

The coconut leaf caterpillar, *Opisina arenosella* Walker

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Abstract

The leaf eating caterpillar *Opisina arenosella* Walker is a serious defoliator pest of coconut in India and Sri Lanka. Pest often appears in outbreak forms in certain regions causing serious damage to coconut and other palms. Natural enemies of *O. arenosella* have been quantified and information on the promising ones collected with a view to utilize in the biological control programmes. Parasitoid component of *O. arenosella* is almost similar in most of the distribution areas but the role played by each of the parasitoids differs because of strainal variations. *Eriborus trochanteratus* (Morley) which is a key parasitoid of *O. arenosella* in Sri Lanka is not effective in most of the distribution areas of *O. arenosella* in India. *Stomatomyia bazziana* Baranov is associated with *O. arenosella* in Sri Lanka but not in India. *Meteoridea hutsoni* (Nixon) is associated with *O. arenosella* in several regions in India but not in Sri Lanka. There are several other examples of variations, which suggest the need for joint studies. In India, indigenous stage specific parasitoids viz., *Goniozus nephantidis* (Muesebeck) (larval), *Elasmus nephantidis* Rohwer (prepupal) and *Brachymeria nosatoi* Habu (pupal) were effectively utilized for the management of *O. arenosella* and demonstrated through field trials. Predators such as *Cardiastethus exiguus* Poppius, *Mallada astur* (Banks), *Jauravia* sp., ants and spiders have shown potential to supplement the parasitoids in combating the pest in egg and early larval stages. Primary parasitoids are constrained by hyperparasitism. But in the inundative release of parasitoids, the hyperparasitoids did not interfere markedly in pest management. Bioecology studies of the pest and natural enemies indicate the need for regular pest surveillance, early detection, and monitoring to regulate the field release of parasitoids for pest control. A significant advance in the management of *O. arenosella* has been made through a bio-intensive integrated pest management (BIPM) approach.

Key words: *Opisina arenosella*, natural enemies, parasitoids, predators, biological control, coconut, BIPM

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Introduction

Coconut palm (*Cocos nucifera* Linnaeus) is an evergreen perennial, oilseed crop with high commercial importance. Among the plantation crops, coconut plays a significant role in poverty alleviation and employment generation in rural sector. The limitations identified in the promotion of the crop as an industry are low productivity due to prevalent pests, diseases and lack of scientific management practices (Thampan, 1981).

Lepesme (1947) has reported more than seven hundred insects feeding on the coconut palm. Nirula (1955) listed 106 insects and one mite infesting the coconut palm. Forty-two species of insects infesting the coconut palm and stored nut meat (copra) were reported by Menon and Pandalai (1960). Lever (1969) in the monograph on coconut pests listed 110 pests comprising two species of mites. Nair (1975) listed 38 species of insects and four species of mites as pests of coconut palm. Global distribution of over 800 species of insects and mites associated with coconut palm and copra was documented by Kurian *et al.* (1979 a, b). Vidyasagar and Bhat (1991) listed fifty seven species of insects, twelve species of rodents and other vertebrates in India. Coconut leaf eating caterpillar, eriophyid mite, rhinoceros beetle, red palm weevil and root grub are major pests of coconut with considerable economic importance.

The leaf eating caterpillar, *Opisina arenosella* Walker (Lepidoptera: Oecophoridae) is a highly fecund voraciously feeding, serious defoliator of coconut palm in India (Rao, 1924), Sri Lanka (Jayaratnam, 1941), Myanmar (Burma) (Ghosh, 1924) and Bangladesh (Alam, 1962). In India, the pest is prevalent in Karnataka, Kerala, Andhra Pradesh, Tamil Nadu, Gujarat, and Orissa. For a long time the pest was known as *Nephantis serinopa* (Meyrick, 1905) and included under the order Lepidoptera and Family Cryptophasidae. Becker (1981) found that *Nephantis* and *Opisina* are monotypic

genera and the type species of both in British museum were conspecific. Hence the coconut caterpillar was renamed as *Opisina arenosella* Walker and placed under Family Oecophoridae. Details of the bionomics, distribution, biocontrol and other methods of control of this pest published in the decades of 1920's to 1950's were reviewed by Nirula (1956). Ramachandran *et al.* (1979), Cock and Perera (1987) and Howard *et al.* (2001) have published more recent reviews. Singh (1994a) gave an account of 15 years of the work done on biological control of coconut pests in India. The present review provides latest updated information.

