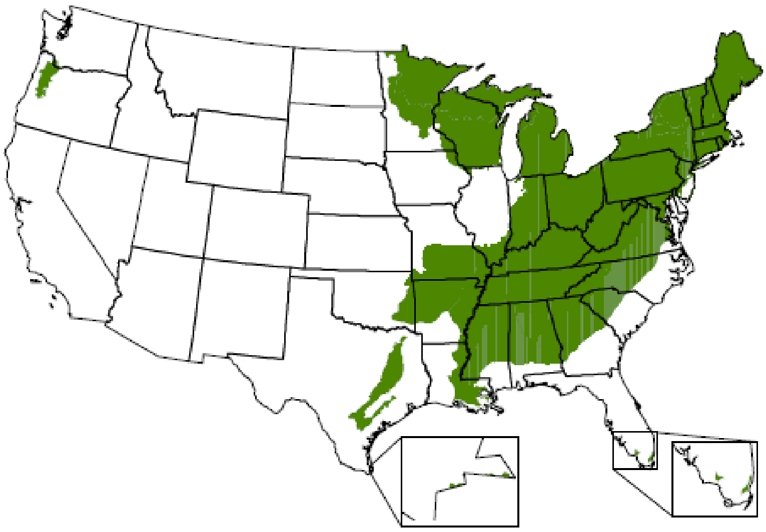


Figure 2. The predicted distribution of fruit-piercing moth, *Eudocima phalonia* in the USA (Source Davis et al. (2005)).

Table 1. Current reported worldwide distribution of *Eudocima phalonia*. Based on EPPO (2017).

Continent/Country/ Region	Distribution	Reference(s)
Africa		
Angola	Present	(Waterhouse & Norris 1987; EPPO 2017)
Benin	Present	(Atachi et al. 1989; EPPO 2017)
Cameroon	Present	(Waterhouse & Norris 1987; EPPO 2017)
Congo	Present	(Waterhouse & Norris 1987; EPPO 2017)
Congo Democratic Republic	Present	(EPPO 2017)
Ghana	Present	(Waterhouse & Norris 1987; EPPO 2017)
Guinea	Present	(EPPO 2017)
Kenya	Present	(Waterhouse & Norris 1987; EPPO 2017)
Liberia	Present	(Waterhouse & Norris 1987; EPPO 2017)
Madagascar	Present	(Waterhouse & Norris 1987) (EPPO 2017)
Malawi	Present	(Waterhouse & Norris 1987; EPPO 2017)
Mozambique	Present	(Waterhouse & Norris 1987; EPPO 2017)
Namibia	Present	(Waterhouse & Norris 1987; EPPO 2017)
Nigeria	Present	(Waterhouse & Norris 1987; EPPO 2017)
Reunion	Present	(Waterhouse & Norris 1987; EPPO 2017)
Sao Tome & Principe	Present	(Waterhouse & Norris 1987; EPPO 2017)
Sierra Leone	Present	(Waterhouse & Norris 1987; EPPO 2017)
Tanzania	Present	(Waterhouse & Norris 1987; EPPO 2017)
Uganda	Present	(Waterhouse & Norris 1987; EPPO 2017)

Continent/Country/ Region	Distribution	Reference(s)
Zimbabwe	Present	(Younghusband 1979; Waterhouse & Norris 1987; EPPO 2017)
America		
USA	Restricted distribution	(EPPO 2017)
USA/ Hawaii	Present	(EPPO 2017)
Asia		
Bhutan	Present	(Waterhouse & Norris 1987; EPPO 2017)
Brunei Darussalam	Present	(Waterhouse & Norris 1987; EPPO 2017)
Cambodia	Present	(EPPO 2017)
China	Present	(Li-ying et al. 1997; EPPO 2017)
Anhui	Present	(Li-ying et al. 1997; EPPO 2017)
Fujian	Present, Widespread	(Li-ying et al. 1997; EPPO 2017)
Guangdong	Present	(Li-ying et al. 1997; EPPO 2017)
Guangxi	Present	(Li-ying et al. 1997; EPPO 2017)
Hainan	Present, Widespread	(Li-ying et al. 1997; EPPO 2017)
Hubei	Present, Widespread	(Li-ying et al. 1997; EPPO 2017)
Hunan	Present, Widespread	(Li-ying et al. 1997; EPPO 2017)
Jiangsu	Present, Widespread	(Li-ying et al. 1997; EPPO 2017)
Jiangxi	Present, Widespread	(Li-ying et al. 1997; EPPO 2017)
Sichuan	Present, Widespread	(Li-ying et al. 1997; EPPO 2017)
Yunnan	Present, Widespread	(Li-ying et al. 1997; EPPO 2017)
Zhejiang	Present, Widespread	(Li-ying et al. 1997; EPPO 2017)
Christmas Island	Present	(Waterhouse & Norris 1987; EPPO 2017)
Hong Kong	Present	(Li-ying et al. 1997; EPPO 2017)
India	Present	(EPPO 2017)
Andaman and Nicobar Islands	Present	(EPPO 2017)
Andhra Pradesh	Present	(EPPO 2017)
Assam	Present	(EPPO 2017)
Bihar	Present	(EPPO 2017)
Gujarat	Present	(EPPO 2017)
Karnataka	Present	(EPPO 2017)

Continent/Country/ Region	Distribution	Reference(s)
Kerala	Present	(EPPO 2017)
Madhya Pradesh	Present	(EPPO 2017)
Maharashtra	Present	(EPPO 2017)
Orissa	Present	(EPPO 2017)
Punjab	Present	(EPPO 2017)
Rajasthan	Present	(EPPO 2017)
Sikkim	Present	(Waterhouse & Norris 1987; EPPO 2017)
Tamil Nadu	Present	(EPPO 2017)
Uttar Pradesh	Present	(EPPO 2017)
West Bengal	Present	(EPPO 2017)
Indonesia	Present, Widespread	(EPPO 2017)
Irian Jaya	Present	(EPPO 2017)
Java	Present	(EPPO 2017)
Kalimantan	Present	(EPPO 2017)
Maluku	Present	(EPPO 2017)
Nusa Tenggara	Present	(EPPO 2017)
Sulawesi	Present	(EPPO 2017)
Sumatra	Present	(EPPO 2017)
Japan	Present	(Waterhouse & Norris 1987; EPPO 2017)
Honshu	Present	(EPPO 2017)
Kyushu	Present	(EPPO 2017)
Shikoku	Present	(EPPO 2017)
Korea Dem. People's Republic	Present, few occurrences	(EPPO 2017)
Korea, Republic	Present	(EPPO 2017)
Malaysia	Present	(Waterhouse 1993; EPPO 2017)
Peninsular	Present	(EPPO 2017)
Sabah	Present	(EPPO 2017)
Sarawak	Present	(EPPO 2017)
Mongolia[1]	Present	(Waterhouse & Norris 1987; EPPO 2017)
Myanmar	Present	(Waterhouse 1993; EPPO 2017)
Nepal	Present	(EPPO 2017)
Pakistan	Present	(Waterhouse 1993; EPPO 2017)
Philippines	Present	(Waterhouse 1993; EPPO 2017)
Singapore	Present	(Waterhouse & Norris 1987; EPPO 2017)
Sri Lanka	Present	(EPPO 2017)
Taiwan	Present	(Waterhouse 1993; EPPO 2017)

Continent/Country/ Region	Distribution	Reference(s)
Thailand	Present, Widespread	(Waterhouse 1993; EPPO 2017)
Viet Nam	Present, Widespread	(Waterhouse 1993; EPPO 2017)
Oceania		
American Samoa	Present	(Sands et al. 1993; Waterhouse 1997; EPPO 2017)
Australia	Present	(Waterhouse & Norris 1987; EPPO 2017)
New South Wales	Present	(Waterhouse & Norris 1987; EPPO 2017)
Northern Territory	Present	(Waterhouse & Norris 1987; EPPO 2017)
Queensland	Present, Widespread	(Waterhouse & Norris 1987; Fay & Halfpapp 1993a; EPPO 2017)
Cook Islands	Present	(Waterhouse & Norris 1987; EPPO 2017)
Fiji	Present	(Sands et al. 1993; Waterhouse 1997; EPPO 2017)
French Polynesia	Present	(Waterhouse 1997; EPPO 2017)
Guam	Present	(Sands et al. 1993; Waterhouse 1997; EPPO 2017)
Micronesia	Present	(Waterhouse 1997; EPPO 2017)
New Caledonia	Present	(Waterhouse 1997; EPPO 2017; Leroy et al. 2018)
New Zealand	**Absent, no longer present**	**(EPPO 2017)**
Niue	Present	(Waterhouse 1997; EPPO 2017)
Norfolk Island	Absent, no longer present	(EPPO 2017)
Northern Mariana Islands	Present	(Sands et al. 1993; EPPO 2017)
Palau	Present	(EPPO 2017)
Papua New Guinea	Present	(Sands et al. 1993; Waterhouse 1997; EPPO 2017)
Samoa	Present	(Sands et al. 1993; Waterhouse 1997; EPPO 2017)
Solomon Islands	Present	(Waterhouse 1997; EPPO 2017)
Tonga	Present	(Sands et al. 1993; Waterhouse 1997; EPPO 2017)
Vanuatu	Present	(Sands et al. 1993; Waterhouse 1997; EPPO 2017)
Wallis and Futuna Islands	Present	(EPPO 2017)

[1]Disputed by Davis et al. (2005)

1.2.3 New Zealand distribution

Eudocima spp. have previously been recorded in New Zealand. *E. phalonia* is an occasional vagrant, referred to as *Othreis fullonia* in historical scientific records (Dugdale 1988). However, as it has not established in New Zealand there are no formal distribution or host records (A. Flynn, pers. comm. 2019). The New Zealand Arthropod Collection (NZAC) currently holds two specimens of *E. phalonia* in the collection; one from Motueka (1942) and one from Westport (1978) (R. Hoare, pers. comm. 2019).

The kiwifruit growing regions in New Zealand may be climatically suitable for the establishment of *E. phalonia.* In eastern Australia, *E. phalonia* is an important pest species in southern Queensland and northern New South Wales (Sands & Schotz 1991). New Zealand has a 0.7 climate match to the coastal areas of southern Queensland, Australia (Phillips et al. 2018). When compared to the cooler coastal areas of northern New South Wales, New Zealand has a 0.8–0.9 climate match. A match index of ≥ 0.7 is usually interpreted as indicating two climates are sufficiently similar for a species to persist in both climatic regions.

1.3 Description

Fruit-piercing moth belongs to the family Erebidae. Moths within the Erebidae typically have quadrifid forewings and quadrifine hindwings.

1.3.1 Eggs

The eggs of *E. phalonia* are round in shape and approximately 1 mm in diameter (Waterhouse & Norris 1987) (Figures 3 and 4). They are yellow in colour when laid and have a vertical pattern (Baptist 1944).

Figure 3. Egg mass of *Eudocima phalonia* on an *Erythrina variegata* leaf. Source Denton et al. (1999).

Figure 4. *Eudocima phalonia* eggs. Newly laid eggs (left), with developing larvae (right). Source Denton et al. (1999).

1.3.2 Larvae

E. phalonia has five larval instars (Waterhouse & Norris 1987). However, according to Sands & Schotz (1991), *E. phalonia* occasionally has six larval instars.

The first instar larvae are green in colour and approximately 4–5 mm in length, with 4 pairs of abdominal legs (Figure 5). The larvae have discreet brown hairs and banding (Hargreaves 1936). The head capsule is approximately 0.5 mm in width. Larvae move with a semi-looping mode of action. The second instar larvae are dark in colour, with developing paired lateral orange eyespots (Hargreaves 1936).

The later instar larvae are dark brown with black markings. The second and third abdominal segments have prominent ocelli with a pale iris. The anal segment is enlarged with the presence of a tubercle (Baptist 1944).

Mature *E. phalonia* larvae are approximately 50 mm in length when extended in the feeding position and approximately 40 mm in length in the characteristic resting position. The head capsule width is approximately 4.5 mm. The larvae can vary in colour: orange or reddish-brown to black ("brown larvae") or pale yellow to green ("green larvae") (Figures 6–8). The entire length of the body has small white specks of varying sizes and shapes and the second and third abdominal segments have noticeable ocelli. The "green larvae" are a pale or bright blue/green colour. The centre of the ocellus is bright blue and the spiracles are crimson (Maddison 1982). In the brown larvae, the centre of the ocellus is dark brown or black in colour with a pale blue core. The periphery of the ocelli are white (above) and red-orange/yellow (below). The brown larvae are common of larval aggregations, while the green larvae are usually solitary (Cochereau 1977). In the resting position, the larvae hold the back part of the body upwards. The head is arched under the anterior or front part of the body (Comstock 1963).

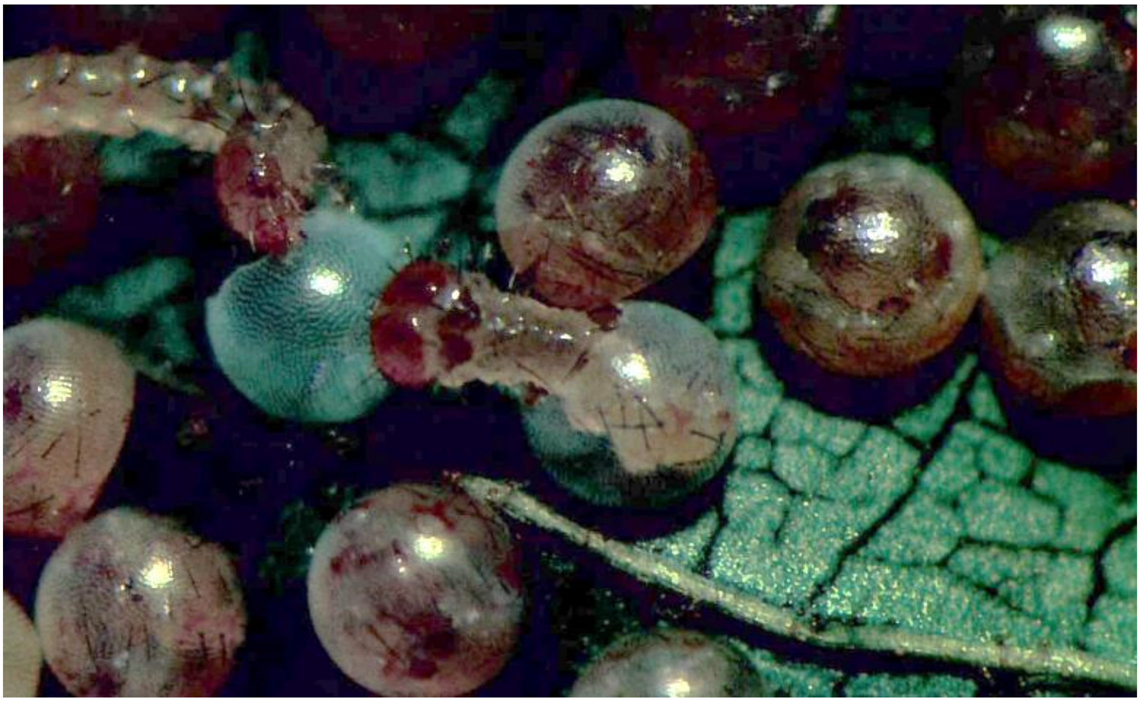


Figure 5. Early-instar *Eudocima phalonia* larvae. Source Denton et al. (1999).

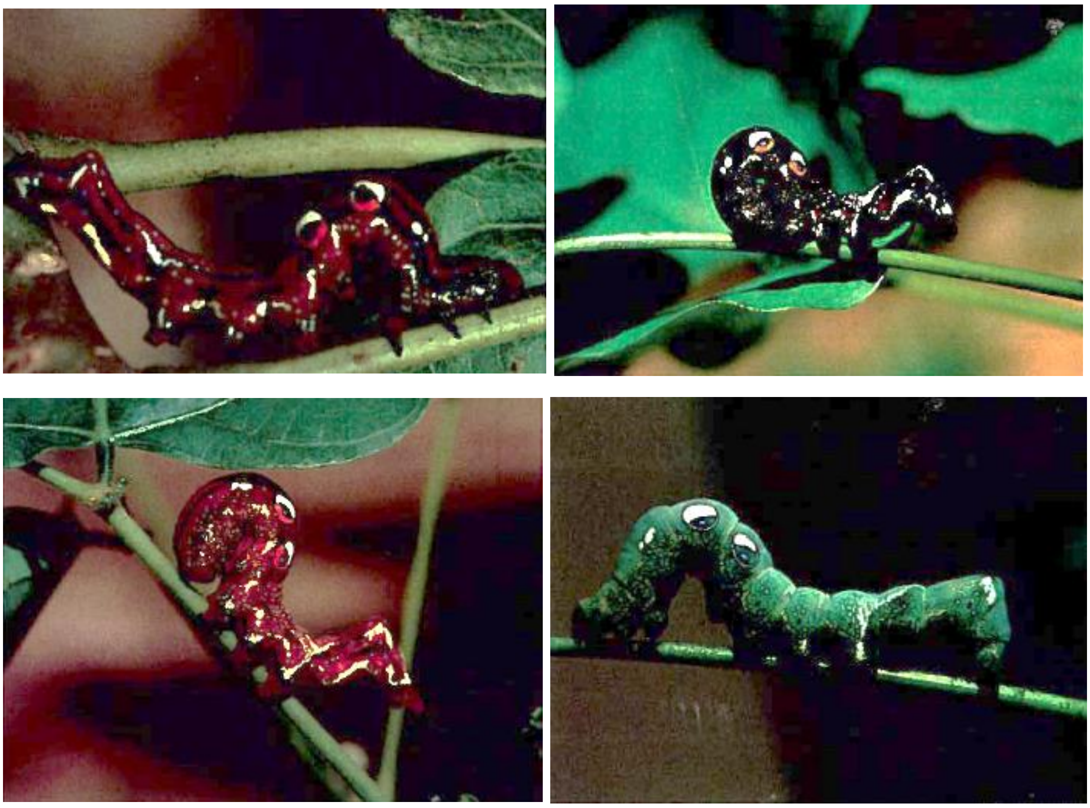


Figure 6. Colour variations of late-instar *Eudocima phalonia* larvae. Source Denton et al. (1999).

Figure 7. Late-instar *Eudocima phalonia* larva (Photograph source: Stefano De Faveri, Department of Agriculture and Fisheries, Queensland (Australia)).

Figure 8. Late-instar *Eudocima phalonia* larva (Photograph source Christian Mille (IAC; Institut Agronomique néo-Calédonien). From Mille (2011), photographed by David Pauland).

1.3.3 Pupae

Mature *E. phalonia* larvae pupate within a silken cocoon generally spun between leaves (Figure 9). Waterhouse & Norris (1987) noted that the leaves and the enclosed cocoon may stay on the host plant or the leaves may desiccate and drop to the ground. Pupae are brownish black in colour, and approximately 30 mm in length (Comstock 1963). Adults may not emerge successfully from pupae when weather conditions are very dry (Hargreaves 1936).

Figure 9. *Eudocima phalonia* pupa. Source Cheraghian (2015), http://ppo.ir/LinkClick.aspx?fileticket=rRNScf%2FdUiA%3D&tabid=884.

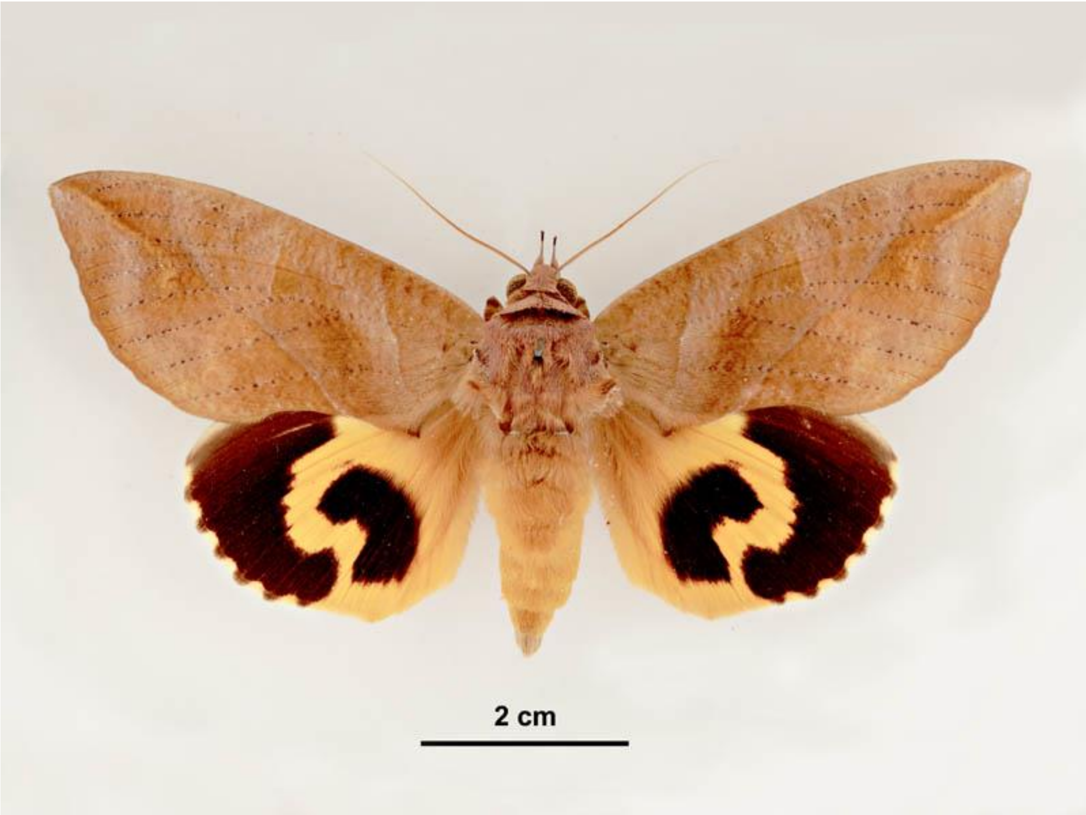
1.3.4 Adults

E. phalonia is a large sexually dimorphic species, with a wingspan of up to 100 mm and a body length of up to 50 mm (Waterhouse & Norris 1987). The head is large and reddish brown in colour. The thorax is also reddish brown with a metathoracic tuft and the abdomen is orange.

The hindwings are a yellow-orange colour and contain a distinctive ark comma-shaped mark (Figures 10 and 11). The border of the hindwings is black in colour with white flecks. The hindwings are not visible when the moth is resting (Figure 12); however, the distinct hindwings are exposed when the moth is disturbed or feeding (Waterhouse & Norris 1987).