Crop losses

This pest periodically assumes epizootic proportions in coastal and backwater areas and in the vicinity of water bodies in the inlands of peninsular India. The caterpillars of *O. arenosella* construct galleries of silken webs reinforced with excreta and scrapes of leaf bits on the lower surface of leaves. Hiding in these galleries they feed on the chlorophyll containing parenchymatous tissue. Damage results in drying of the outer and middle whorl of leaves, reduction in the rate of production of flower spikes, retardation of growth, reduction in photosynthetic efficiency and decline in yield. In addition, the damage renders the leaves unsuitable for other purposes like thatching. Young palms often die due to the pest attack. Under severe outbreak conditions, the entire coconut plantation presents a 'burnt up' appearance. The potential rate of multiplication of this pest under favourable conditions makes the management more difficult. The pest infests the coconut palm throughout the year. Joy and Joseph (1972a) reported reduction in yield from 1875 nuts to 694 nuts (63%) per acre due to *Opisina* attack. The occurrence of the pest causing over 40 per cent damage is considered an outbreak (Perera, 1993). Annual loss in the pest infested fields is estimated as Rs. 7280/ha. (Rajagopal and Arulraj, 2003), which comes to about 165.4

UD\$/ha.

Distribution

Opisina arenosella was first recorded in the eastern part of Sri Lanka from Batticaloa district (Green, 1898). Subsequently; it has been recorded from eastern, northern, southern, western, northwestern and central provinces of Sri Lanka (Dharmaraju, 1963).

Opisina arenosella was noted in India for the first time during 1907 on palmyrah palms in Coimbatore, Tamil Nadu. First record of its presence on coconut leaves in India was from Bapatla, Andhra Pradesh, in 1909 (Rao *et al.*, 1948). In 1917 it appeared in serious form around Quilon and Travancore in Kerala (Pillai, 1919). Around 1921, an outbreak of the pest occurred in coastal Karnataka at Mangalore (Rao, 1924). The pest appeared in Cochin in 1924 (Venkatasubban, 1932). In interior Karnataka it was reported for the first time during 1964 (Puttarudriah and Shastry, 1964). Since then periodically it has been reported causing serious damage to coconut leaflets in various coconut growing areas such as Assam, Bihar, Goa, Gujarat, Maharashtra, Orissa, Tripura and West Bengal. Distribution and status of the pest in India is depicted in Table 1.

Host plants

Although the *O. arenosella* is best known as a pest of coconut palm, palmyra (*Borassus flabellifer* Linnaeus) is presumed to be the original host. Sago palm (*Caryota urens* Linnaeus) (Rao *et al.*, 1948), ornamental palms *viz.*, Doum palm (*Hyphaene thebaica* (Linnaeus) Martius) (Lever, 1969), wild date palm (*Phoenix sylvestris* (Linnaeus) Roxburgh) (Baburayanayak, 1970), date palm (*Phoenix dactylifera* Linnaeus.) (Butani, 1975), fish tail palm (*Caryota sp.*) (Kapadia, 1982), fan palm (*Livistonia chinensis* (Jacquin) Martius). (Talati and Kapadia, 1984) and talipot palm (*Corypha umbraculifera* Linnaeus.) (Talati and Butani,

1988) were also reported as host plants of *O. arenosella*. Murthy *et al.* (1995) reported that the pest's order of preference for oviposition and feeding was palmyra, coconut and banana, while *Areca catechu* Linnaeus was rejected. Manjunath (1985) reported banana as a host plant. In Killikulam region of Tamil Nadu 20 per cent infestation by *O. arenosella* on palmyrah palm was recorded (AICRP, 1997). Larvae of *O. arenosella* scrape chlorophyll and form galleries on the lower side of the leaves of *B. flabellifer* (Sankaralingam *et al.*, 1999). Chandrika Mohan and Shameer (2002) reported laboratory feeding and development of *O. arenosella* on cashew (*Anacardium occidentale* Linnaeus), jack (*Artocarpus heterophylla* Lam.) and oil palm (*Elaeis guineensis* Jacquin).

Sujatha and Singh, (2002) reported that *O. arenosella* infested palmyrah palms intercultivated with coconut in south interior Karnataka had heavy leaf infestation (45.0 to 82.0 per cent). Population of *O. arenosella* showed peak during winter (December-January) followed by maximum leaf damage. Natural enemies also thrived well on *O. arenosella* infesting *B. flabellifer*. The parasitoid, *Apanteles taragamae* Viereck occurred throughout the year and per cent parasitism ranged 8.5 (November) to 15.0 (January). Hyperparasitism (20.0 per cent) by *Eurytoma* spp. during January affected its population build up. *Meteoridae hutsoni* Nixon occurred on coconut throughout the year, whereas on palmyrah it was active only during January and effected 21.5 per cent parasitism of late instar larvae of *O. arenosella*. Predatory fauna comprised of *Cardiastethus exiguus* Poppius, *Phytoseiulus* sp., *Mallada astur* Banks and *Jauravia* sp. Synchronized parasitoid and predatory activity throughout the winter resulted in desired pest suppression (Table 2). The damage caused by *O. arenosella* on coconut palm, wild date palm and palmyrah palm is shown in Figure 1.