The colour and patterning of the forewings are sexually dimorphic. In the male, the forewings are leaf-like and are reddish brown to purplish brown in colour. The wings are marked with dark spots along the veins. The underside of the forewings has a distinct orange-yellow band. The forewings of the female are more variegated and patterned with dark red brown and yellowish-brown specks. The underside of the forewings has a distinct yellow-orange band as in the male (Baptist 1944).

Figure 10. *Eudocima phalonia* female dorsal (above) and ventral view (below) (Photograph source: Museums Victoria (PaDiL)).



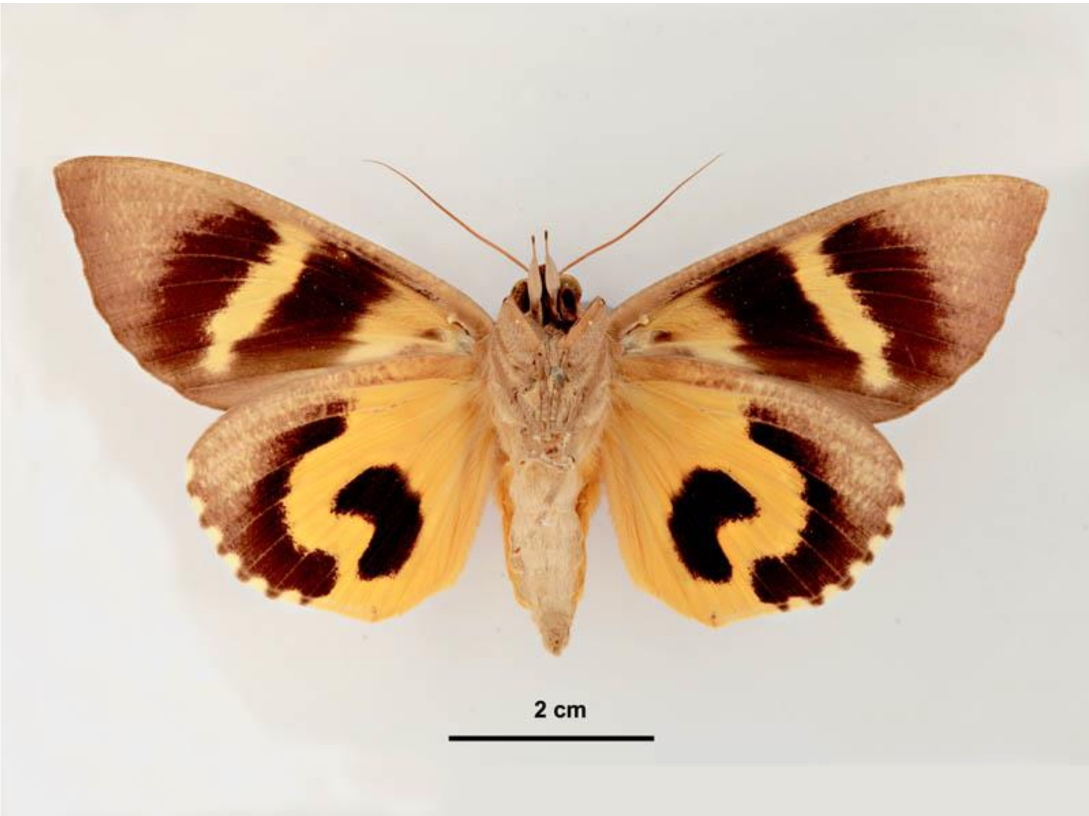


Figure 11. *Eudocima phalonia* male dorsal (above) and ventral view (below) (Photograph source: Museums Victoria (PaDiL)).

Figure 12. *Eudocima phalonia* female in the resting position (Photograph source: Stefano De Faveri, Department of Agriculture and Fisheries, Queensland (Australia)).

1.4 Host plants

Davis et al. (2005) provided a comprehensive list of *E. phalonia* host plants, listing more than 100 plant species in over 34 families. The host plants of adult *E. phalonia* are different from the larval host plants. Unlike many Lepidoptera, it is the adult *E. phalonia*, not the larval stage, which causes the damage to fruit. A summary of the recorded host plants of *E. phalonia* adults and larvae and associated references are presented in Appendices 1 and 2, respectively.

1.4.1 Adult host plants

E. phalonia adults are a serious pest of ripening fruits, and are known to attack over 40 different types of fruit (Baptist 1944; Cochereau 1977; Banziger 1982; Kumar & Lal 1983; Waterhouse & Norris 1987; Fay & Halfpapp 1993b; Martin-Kessing & Mau ; Fay 2002; Muniappan et al. 2004; Davis et al. 2005) (Appendix 1). Hosts include apple (*Malus* spp.), grape (*Vitis* sp.), kiwifruit (*Actinidia* spp.), mandarin (*Citrus reticulata*), orange (*Citrus sinensis*), peach (*Prunus* spp.), pear (*Pyrus* spp.), plum (*Prunus* spp.) persimmon (*Diospyros kaki*) and tomato (*Solanum lycopersicum*).

1.4.2 Larval host plants

E. phalonia larvae feed on the foliage of trees, vines and shrubs within the Menispermaceae and Fabaceae (Leguminosae) (Appendix 2) (Cochereau 1973; Banziger 1982; Waterhouse & Norris 1987; Fay 1994, 1996; Sands & Chan 1996; Davis et al. ; Reddy et al. 2005; Ramkumar et al. 2010) . In regions other than the Pacific, host plants within the genus *Tinospora* (Menispermaceae) are preferred. However, in the Pacific, Guam and Papua New Guinea, the larval *E. phalonia* attack *Erythrina* (Fabaceae) as well as Menispermaceae (Figure 13) (Denton et al. 1999; Reddy et al. 2005).

Reddy et al. (2005) investigated the host adaptation of *E. phalonia* in Guam. The authors reported that the Guam population of *E. phalonia* is a biotype that has extended its host range from host plants within the Menispermaceae family to host plants within the Fabaceae family (*Erythrina* spp.). This was possibly due to a number of factors, including the occurrence of similar alkaloids in both species or genetic changes.

According to Flora of New Zealand (2019), the Menispermaceae are not present within New Zealand. However, a number of *Erythrina* spp. are found in New Zealand. These include *Erythrina caffra, E. crista-galli* and *E. falcata.*

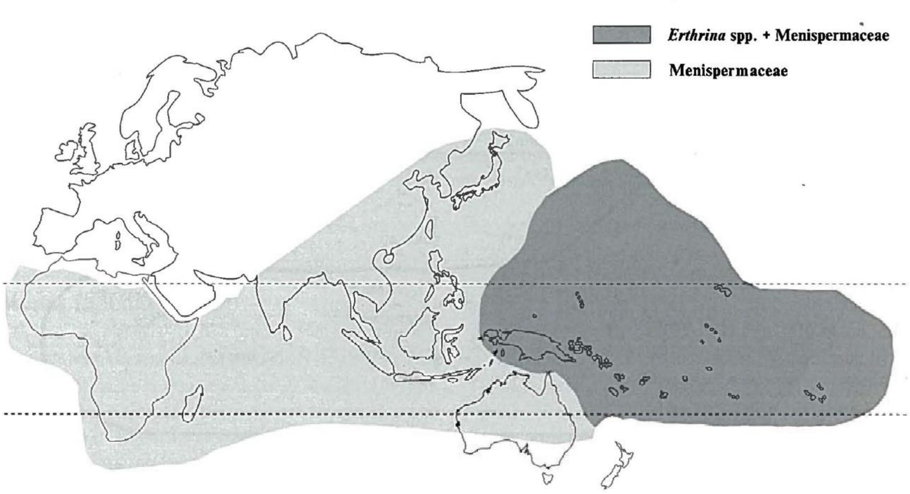


Figure 13. Worldwide distribution of *Eudocima phalonia* in relation to its larval host plants (Source: Denton et al. (1999)).

1.5 Damage

1.5.1 Primary damage

Primary damage by *E. phalonia* is caused by adult feeding on the fruit. The moths of both sexes use their barbed proboscises to pierce the rind or skin of fruit and extract the juices (Cochereau 1977). The pin-hole sized piercings are the initial external sign of an attack by *E. phalonia*. As a result of the piercing, fruit juice exudate can be seen surrounding the feeding holes, discolouring the skin of the fruit (Figure 14). Internally, the damaged tissue becomes spongy and dry and the fruit can lose their market value (Figure 15) (Reddy et al. 2007).

Interestingly, secondary moth feeders often visit fruit damaged by fruit-piercing moths, taking advantage of the access holes to feed on the fruit (DAF 2017). While minor feeding events by *E. phalonia* can directly blemish fruit, heavy feeding by the pest can destroy it (Davis et al. 2005). Early fruit drop has also been reported as a symptom of fruit-piercing moth damage (Figure 14) (Fay 2002).

Figure 14. A. Damage caused by fruit-piercing moth in citrus, B. Fruit drop of damaged fruit. Source Cheraghian (2015).

Figure 15. Internal damage caused by fruit-piercing moth in citrus. Source Cheraghian (2015).

Reported losses in crops caused by *E. phalonia* alone are not always easily identifiable because of the presence of other *Eudocima* species (Fay & Halfpapp 1999). *E. phalonia* may comprise up to 90% of moths causing damage to fruit within a crop. Approximately 90% of moths causing damage on lychees and carambola fruit in Queensland, Australia, were recorded as *E. phalonia* (Fay & Halfpapp 1993b). Banziger (1982) reported that *E. phalonia* was responsible for approximately 50–70% and 70–90% of primary damage caused by fruit-piercing moths on citrus and longan in Thailand respectively. According to Fay (2002), damage by fruit-piercing moth is sometimes undetected because of early fruit drop or pathogen attack.

Damage in citrus crops by fruit-piercing moths is well reported and damage can vary considerably. Waterhouse & Norris (1987) reported up to 95% of citrus crops had been lost in New Caledonia. In Fiji, 10–15% of ripe fruit was regularly lost (Kumar & Lal 1983), with losses of up to 73% reported in some years (Waterhouse & Norris 1987). Crop losses of 20-30% were reported in China (Cai & Geng 1997), and losses of 10-55% were reported in India (Dadmal & Pawar 2001).

In New Caledonia, up to 100% of tomatoes have been damaged by *E. phalonia* in some seasons (Waterhouse & Norris 1987). Similarly, the tomato crop in American Samoa was completed devastated by *E. phalonia* in 1961 (Comstock 1963).

A number of authors have reported that although *E. phalonia* adults may attack fruits of varied ripeness, they have a preference for ripe fruits (Baptist 1944; Fay & Halfpapp 1993b; Denton et al. 1999; Fay 2002). According to Fay (2002) and Kumar (1983) green fruits are generally attacked only when moth populations are high. Fay & Halfpapp (1993b) reported significant differences in soluble solids content (°Brix), fruit colour and pH between undamaged and damaged carambola fruit in Australia. Early maturing varieties and certain cultivars of fruits may be more susceptible to damage by *E. phalonia*. Fay & Halfpapp (2006) reported that navel oranges and certain mandarins are more susceptible to attack than other species and cultivars.

1.5.2 Secondary damage

Secondary infection may result through pathogenic contamination of fruit at the wounding site and can cause rotting and premature fruit drop (Sands et al. 1993). Pathogens found in association with *E. phalonia* damage include *Fusarium* and *Oospora* species (Hargreaves 1936).

1.5.3 Damage to kiwifruit

Kiwifruit (*Actinidia* spp.) is recorded as a host of *E. phalonia* (Waterhouse & Norris 1987; Fay & Halfpapp 1993a; Martin-Kessing & Mau 1993; Denton et al. 1999); however, no information has been given in relation to the level or appearance of damage. C. Richardson (Zespri Group Ltd) confirmed damage has been recorded on *Actinidia chinensis* var. *chinensis* ‘Hort16A’ growing in Queensland (Australia) but the occurrence and amount of damage is seasonal. In 2018, one uncovered orchard lost 30–40% of the crop but a neighbouring netted orchard had no damage. Fruit are reported to drop 3–4 days after being attacked by the moth.

1.6 Pest status

E. phalonia is regarded as one of the most significant invasive pests in the Pacific region (Waterhouse & Norris 1987), capable of causing significant damage to crops of economic importance.

In eastern Australia, *E. phalonia* is an important pest species in southern Queensland and northern New South Wales (Sands & Schotz 1991). Although the species occurs as far south as Wollongong, it is not regarded as a pest species in its southern range.

Denton et al. (1999) commented that although *E. phalonia* was found throughout Micronesia, the pest status varied between islands. It is considered a major pest on Guam, Tinian, Saipan and Kosrae, but only a minor pest on Rota, Palau and Pohnpei.

E. phalonia is considered a quarantine pest in New Zealand, as well as Argentina, Cambodia, Costa Rica and Brazil (EPPO 2015).

1.6.1 Pest status in kiwifruit

The economic impacts on kiwifruit have not been documented. However, if *E. phalonia* were to establish on kiwifruit in New Zealand significant economic loss would be inevitable. *E. phalonia* would be classified as a production pest because of the damage caused to fruits.

1.7 Biology and ecology

The biology and ecology of *E. phalonia* have been discussed in detail by a number of authors (Hargreaves 1936; Baptist 1944; Cochereau 1977; Banziger 1982; Kumar & Lal 1983; Waterhouse & Norris 1987; Denton et al. 1999).

1.7.1 Lifecycle

The *E. phalonia* life cycle consists of four main life-stages: egg, larva (5-6 instars), pupa and adult.

The population density and seasonal abundance of *E. phalonia* is influenced by a number of factors including temperature, rainfall, humidity and host plant availability. Fruit-piercing moths (including *E. phalonia*) were recorded from November to August in northern Queensland, Australia (Fay & Halfpapp 1999). Most activity occurred during the summer and autumn fruiting months, with the lowest activity during the drier months (July–October). The authors noted that fruit-piercing moth breeding is low during the latter part of the drier months, as its larval host plant *T. smilacina* is generally leafless over this period.

Kumar & Lal (1983) reported that females lay eggs from June to October in Fiji. The larval population peaks in August and is low from November to May.

E. phalonia lays its eggs on host plants year round in Micronesia, with a peak in the wetter season when food is widely available for developing larvae (Denton et al. 1999).

In China, four to five overlapping generations of *E. phalonia* occur every year, the first generation of which appears in late March (Cai & Geng 1997).

In Malaysia, *E. phalonia* was detected during most of the year, with the highest flight activity coinciding with the main fruiting season during the dry months (May-June). The lowest flight activity occurred from September to February, during the wet season (Leong & Kueh 2011).

1.7.2 Eggs

E. phalonia eggs hatch in approximately 3–4 days at 25–33°C (Hargreaves 1936; Kumar & Lal 1983; Waterhouse & Norris 1987; Kueh 2012). Denton et al. (1999) reported *E. phalonia* egg hatch 2–4 days following egg lay in Micronesia, with no reference to temperature. Eggs are usually laid singly on the underside of leaves; however, they may also be laid on the bark or vegetation in close proximity to the host plant. When *E. phalonia* adult populations are high, egg batches comprising up to several hundred eggs may be laid (Waterhouse & Norris 1987).

Sands & Schotz (1991) reported that a single *E. phalonia* female laid 530 eggs in one night and that *E. phalonia* eggs were laid singly or in pairs in Australia. However, in the Pacific Islands the pest may lay large batches of eggs, especially on *Erythrina* spp.

1.7.3 Larvae

Larval development times can vary in relation to the quality of the host plant (Fay 1994). *E. phalonia* larvae reared on the leaves of *Erythrina variegata and E. lithosperma* required approximately 21 days at 28–33°C (Table 2) (Kumar & Lal 1983). Kueh (2012) reared *E. phalonia* on bandicoot berry (*Leea indica*) in the field at 28–32°C, and the mean larval developmental period was comparable (20.8 days).

According to Sands & Schotz (1991)**,** *E. phalonia* larvae will search for food for up to 3 days, before dying if a suitable host is not found.

1.7.4 Pupae

Mature *E. phalonia* larvae pupate within a silken cocoon generally spun between leaves and the leaves may stay on the tree or become dessicated and fall to the ground (Waterhouse & Norris 1987) . The pupal developmental period is approximately 14–18 days (Kumar & Lal 1983; Waterhouse & Norris 1987; Kueh 2012). No diapause is known for *E. phalonia.*

1.7.5 Adults

Total development of *E. phalonia* (egg lay to adult emergence) required 43 days at 28–33°C (Table 2) (Kumar & Lal 1983). Kueh (2012) reported that total development required 39.6 days in the field at 28–32°C.

Adult females live for 27–30 days, while adult males live for 26–28 days (Kumar & Lal 1983). Bhumannavar & Viraktamath (2001b) reported the longevity of adult female *Eudocima* spp. (including *E. phalonia*) as 40 days. Sands & Schotz (1991) found no difference in adult longevity between moths fed a 10% sucrose solution and those fed ripe banana.

The sex ratio of adult moths within an orchard can vary with fruit variety, ripeness of fruit, or distance between moth feeding and larval breeding sites (Sands & Schotz 1991). Male fruit-piercing moth tend to be more common in field populations. In Australia, the majority (two-thirds) of feeding *E. phalonia* moths were found to be male (Fay & Halfpapp 1999).

E. phalonia adults are strong fliers and may fly over long distances (Baptist 1944; Waterhouse & Norris 1987). Waterhouse & Norris (1987) and Maddison (1982) noted that *E. phalonia* occasionally arrives in New Zealand, although it is not established here. Davis et al. (2005) commented that *E. phalonia* have been reported to live several months in cooler climates. *E. phalonia* adults migrate annually from the tropics to temperate regions in eastern Australia (Sands & Schotz 1991). This migration occurs in late spring or early summer (Sands & Schotz 1991).

Mating takes place 24–72 h after emergence when *E. phalonia* are held in field cages (Sands & Schotz 1991). In Australia, 53% of field-collected adult female *E. phalonia* were mated and contained mature oocytes (Fay & Halfpapp 1999). Of the remaining adult females collected, 38% had immature oocytes and were unmated, 3% possessed mature eggs but were unmated, and 6% possessed developed oocytes and contained spermatophores.

The pre-oviposition period of *E. phalonia* adult females varies from 4 to 8 days (Kumar & Lal 1983; Sands & Schotz 1991; Bhumannavar & Viraktamath 2001b). The oviposition and post-oviposition periods of *Eudocima* spp. (including *E. phalonia*) were reported as 7–8 and 25–28 days respectively (Bhumannavar & Viraktamath 2001b).

Large cages, glasshouse or screenhouses were used to successfully rear *E. phalonia* on host plant material (Kumar & Lal 1983; Fay 1994; Muniappan et al. 1995; Bhumannavar & Viraktamath 2001b; Reddy et al. 2005). Bhumannavar & Viraktamath (2001b) commented that sufficient space was required for the moths to mate and lay fertilised eggs.

E. phalonia are nocturnal and moths feed at night from just after dusk (Waterhouse & Norris 1987). The adults continue to feed throughout their lifetime. Baptist (1944) provided a detailed observation of *E. phalonia* feeding behaviour. The adult moth settles on a fruit and subsequently pierces the fruit with its proboscis. The author noted that the proboscis is always inserted in a direct straight line. Magar (2012) reported that a single feeding event took over 30 minutes. A moth may feed on several fruit in a night.

Magar (2012) provided a description of the dissected proboscis of *E. phalonia*. A microscopic investigation of the dissected proboscis "revealed the presence of sclerotised blades, erectile barbs, serrations and the tip of the proboscis was sharply pointed". The proboscises of female and male *E. phalonia* were reported to be 16.20 and 15.13 mm respectively (Magar 2012). Similar results were reported by Ramkumar et al. (2010), who reported proboscis lengths of female and male *E. phalonia* as 17.50 and 15.25 mm respectively. The sclerotized proboscis tips of female and male *E. phalonia* were 1.49 and 1.34 mm respectively. Fay (2002) noted that the *E. phalonia* proboscis penetrates 15 mm into the fruit. Images of the *E. phalonia* proboscis are presented in Figures 16 and 17.

Figure 16. *Eudocima phalonia* proboscis (Photograph source: Museums Victoria (PaDiL)).

Figure 17. Close-up of *Eudocima phalonia* proboscis (Photograph source: Museums Victoria (PaDiL)).

According to Sands & Schotz (1991), female fruit-piercing moths require more food than males and adult moths search for fruit immediately after emergence from their pupae. The authors also reported that each moth will average one to three piercings per night, with young moths piercing more frequently than older moths.

Table 2. Developmental times for *Eudocima phalonia* reared on leaves of *Erythrina variegata* and *E. lithosperma* in the laboratory at 28–33°C in Fiji (Source: Kumar & Lal (1983)).

Developmental stage	Average number of days (± SE)
Egg	4.0 ± 0.0
1st instar larva	4.2 ± 0.16
2nd instar larva	3.6 ± 0.15
3rd instar larva	2.6 ± 0.12
4th instar larva	3.7 ± 0.35
5th instar larva	7.1 ± 0.65
Total larval period	21.2 ± 1.43
Pupa	17.8 ± 0.64
Egg lay to adult emergence	43.0 ± 2.07

1.8 Natural enemies

A number of natural enemies of *E. phalonia* have been identified and studied worldwide (Table 3).

Cochereau (1977) conducted a comprehensive survey of *E. phalonia* natural enemies in New Caledonia.

Sands & Schotz (1991) provided a list of natural enemies of fruit-piercing moths in Australia. However, it was unclear whether the parasitoids (*Ooencyrtus* spp., *Telenomus* sp. (Figure 18) and *Anastatus* sp.) were reared from *Eudocima salamina* or *E. phalonia*.

Sands & Liebregts (2005) conducted surveys for parasitoids of *E. phalonia* in Papua New Guinea in 1987 and 1988. *E. phalonia* is not a pest in Papua New Guinea, where it is believed to be regulated by natural enemies. Surveys revealed two abundant parasitoids: *Ooencyrtus* sp. and *Telenomus lucullus* (Nixon). Further surveys were conducted in Tonga, Samoa, Fiji and the Cook Islands to identify any native natural enemies prior to the importation and release of biological control agents from Papua New Guinea.

A detailed laboratory study into the developmental biology of the larval parasitoid *Euplectrus melanocephalus* was conducted in Australia (Jones & Sands 2002). Muniappan et al. (2004) investigated the developmental biology of *Euplectrus maternus* in Guam.

Figure 18. *Telenomus* sp. ovipositing on eggs of *Eudocima phalonia* eggs. Source Denton et al. (1999).

Table 3. Recorded natural enemies of *Eudocima phalonia*.

	Species	Country or Region	Present in New Zealand	Reference
	Hymenoptera			
Egg parasitoid	*Ooencyrtus* sp.	Micronesia	No	(Muniappan et al. 1993; Denton et al. 1999)
	Ooencyrtus sp.	New Caledonia	No	(Cochereau 1977)
	Ooencyrtus sp.	Papua New Guinea	No	(Sands & Liebregts 2005)
	Telenomus lucullus	Papua New Guinea	No *Telenomus crinisacri* present	(Sands & Liebregts 2005)
	Telenomus sp.	Fiji	*Telenomus crinisacri* present	(Sands & Liebregts 2005)
	Telenomus sp.	Micronesia	*Telenomus crinisacri* present	(Muniappan et al. 1993; Denton et al. 1999)
	Telenomus sp.	New Caledonia	*Telenomus crinisacri* present	(Cochereau 1977)
	Telenomus sp.	Rarotonga, Cook Islands	*Telenomus crinisacri* present	(Sands & Liebregts 2005)
	Telenomus sp.	Tonga	*Telenomus crinisacri* present	(Sands & Liebregts 2005)
	Trichogramma chilonis	Hawaii	*No* *Trichogramma falx, T. funiculatum, T. maori, T. minutum, T. valentinei* present	(Martin-Kessing & Mau 1993)
	Trichogramma sp.	Fiji	*Trichogramma falx, T. funiculatum, T. maori, T. minutum, T. valentinei* present	(Sands & Liebregts 2005)
	Trichogramma sp.	Micronesia	*Trichogramma falx, T. funiculatum, T. maori, T. minutum, T. valentinei* present	(Muniappan et al. 1993; Denton et al. 1999)
	Trichogramma sp.	New Caledonia	*Trichogramma falx, T. funiculatum, T. maori, T. minutum, T. valentinei* present	(Cochereau 1977)
	Trichogramma sp.	Rarotonga, Cook Islands	*Trichogramma falx, T. funiculatum, T. maori, T. minutum, T. valentinei* present	(Sands & Liebregts 2005)
	Trichogramma sp.	Samoa	*Trichogramma falx, T. funiculatum, T. maori, T. minutum, T. valentinei* present	(Sands & Liebregts 2005)
	Trichogramma sp.	Tonga	*Trichogramma falx, T. funiculatum, T. maori, T. minutum, T. valentinei* present	(Sands & Liebregts 2005)

	Species	Country or Region	Present in New Zealand	Reference
Larval parasitoid	**Hymenoptera**			
	Echthromorpha striata	New Caledonia	No *Echthromorpha intricatoria* present	(Cochereau 1977)
	Euplectrus maternus	India	No *Euplectrus agaristae, E. flavipes* present	(Muniappan et al.)
	Euplectrus melanocephalus	Australia	No *Euplectrus agaristae, E. flavipes* present	(Jones & Sands 2002)
	Euplectrus platyhypenae	Fiji	No *Euplectrus agaristae, E. flavipes* present	(Maddison 1982)
	Euplectrus platyhypenae	Hawaii	No *Euplectrus agaristae, E. flavipes* present	(Martin-Kessing & Mau 1993)
	Euplectrus platyhypenae	New Caledonia	No *Euplectrus agaristae, E. flavipes* present	(Cochereau 1977)
	Euplectrus sp.	Indonesia	*Euplectrus agaristae, E. flavipes* present	(Van der Laan 1981)
	Lissopimpla pacifica	New Caledonia	No *Lissopimpla excelsa* present	(Cochereau 1977)
	Diptera			
	Carcelia iridipennis	Indonesia	No	(Bezzi 1925)
	Winthemia caledoniae	New Caledonia	No	(Cochereau 1977)
	Winthemia sp.	American Samoa	No	(Hoyt 1955)
Pupal parasitoid	**Hymenoptera**			
	Brachymeria sp.	Micronesia	*Brachymeria phya, B. rubrifemur, B. teuta* present	(Denton et al. 1999)
	Trichospilus diatraeae	Micronesia	No	(Denton et al. 1999)
Egg predator	**Hemiptera**			
	Germalus montandoni	New Caledonia	No	(Cochereau 1977)
	Nesogermalus dissidens	New Caledonia	No	(Cochereau 1977)
	Ploiaria glabella	New Caledonia	No *Ploiaria chilensis* present	(Cochereau 1977)

	Species	Country or Region	Present in New Zealand	Reference
	Neuroptera			
	Chrysopa basalis	New Caledonia	No	(Cochereau 1977)
	Chrysopa noumeana	New Caledonia	No	(Cochereau 1977)
	Chrysopa otalatis	New Caledonia	No	(Cochereau 1977)
	Nesomicromus tasmaniae	New Caledonia	No	(Cochereau 1977)
	Nothochrysa chloromelas	New Caledonia	No	(Cochereau 1977)
	Synthochrysa montrouzieri	New Caledonia	No	(Cochereau 1977)
	Hymenoptera			
	Monomorium sp.	New Caledonia	*Monomorium antarcticum, M. antipodum, M floricola, M. pharaonic, M. smithii, M. sydneyense* present	(Cochereau 1977)
	Tetramorium sp.	New Caledonia	*Tetramorium bicarinatum, T. grasii*	(Cochereau 1977)
Larval predator	**Hymenoptera**			
	Polistes olivaceus	New Caledonia, Micronesia	No *Polistes chinensis, P. humilis* present	(Cochereau 1977)
	Polistes olivaceus	Micronesia	No *Polistes chinensis, P. humilis* present	(Cochereau 1977) (Denton et al. 1999)
	Mantodea			
	Hierodula patellifera	Micronesia	No	(Denton et al. 1999)
	Tenodera costalis	New Caledonia	No	(Cochereau 1977)
Egg pathogen	**Hypocreales**			
	Fusarium sp.	Micronesia	Numerous species present	(Denton et al. 1999)

2 PEST MANAGEMENT

In this section, the literature was reviewed for existing management methods for *E. phalonia*. Although *E. phalonia* is considered to be an economically significant pest, tools to monitor and manage field populations reliably require further development.

2.1 Monitoring techniques

2.1.1 Visual inspections for adults

Monitoring for *E. phalonia* has often relied on visual inspections of fruit to identify and monitor the presence of the pest. The red eyes of the adult moths reflect light, assisting with the detection of the pest (Gilligan & Passoa 2016).

Fay & Halfpapp (1999) monitored adult fruit-piercing moth activity in carambola and lychee orchards in Queensland, Australia, over a period of 8 years (1985–1993). Monitoring involved the inspection of fruit 30 min after sundown, as the moths are most active in the first few hours of the night. Torches were used to detect the feeding moths for a period of 1 h regardless of weather, and any fruit-piercing moths detected during the inspection were collected into a small cage (30 x 30 x 30 cm). *E. phalonia* was found to be the major species in both the carambola and lychee orchards in the coastal and tableland sites from November to mid-March.

Fruit-piercing moth activity is best determined by visually assessing fruit using a torch every few weeks prior to harvest (Fay 2002). Assessments should focus on the two outer rows of an orchard, as over 80% of damage by fruit-piercing moth occurs in the outer rows of trees (Fay & Halfpapp 1993b).

Gilligan & Passoa (2016) produced a screening aid document detailing a visual survey method for *E. phalonia* in fruit orchards.

2.1.2 Trapping adults using fruit baits

Fruit bait traps have also been used to monitor seasonal populations of *E. phalonia*, with banana baits the most commonly used. Leong & Kueh (2011) monitored the seasonal population of *E. phalonia* in a citrus orchard and adjacent forest in the Kuching District of Sarawak in Malaysia. Fresh ripe bananas were used as bait within large cages (1.8 x 1.8 x 1.8 m) during the local mandarin growing seasons (July 2007–January 2009). The fresh bananas were replaced every 3 days, and the moths caught in each cage recorded on the same day. Kueh (2012) also used fresh ripe bananas as bait within smaller cages (0.6 x 0.6 x 0.6 m) during the local mandarin growing seasons (January 2008–June 2009). Methodology for the placement of fresh bananas and recording of moths was the same as that given by Leong & Kueh (2011).

Fay (2002) noted that approximately 20 banana baited traps/ha are occasionally placed around the periphery of orchards to monitor *E. phalonia*. Growers consider 2–3 moths caught per night in a single trap as significant. However, the author questioned the commercial efficacy of these large traps to monitor the pest.

When provided with different fruit baits, *E. phalonia* adults were attracted to baits in the following order (most attractive to least attractive): banana, guava, orange, kiwifruit, apple, pineapple, pear, papaya, mango, grapefruit, tomato, green grape, star fruit, plum, sour sop

(Reddy et al. 2007). This is consistent with the findings of Denton et al. (1999), who found that banana was most preferred by *E. phalonia* adults, compared with guava, mango, papaya and other fruits. Reddy et al. (2007) also found that *E. phalonia* adults were significantly more attracted to fruit puree with Agar or Phytagel™ than fruit puree with Agarose.

2.1.3 Attractants

No commercial lure is currently available for monitoring *E. phalonia.* However, the development of attractants is an active area of research. A PhD student based in New Caledonia is currently investigating the fruit volatiles which may be attractive to *E. phalonia* (L. Leroy, pers. comm. 2018). Part of this research will be conducted at Plant & Food Research (Lincoln). Research in relation to the sex pheromone of *E. phalonia* is underway in Queensland, Australia (S. De Faveri, pers. comm. 2019), and Agri-Science Queensland (Australia) has created a bait to lure and kill fruit-piercing moths (*Eudocima* spp.). This bait is yet to be commercialised.

In Australia, chemical attractant blends were developed and were primarily based on the odour components of kiwifruit. Different ratios of the fruit volatiles were incorporated into sugar-based baits (artificial ‘fruit’) and tested for attractiveness in both flight cage and field experiments in a citrus orchard (Fay & Halfpapp 1994). Results indicated that ripe ‘fruit’ were more attractive than the mature or very ripe ‘fruit’. Fay & Halfpapp (2001) conducted further field experiments and found that baits with aldehydes, esters and an alcohol were more attractive to primary fruit-piercing moths, including *E. phalonia,* compared with baits containing esters only. Also, highly volatile general fruit esters (for instance n-butyl acetate and methyl butyrate) were more attractive than less volatile, more specific esters. In addition, dipping baits into a hot paraffin wax extended the field life of baits and did not affect the attractiveness of the baits. The authors noted that prior to peak moth numbers, baits could be placed in every third or fourth tree within an orchard. However, numbers of baits may need to be increased in orchards at harvest.

Monitoring of *E. phalonia* in lychees and carambolas in Australia found that the majority (two-thirds) of feeding moths were males (Fay & Halfpapp 1999). The female-produced sex pheromone of *E. phalonia* is yet to be isolated and identified, and the synthesised attractant could be a significant monitoring and control tool (Fay 2002). The sex pheromone of a related moth species (*Oraesia excavata* Butler) has been identified, and comprises of expoxides derived from long-chained unsaturated hydrocarbons (Ohmasa et al. 1991).

2.2 Management options

A number of management options have been trialled for *E. phalonia* (Reddy et al. 2005). Authors have recommended an integrated approach for the management of *E. phalonia* including the use of biological control, bagging of fruit and netting trees; however, this system is yet to be implemented because of cost (Fay 2002; Muniappan et al. 2002) (Table 5).

2.2.1 Chemical

There is a lack of data concerning the chemical control of *E. phalonia.* Leong & Kueh (2011) reported that the use of a horticultural mineral oil (HMO) was effective in reducing the degree of fruit damage by *E. phalonia* within a mandarin orchard. There was no significant difference in fruit damage between dimethoate- and HMO-treated plots.

Fay & Halfpapp (2001) highlighted that the successful control of fruit-piercing moths such as *E. phalonia* may be difficult with conventional insecticide sprays as (a) the adult moth has insufficient contact time with the fruit affecting moth mortality, and (b) fruit are generally damaged late in the season, approaching harvest. Therefore, an appropriate withholding period may not be attained. Other authors also commented that the application of insecticides for the control of *E. phalonia* was undesirable (Fay 2002; Reddy et al. 2007).

Chemical insecticides would need to be applied to both local adult moth populations and the larval host plants (Denton et al. 1999). However, larval host plants are often located a considerable distance away from the foraging areas of adult moths, making implementation difficult.

2.2.2 Cultural

Bagging of fruit

In certain regions of Asia, bags are used to cover fruit during pest susceptible periods (Banziger 1982). Although effective in preventing damage by *E. phalonia* and other economic pests, it is a labour-intensive management option. Fay (2002) commented that this option is not commercially viable for many crops in Australia except for those of high value such as persimmons or certain varieties of mango. Previous studies on the bagging of *A. chinensis* var. *chinensis* ‘Hort16A’ to prevent insect damage similarly found the practice to be cost-prohibitive (McKenna & Maher 2000).

Netting on individual trees or blocks

According to Fay (2002), tree or block netting (10 x 10 mm mesh) may provide a management option for *E. phalonia* in high value crops within a limited area. Anecdotal evidence from Queensland also suggests that netted kiwifruit blocks, with the side nets being dropped at night, are less likely to be damaged by *E. phalonia* (C. Richardson, Zespri pers. comm. 2019).

Early harvest of fruit

Some crops could be harvested early, but for the majority of fruit crops, maturity guidelines would prevent this (Underhill & Wong 1990).

Removal of larval host plants

E. phalonia can fly over considerable distances, but localised populations are a significant contributing factor to pest populations within an orchard. In situations where it is practical, the removal of larval host plants may be beneficial (Fay 2002).

Block plantings

Planting fruit crops in large square blocks rather than long narrow blocks should reduce damage by *E. phalonia* (Fay 2002). This is because damage primarily occurs in the outer rows of trees within an orchard.

Light barriers

Fay & Halfpapp (1995) reported that fruit-piercing moth are repelled by light and activity could be reduced by 60–70% with the use of yellow light barriers formed around carambola blocks in Australia. However, Fay (2002) noted that this management option required significant infrastructure and access to electricity.

Hand collection of moths

Baptist (1944) suggested that the hand collection of moths was best achieved with a hand net and a torch. *E. phalonia* adults could be followed at night without difficulty and caught while the moths were feeding. Dodia et al. (1986) also recommended this method.

2.2.3 Biological

A number of attempts have been made to introduce and establish biological control agents of *E. phalonia,* with varying success (Table 4) (Kumar & Lal 1983; Waterhouse & Norris 1987; Muniappan et al. 2004; Sands & Liebregts 2005).

Early attempts to control *E. phalonia* in American Samoa and Samoa with the egg parasitoid *Ooencyrtus cochereaui* were unsuccessful (Waterhouse & Norris 1987). The parasitoid *Winthemia caledoniae* was released into Tonga from New Caledonia in 1973 and into Fiji from New Caledonia in 1983–84 but also failed to establish in both countries (Waterhouse and Norris, 1987).

The egg parasitoids *Ooencyrtus* sp. and *Telenomus lucullus* were introduced to Samoa, Fiji, Tonga and the Cook Islands. Both species established in Fiji and Tonga. Only *Telenomus lucullus* established in Samoa, and only *Ooencyrtus* sp. established in the Cook Islands (Sands et al. 1993).

Sands et al. (1993) commented that although field data showed increases in egg parasitism and decreases in fruit-piercing moth larvae in the countries where *Ooencyrtus* sp. and *T. lucullus* were released, decreases in adult moth numbers were difficult to determine. The authors also noted that *Ooencyrtus* sp. and *T. lucullus* were not released into Australia because of host specificity testing results. When non-target indigenous Australian Noctuidae in the presence of host plant material were exposed to the parasitoids, *Ooencyrtus* sp. oviposited in the eggs of all the non-target species. However, when the eggs were exposed in the absence of plant material (on gauze only), *Ooencyrtus* sp. did not oviposit in the eggs.

The larval parasitoid *Euplectrus maternus* was released into Guam from India in 1998–99 for the biological control of *E. phalonia* (Muniappan et al. 2004). A total of 5059 were released over a 27-month period. However, *E. maternus* has not established in Guam. The authors suggested that the parasitoid, introduced from India where *E. maternus* parasitises *Eudocima* spp. on Menispermaceae, had not adapted to parasitising *E. phalonia* in Guam, where *E. phalonia* feeds on *Erythrina* spp.

Table 4. Introductions of parasitoids for biological control of *Eudocima phalonia*. Based on Sands & Liebregts (2005).

	Species	Country of origin	Country released	Established?	Reference
Egg parasitoid	*Ooencyrtus cochereaui*	New Caledonia	American Samoa	No	(Waterhouse & Norris 1987)
	Ooencyrtus cochereaui	New Caledonia	Samoa	No	(Waterhouse & Norris 1987)
	Ooencyrtus crassulus	Samoa	Tonga (1992)	Yes	(Sands & Liebregts 2005)
	Ooencyrtus sp.	Papua New Guinea	Samoa (1989)	No	(Sands & Liebregts 2005)
	Ooencyrtus sp.	Papua New Guinea	Fiji (1992)	Yes	(Sands & Liebregts 2005)
	Ooencyrtus sp.	Papua New Guinea	Tonga (1992)	Yes	(Sands & Liebregts 2005)
	Ooencyrtus sp.	Papua New Guinea	Cook Islands (1996)	Yes	(Sands & Liebregts 2005)
	Telenomus lucullus	Papua New Guinea	Samoa (1989)	Yes	(Sands & Liebregts 2005)
	Telenomus lucullus	Papua New Guinea	Fiji (1992)	Yes	(Sands & Liebregts 2005)
	Telenomus lucullus	Papua New Guinea	Tonga (1993)	Yes	(Sands & Liebregts 2005)
	Telenomus lucullus	Papua New Guinea	Cook Islands (1996)	No	(Sands & Liebregts 2005)
Larval parasitoid	*Euplectrus maternus*	India	Guam (1998-99)	No	(Muniappan et al. 1993)
	Winthemia caledoniae	New Caledonia	Fiji (1983-84)	No	(Kumar & Lal 1983)
	Winthemia caledoniae	New Caledonia	Tonga (1979)	No	(Waterhouse & Norris 1987)

Table 5. Current and potential methods for pre- and post-harvest management of fruit-piercing moth, *Eudocima phalonia.*

	Target life stage	Method	Expected outcomes(s)	Likely impact on *E. phalonia* populations	Used elsewhere	Key limitation(s)	Ease of on orchard implementation	Technical difficulty of research	Relative development costs	Developmental time <3 years, 4-6 y, >7 y
Monitoring	All	Surveying	Detect presence of *E. phalonia*	Low	Australia	Survey areas may not be representative	Easy	Easy	Low	Short
Monitoring	Adult	Trapping (fruit baits)	Detect presence of *E. phalonia*. Estimate of seasonal phenology	Low-medium	Australia, Malaysia, Guam	Ongoing replacement of fruit	Easy	Easy	Low	Short
Monitoring	Adult	Attractants	Improved trapping. Use in lure and kill approach	Medium	No. Experimental only (Australia, New Caledonia)	Ongoing replacement of attractant	Easy	Moderate	Medium	Medium
Chemical	Larvae	Foliar sprays (contact or systemic) applied to larval host plants	Knock-down and/or persistent activity	Medium	Unknown	Locating larval populations off-orchard. Efficacy. Potential spraying in public areas	Easy (on orchard) Moderate (off-orchard)	Moderate	Medium (if already present in New Zealand)	Medium
Cultural	Adult	Bagging fruit	Prevention of fruit damage by feeding adult moths	Low	Asia, Australia	Extremely labour intensive	Difficult	Moderate	Medium	Medium
Cultural	Adult	Netting trees or blocks	Prevention of fruit damage by feeding adult moths	Low	Australia	Cost of implementation Potential impacts on pollination, beneficial insects, fruit quality	Easy (if orchard blocks already partially covered) Moderate (if blocks require complete netting)	Easy	Low	Short

	Target life stage	Method	Expected outcomes(s)	Likely impact on *E. phalonia* populations	Used elsewhere	Key limitation(s)	Ease of on orchard implementation	Technical difficulty of research	Relative development costs	Developmental time <3 years, 4-6 y, >7 y
	Adult	Light barriers	Reduced flight activity and feeding in orchards	Low	Australia	Infrastructure required Potential light pollution if orchard near township	Moderate	Moderate	Medium	Medium
	Larvae	Larval host plant removal combined with herbicide application	Reduced number of host plants	Medium	Unknown	Unknown host range in New Zealand.	Easy (on-orchard) Moderate (off-orchard)	Easy	Low	Short
Biological	All	Classical biocontrol - introduction of new parasitoids	Ongoing population suppression	Medium	Natural enemies identified. Research in New Caledonia, Papua New Guinea, Samoa, Tonga, Guam, Cook Islands, Fiji	No natural enemies identified in New Zealand Identification and rearing of suitable parasitoid Regulatory approvals	Easy, once research is complete	Difficult	High	Long
	Larvae Adults	Entomopathogens	Medium-term population suppression	Medium	Unknown	Entomopathogens yet to be identified Offshore products may not be suitable for use in New Zealand and on kiwifruit.	Easy, once research is complete	Moderate	Medium-high	Medium–long

3 PEST MANAGEMENT IN KIWIFRUIT

Damage caused by *E. phalonia* to kiwifruit could cause significant production losses to the New Zealand kiwifruit industry. Following the review of the available literature concerning *E. phalonia*, there appear to be significant gaps in the data concerning control options for the pest. If *E. phalonia* were to establish in New Zealand, control would require an integrated approach, encompassing approved insecticides, cultural methods, new technologies such as lure and kill, and biological control, with monitoring playing a crucial role to in determining population abundance and spread. Further research is required to address these knowledge gaps.

3.1 Chemical control

Chemical control of adult *E. phalonia* is not considered a viable option. *E. phalonia* are nocturnal, and moths feed on fruiting crops at night then subsequently return to surrounding bush. As previously mentioned, the moth has insufficient contact with the fruit, affecting moth mortality, and fruit are usually damaged late in the season, approaching harvest. Therefore, an adequate withholding period cannot be attained (Fay & Halfpapp 2001). However, chemical control of *E. phalonia* larvae on nearby host plants may be an option.

3.2 Cultural control

Of the cultural practices that have been investigated overseas against *E. phalonia*, several may have potential for use in kiwifruit orchards.

A number of growers already use nets to cover their kiwifruit blocks. While some are fully enclosed (with netting to ground level along the sides), others are not. These fully enclosed nets have the potential to exclude adult *E. phalonia* from the crop but would involve an extra cost to growers. Also, there are a number of potential limitations to the use of fully enclosed nets. These limitations are currently being reviewed (McKenna in prep.) and include negative impacts on dry matter, pollination and increasing populations of other pests. However, it may be possible to drop the side netting in the evening and raise it in the morning to overcome these issues while excluding feeding adult moths at night.

In situations where netting is not considered practical or cost-effective, the use of night lights as a repellent may be an option. *E. phalonia* adults are repelled by light, and surrounding at-risk blocks with lights may help to reduce the incidence of moth attack. This technique would require new infrastructure, but with the ready availability of solar energy it may be a cost-effective solution. An assessment may be required to confirm the impact of the lights on non-target species.

The removal of larval host plants may be an important step to slow the spread of *E. phalonia* should the pest establish in New Zealand. *Erythrina* x *sykesii* is considered a weed in New Zealand. Identification of these host plants and either removal (or treatment where removal is not feasible), will probably help to reduce the increase and spread of *E. phalonia* into kiwifruit blocks.

Identification of attractants based on pheromone or plant volatiles would allow for the development of lure and kill technology. As this is an active area of research in Australia and New Caledonia, collaborations between New Zealand and these overseas researchers should be maintained and strengthened.

3.3 Biological control

To date, no known biological agents of *E. phalonia* have been identified as present in New Zealand. A classical biological control programme would be required for biocontrol to have a role in the long-term management of *E. phalonia* populations in New Zealand. The use of biopesticides and entomopathogens as control agents has received little focus offshore and also warrants investigation.

3.4 Summary

Table 6 summarises the potential methods that could enable a fit-for-purpose management system for *E. phalonia*. There are significant gaps concerning definitive control options for *E. phalonia.* Below we outline potential questions and/or research gaps which Zespri may wish to consider for the development of a management plan.

- Of the management options mentioned, the use of semiochemicals may show the most promise for future management of *E. phalonia*. Preliminary work has been conducted overseas on fruit volatile attractants and the *E. phalonia* sex pheromone, but further research is needed. Collaborations with Australian and New Caledonian researchers would be beneficial. Applications would include monitoring, trapping and mating disruption. The semiochemicals could also be used in conjunction with enhanced trap design and the use of an insecticide, to create a “lure and kill” system.
- Climate-matching analysis concerning the potential arrival and establishment of *E. phalonia* in New Zealand would assist in predicting areas (including kiwifruit-growing regions) at most risk.
- Very few papers have been published since 2010 concerning control options for *E. phalonia.* It would be worthwhile determining whether other management options are currently being trialled for *E. phalonia* overseas.
- It would be useful to understand the current status of *E. phalonia* in the Pacific Islands following the introduction of the biological control agents.

Table 6. A potential management plan for fruit-piercing moth, *Eudocima phalonia*, in kiwifruit (based on methods currently available). All techniques would be suitable for use in both conventional and organic orchards. CPP = Crop Protection Programme.

Period	Method	Active Ingredient	Product name (available in New Zealand)	Allowed in CPP	Adverse impact risk	Comments
Dormant	Primary host plant removal	NA	NA	Yes	Low	
Fruit-set to monitoring	Netting	NA	NA	Yes	None	Top and side nets would be required
	Spraying of larval host plants	Multiple options listed in CPP	Refer to CPP	Yes	Low	Multiple options targeting lepidopteran pests are listed in the CPP. Testing against *E. phalonia* larvae would be required
	Repellent lights	NA	NA	Yes	Low	Would be unsuitable for use in built-up areas
Monitoring	Trapping with fruit baits	NA	NA	Yes	None	
	Visual inspections	NA	NA	Yes	None	

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APPENDIX 1. HOST PLANT LIST FOR ADULT *EUDOCIMA PHALONIA*. BASED ON DAVIS ET AL. (2005).

Family	Host species	Common name	References
Actinidiaceae	*Actinidia chinensis*	Chinese gooseberry (Kiwifruit)	(Waterhouse & Norris 1987; Fay & Halfpapp 1993a; Martin-Kessing & Mau 1993; Denton et al. 1999)
Anacardiaceae	*Anacardium occidentale*	cashew nut	(Baptist 1944; Cochereau 1977; Waterhouse & Norris 1987)
Anacardiaceae	*Mangifera indica*	mango	(Baptist 1944; Cochereau 1977; Banziger 1982; Kumar & Lal 1983; Waterhouse & Norris 1987; Fay & Halfpapp 1993b; Muniappan et al. 2004)
Anacardiaceae	*Spondia axillaris*	hog plum	(Banziger 1982)
Annonaceae	*Annona squamosa*	custard apple	(Waterhouse & Norris 1987; Denton et al. 1999)
Annonaceae	*Annona squamosa*	sugar apple	(Cochereau 1977)
Baccaurea	*Baccaurea* sp.		(Banziger 1982)
Bromeliaceae	*Ananas comosus*	pineapple	(Cochereau 1977; Waterhouse & Norris 1987)
Cactaceae	*Opuntia*	pricklypear	(Cochereau 1977)
Caricaceae	*Carica papaya*	pawpaw	(Cochereau 1977; Banziger 1982; Kumar & Lal 1983; Waterhouse & Norris 1987; Fay & Halfpapp 1993b)
Cucurbitaceae	*Citrullus lanatus* var. *lanatus* *(syn= Citrullus vulgaris)*	watermelon	(Cochereau 1977)
Cucurbitaceae	*Cucumis melo*	melon; cantaloupe	(Cochereau 1977)
Cucurbitaceae	*Cucumis* sp.	melon	(Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Denton et al. 1999)
Ebenaceae	*Diospyros grandulosa*		(Banziger 1982)

Family	Host species	Common name	References
Ebenaceae	*Diospyros kaki*	persimmon	(Banziger 1982; Waterhouse & Norris 1987; Fay & Halfpapp 1993b)
Irvingiaceae	*Irvingia malayana*	pauh kijang	(Banziger 1982)
Lamiaceae	*Vitex pinnata*	milla	(Banziger 1982)
Lardizabalaceae	*Akebia quinata*	five-leaf akebia	(Shiraki 1952)
Lardizabalaceae	*Akebia trifoliata*	three-leaf akebia	(Shiraki 1952)
Meliaceae	*Sandoricum koetjape*	santol	(CABI 2019)
Moraceae	*Artocarpus altilis*	breadfruit	(Cochereau 1977; Waterhouse & Norris 1987)
Moraceae	*Artocarpus heterophyllus*	jackfruit	(Cochereau 1977)
Moraceae	*Ficus carica*	common fig	(CABI 2019)
Moraceae	*Ficus edulis*	fig	(Cochereau 1977)
Moraceae	*Ficus hispida*	rough-leafed fig	(Banziger 1982)
Moraceae	*Ficus racemosa*	cluster fig	(Banziger 1982)
Moraceae	*Ficus* sp.	fig	(Cochereau 1977; Waterhouse & Norris 1987)
Musaceae	*Musa paradisiaca* var. sapientium	plantain	(Cochereau 1977)
Musaceae	*Musa* sp.	banana	(Waterhouse & Norris 1987; Muniappan et al. 1995; Muniappan et al. 2004)
Myrtaceae	*Eugenia brasiliensis*	brazil cherry	(CABI 2019)
Myrtaceae	*Psidium cattleianum*	strawberry guava	(CABI 2019)
Myrtaceae	*Psidium guajava*	guava	(Cochereau 1977)

Family	Host species	Common name	References
Myrtaceae	*Psidium* sp.	guava	(Banziger 1982; Kumar & Lal 1983; Banziger 1987; Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Sands et al. 1993; Denton et al. 1999)
Myrtaceae	*Syzygium jambos*	rose apple	(Banziger 1982)
Myrtaceae	*Syzygium malaccense*	Malay apple	(CABI 2019)
Oxalidaceae	*Averrhoa carambola*	carambola; starfruit	(Cochereau 1977; Waterhouse & Norris 1987; Fay & Halfpapp 1993b)
Passifloraceae	*Passiflora edulis*	passionfruit	(Waterhouse & Norris 1987)
Myrtaceae	*Passiflora quadrangularis*	giant granadilla	(Cochereau 1977)
Pontederiaceae	*Eichhornia*	water hyacinth	(CABI 2019)
Punicaceae	*Punica granatum*	pomegranate	(Baptist 1944; Banziger 1987, Bhumannavar & Viraktamath 2001a, Muniappan et al. 2004)
Rosaceae	*Fragaria* sp.	strawberry	(Banziger 1982)
Rosaceae	*Malus domestica*	apple	(Waterhouse & Norris 1987)
Rosaceae	*Prunus armeniaca*	apricot	(Waterhouse & Norris 1987)
Rosaceae	*Malus sylvestris*	crab-apple tree	(CABI 2019)
Rosaceae	*Prunus americana*	American plum	(CABI 2019)
Rosaceae	*Prunus domestica*	plum	(Denton et al. 1999)
Rosaceae	*Prunus persica*	peach	(Cochereau 1977; Waterhouse & Norris 1987; Denton et al. 1999)
Rosaceae	*Prunus persica var. nectarina*	peach	(Cochereau 1977; Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Denton et al. 1999)
Rosaceae	*Prunus salicina*	Japanese plum	(CABI 2019)
Rosaceae	*Prunus* sp.	stonefruit	(Sands et al. 1993)

Family	Host species	Common name	References
Rosaceae	*Pyrus* sp.	pear	(Shiraki 1952)
Rosaceae	*Rubus* sp.		(Banziger 1982)
Rubiaceae	*Coffea arabica*	arabica coffee	(Cochereau 1977)
Rubiaceae	*Coffea* sp.	coffee	(Waterhouse & Norris 1987; Denton et al. 1999)
Rutaceae	*Casimiroa edulis*	white sapote	(CABI 2019)
Rutaceae	*Citrus*		(Baptist 1944; Kumar & Lal 1983; Bhumannavar & Viraktamath 2001a)
Rutaceae	*Citrus autantifolia*	lime	(Cochereau 1977; Denton et al. 1999)
Rutaceae	*Citrus reticulata*	mandarin	(Baptist 1944; Cochereau 1977; Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Denton et al. 1999)
Rutaceae	*Citrus limon*	lemon	(Cochereau 1977; Denton et al. 1999)
Rutaceae	*Citrus maxima*	pummelo	(Cochereau 1977; Denton et al. 1999)
Rutaceae	*Citrus sinensis*	orange	(Baptist 1944; Comstock 1963; Cochereau 1977; Banziger 1982; Kumar & Lal 1983; Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Denton et al. 1999; Bhumannavar & Viraktamath 2001a; Muniappan et al. 2004)
Rutaceae	*Citrus sinensis ‘Navel’*	Navel orange	(Waterhouse & Norris 1987; Martin-Kessing & Mau 1993)
Rutaceae	*Citrus x paradisi*	grapefruit	(Baptist 1944; Comstock 1963; Kumar & Lal 1983; Dodia et al. 1986; Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Denton et al. 1999)
Salviniaceae	*Salvinia molesta*	Kariba weed	(CABI 2019)
Sapindaceae	*Dimocarpus longan*	longan tree	(Banziger 1982, 1987; Fay & Halfpapp 1993b; Martin-Kessing & Mau 1993; Sands et al. 1993; Denton et al. 1999)
Sapindaceae	*Litchi chinensis*	lychee	(Banziger 1982, 1987; Waterhouse & Norris 1987; Fay & Halfpapp 1993b; Martin-Kessing & Mau 1993; Sands et al. 1993; Fay 1994; Denton et al. 1999; Fay & Halfpapp 1999; Muniappan et al. 2004)

Family	Host species	Common name	References
Sapindaceae	*Nephelium lappaceum*	rambutan	(Banziger 1982)
Sapindaceae	*Pometia pinnata*	fijian longan	(CABI 2019)
Sapotaceae	*Chrysophyllum cainito*	cainito, star apple	(CABI 2019)
Solanaceae	*Capsicum annuum*	bell pepper	(Cochereau 1977; Denton et al. 1999)
Sapotaceae	*Capsicum* sp.	capsicum	(Waterhouse & Norris 1987)
Solanaceae	*Solanum lycopersicum*	tomato	(Baptist 1944; Comstock 1963; Cochereau 1977; Kumar & Lal 1983; Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Denton et al. 1999; Bhumannavar & Viraktamath 2001a; Muniappan et al. 2004)
Sapotaceae	*Solanum melongena*	aubergine, eggplant	(Denton et al. 1999; Muniappan et al. 2004)
Solanaceae	*Muntingia calabura*	Jamaica cherry	(Banziger 1982)
Vitaceae	*Vitis* sp.	grape	(Banziger 1982; Denton et al. 1999; Muniappan et al. 2004)
Vitaceae	*Vitis vinifera*	grapevine	(CABI 2019)
Vitaceae	*Leea indica*	bandicoot berry	(Banziger 1982)

APPENDIX 2. HOST PLANT LIST FOR LARVAL *EUDOCIMA PHALONIA*. BASED ON DAVIS ET AL. (2005).

Family	Host species	Common name	References
Clusiaceae	*Garcinia mangostiana*[1]	mangosteen	(Banziger 1982)
Ebenaceae	*Diospyros australis*[1]	black plum	(Denton et al. 1999)
Euphorbiaceae	*Excoecaria reticulata*	duiker berry	(Hargreaves 1936)
Fabaceae	*Erythrina berteroana*[1]	machete	(Waterhouse & Norris 1987)
Fabaceae	*Erythrina crista-galli*	crybaby tree	(Waterhouse & Norris 1987; Muniappan et al. 1993)
Fabaceae	*Erythrina fusca*	bucayo	(Baptist 1944; Cochereau 1977; Waterhouse & Norris 1987; Muniappan et al. 1993; Fay 1996)
Fabaceae	*Erythrina herbacea*[1]		(Waterhouse & Norris 1987)
Fabaceae	*Erythrina pallida*		(Waterhouse & Norris 1987)
Fabaceae	*Erythrina parcelli*		(Waterhouse & Norris 1987)
Fabaceae	*Erythrina* sp.		(Comstock 1963; Cochereau 1977; Banziger 1982, 1987; Waterhouse & Norris 1987; Muniappan et al. 1993; Sands et al. 1993; Sands & Chan 1996; Denton et al. 1999)
Fabaceae	*Erythrina subumbrans*	December tree; dadap	(Kumar & Lal 1983; Waterhouse & Norris 1987; Muniappan et al. ; Fay 1996)
Fabaceae	*Erythrina tahitensis*	wili	(Waterhouse & Norris 1987; Muniappan et al. 1993)
Fabaceae	*Erythrina variegata* (syn. = *E. indica*., *E. variegata* var. *fastigiata)*	Indian coral tree	(Hargreaves 1936; Cochereau 1977; Kumar & Lal 1983; Waterhouse & Norris 1987; Muniappan et al. 1993; Fay 1996; Muniappan et al. 2004)
Fabaceae	*Erythrina variegata* var. orientalis	tiger's claw	(Comstock 1963; Cochereau 1977; Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Muniappan et al. 1993; Sands et al. 1993)
Fabaceae	*Erythrina velutina*[1]	mulungu tree	(Waterhouse & Norris 1987)

Family	Host species	Common name	References
Malvaceae	*Grewia tomentosa*		(Banziger 1982)
Malvaceae	*Theobroma cacao*	cacao	(Comstock 1963)
Menispermaceae	*Anamirta cocculus*	fish berry	(Baptist 1944; Banziger 1982; Bhumannavar & Viraktamath 2001a, b)
Menispermaceae	*Arcangelisia flava*	albutra	(Banziger 1982)
Menispermaceae	*Albertisia ferruginea*		(Banziger 1982)
Menispermaceae	*Carronia multisepalea*		(Fay 1994)
Menispermaceae	*Carronia protensa*		(Fay & Halfpapp)
Menispermaceae	*Carronia* sp.		(Muniappan et al.)
Menispermaceae	*Cocculus hirsutus*	broom creeper, vasan vel	(Hargreaves 1936; Baptist 1944; Banziger 1982; Bhumannavar & Viraktamath 2001a, b; Muniappan et al. 2004)
Menispermaceae	*Cocculus indicus*		(Hargreaves 1936; Baptist 1944)
Menispermaceae	*Cocculus laurifolius*	laurel-leaf snailsneed	(Banziger 1982)
Menispermaceae	*Cocculus* sp.	coralbead	(Muniappan et al. 1993)
Menispermaceae	*Cocculus trilobus*		(Muniappan et al. 1993)
Menispermaceae	*Coscinium blumeanum*		(Banziger 1982)
Menispermaceae	*Cyclea peltata*		(Muniappan et al. 2004)
Menispermaceae	*Dioscoreophyllum tenerum*		(Hargreaves 1936)
Menispermaceae	*Dioscoreophyllum volkensii*		(Banziger 1982)
Menispermaceae	*Diploclisia glaucescens*		(Banziger 1982; Bhumannavar & Viraktamath 2001a, b)

Family	Host species	Common name	References
Menispermaceae	*Fawcettia* sp.		(Muniappan et al. 1993)
Menispermaceae	*Fibraurea chloroleuca*		(Banziger 1982)
Menispermaceae	*Hypserpa decumbens*		(Banziger 1982; Fay & Halfpapp)
Menispermaceae	*Hypserpa laurina*		(Fay & Halfpapp 1993a)
Menispermaceae	*Hypserpa reticulata*		(Fay & Halfpapp 1993a)
Menispermaceae	*Hypserpa* sp.		(Muniappan et al. 1993; Fay 1996)
Menispermaceae	*Legnephora moorei*		(Banziger 1982; Fay & Halfpapp 1993a; Fay 1994)
Menispermaceae	*Legnephora* sp.		(Muniappan et al. 1993)
Menispermaceae	*Pachygone ledermanii*		(Fay & Halfpapp 1993a)
Menispermaceae	*Pachygone llongifolia*[1]		(Fay & Halfpapp 1993a)
Menispermaceae	*Pachygone ovatai*		(Fay & Halfpapp 1993a)
Menispermaceae	*Pachygone* sp.		(Fay 1996)
Menispermaceae	*Parabaena sagittata*		(Banziger 1982)
Menispermaceae	*Pericampylus incanus*		(Hargreaves 1936; Baptist ; Banziger 1982)
Menispermaceae	*Pleogyne australis*		(Fay 1994)
Menispermaceae	*Pleogyne* sp.		(Muniappan et al. 1993)
Menispermaceae	*Pycnarrhena novoguineensis*[1]		(Fay & Halfpapp 1993a)
Menispermaceae	*Sacropetalum harveyanum*	pearl vine	(Fay & Halfpapp 1993a)
Menispermaceae	*Sacropetalum* sp.		(Muniappan et al. 1993; Fay 1994, 1996)

Family	Host species	Common name	References
Menispermaceae	*Stephania aculeata*	prickly tape vine	(Banziger ; Fay 1996)
Menispermaceae	*Stephania bancroftii*[1]		(Fay & Halfpapp 1993a)
Menispermaceae	*Stephania dinklagei*		(Hargreaves 1936; Banziger 1982)
Menispermaceae	*Stephania forsteri*	laui'atolo	(Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Muniappan et al. 1993)
Menispermaceae	*Stephania harveyanum*[1]		(Fay 1994)
Menispermaceae	*Stephania hernandiaefolia*		(Baptist 1944)
Menispermaceae	*Stephania japonica*	southern japonica	(Banziger 1982; Waterhouse & Norris 1987; Fay & Halfpapp 1993a; Sands et al. 1993; Fay 1994; Bhumannavar & Viraktamath 2001a; Muniappan et al. 2004)
Menispermaceae	*Stephania japonica* var. discolor[1]	snake vine	(Fay & Halfpapp 1993a)
Menispermaceae	*Stephania japonica* var. forsteri		(Sands et al. 1993)
Menispermaceae	*Stephania japonica* var. timoriensis[2]		(Fay & Halfpapp 1993a; Fay 1996)
Menispermaceae	*Stephania* sp.		(Hargreaves 1936; Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Muniappan et al. 1993; Fay 1996)
Menispermaceae	*Stephania wightii*		(Bhumannavar & Viraktamath 2001a)
Menispermaceae	*Tiliacora acuminata*[1]		(Bhumannavar & Viraktamath 2001b)
Menispermaceae	*Tiliacora australiana*		(Fay & Halfpapp 1993a; Fay 1994)
Menispermaceae	*Tiliacora funifera*		(Banziger 1982)
Menispermaceae	*Tiliacora* sp.		(Hargreaves 1936; Banziger 1982; Kumar & Lal 1983; Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Fay 1994, 1996)
Menispermaceae	*Tiliacora triandra*	yaanang	(Banziger 1982)

Family	Host species	Common name	References
Menispermaceae	*Tiliacora warneckei*		(Baptist 1944)
Menispermaceae	*Tinomiscium petiolare*		(Banziger 1982)
Menispermaceae	*Tinospora augusta*[1]		(Fay & Halfpapp 1993a)
Menispermaceae	*Tinospora baezigeri*		(Banziger 1982, 1987; Fay & Halfpapp)
Menispermaceae	*Tinospora cordifolia*	guduchi, gulancha tinospora	(Baptist 1944; Comstock 1963; Banziger 1982; Fay & Halfpapp 1993a; Bhumannavar & Viraktamath 2001a, b)
Menispermaceae	*Tinospora crispa*	putarwali	(Banziger 1982, 1987; Fay & Halfpapp 1993a)
Menispermaceae	*Tinospora homosepala*		(Sands & Chan 1996)
Menispermaceae	*Tinospora sinensis*	Chinese tinospora	(Banziger 1982, 1987; Fay & Halfpapp 1993a)
Menispermaceae	*Tinospora smilacina*	snake vine	(Baptist 1944; Banziger 1982; Fay & Halfpapp 1993a; Fay 1994; Sands & Chan 1996; Fay & Halfpapp 1999)
Menispermaceae	*Tinospora* sp.		(Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Muniappan et al. 1993; Fay 1994, 1996)
Menispermaceae	*Tinospora* spp. aff. *glabra*		(Banziger 1982)
Menispermaceae	*Triclisia patens*		(Hargreaves 1936)
Menispermaceae	*Triclisia* sp.		(Waterhouse & Norris 1987; Martin-Kessing & Mau 1993; Muniappan et al. 1993)

[1]Experimental (laboratory) larval host plant
[2]Considered an experimental host by Fay & Halfpapp (1993a) and also a wild host by Fay (1996)

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