Fig. 1. Damage to palms by *Opisina arenosella*: A. Coconut palm (*Cocos nucifera*); B. Wild date palm (*Phoenix sylvestris*); C. Palmyrah palm (*Borassus flabellifer*)

Table 1. Distribution and status of *Opisina arenosella* on coconut in India

States	Place/Districts	Pest status/ Remarks	Reference
Andhra Pradesh	East and West Godavari Dist.	Severe*	Dharmaraju (1952)
Assam	North Eastern Hill Region	Severe in hot summer	Sarkar (1986)
Goa	-	13 to 85.7% leaf damage	Sunderaraju (1979)
Gujarat	Saurashtra, Kutch region	38.4% leaflet damage	Patel <i>et al.</i> (1984)
	Junagadh	Severe	Vyas and Butani (1986)
	Mahuva	-	Kapadia (1983)
Karnataka	Interior areas	Throughout the year with a peak during September-January	Nadarajan and ChannaBasavanna (1980) Sujatha and Singh (2004b)
	Interior (Bangalore)	Severe during summer (March-May)	Pushpalatha and Veeresh (1995)
Kerala	Quilon and Travancore	Severe in May	Pillai (1919)
	Cochin	Severe	Venkatasubban (1932)
	Badagara	Severe in summer	Joy and Joseph (1972 a)
	North Malabar	Severe in summer	Narendran <i>et al.</i> (1979)
	South Kerala	Severe in June	Sathiamma <i>et al.</i> (1973)
Maharashtra	Ratnagiri, Bombay, Karwar, Poona	Severe	Nirula <i>et al.</i> (1951)
Orissa	Ganjam, Puri, Cuttack, Balasore	Severe	Nirula <i>et al.</i> (1951) and Ghode <i>et al.</i> (1987)
Tamil Nadu	Tirunelveli, Salem, North Arcot	Severe	Selvasekharan and Chandrasekharan (1984)

The findings on the comparative performance of natural enemy complex of *O. arenosella* on palmyrah and coconut palms in the same habitat indicated that in nature coconut is preferred to palmyrah by the pest and most of its natural enemies. Larval parasitoids are readily subjected to the attack of hyperparasitoids, which in turn affect their population buildup on palmyrah. Combined activity of *M. hutsoni*, *Brachymeria* spp. and predation of eggs and neonatal larvae by a mixed fauna of anthocorids during winter might have resulted in the decline of the pest after an outbreak. Equal distribution of coccinellid and chrysopid larvae on coconut and palmyrah palms of 15m height during rainy period revealed their adaptability to survive on both smooth and rough surfaces of coconut and palmyrah leaves, respectively. However, palmyrah can serve as an alternate host for the conservation of promising natural enemies of *O. arenosella* viz., *A. taragamae*, *B. nephantidis* Gahan and egg and early larval predators, viz., anthocorids, chrysopids, coccinellids and mites (Sujatha, 2001).

Relative abundance of *Opisina arenosella* on different cultivars of coconut

Jack and Sands (1929) reported that Malayan Dwarf Yellow was more readily subjected to pest attack than Dwarf Green. In Mahuva, Gujarat, among the three varieties screened, viz., Dwarf Green (DG), Tall x Dwarf (hybrid) and West Coast Tall (WCT), percentage of leaf damage was highest in WCT (68.97) followed by TxD (68.62) and Dwarf Green (55.25). Leaflet character influenced the pest damage and DG was comparatively tolerant to the pest attack (Kapadia, 1981) and suggested that DG variety could be exploited as one of the parents for breeding varieties resistant/tolerant to the pest. Patel *et al.* (1984) reported the high susceptibility of the variety Bona when compared to WCT and TxD in Gujarat. Seasonal analysis of pest population on Kenthali Dwarf (KD) cultivar in coastal Karnataka revealed significantly high larval

population throughout January-June. Poor response to stage-specific parasitoids was correlated with highest leaf damage (92.9 per cent) in KD during July and hence revealed its susceptibility to *O. arenosella* attack (Sujatha, 2001). Chandrika and Shameer (2001) reported significantly higher fecundity and frequency of adult emergence of the pre-pupal parasitoid, *Elasmus nephantidis* Rohwer per host on GD than Orange Dwarf (COD) and WCT.

Seasonal occurrence

In India, Rao (1924) and Nirula (1956) studied the occurrence of the pest along the East and West coasts. Nirula *et al.* (1951) and Antony (1962) gave an account of the bionomics, life history and morphology of *O. arenosella* in Kerala. Severe pest incidence during summer (March to May) and low during September to December in East and West coastal areas was recorded (Nirula, 1956; Joy and Joseph 1972a; Narendran *et al.*, 1979; and Mohammed *et al.*, 1982a). Sathiamma *et al.* (1973) observed high pest population during June and August, which showed a positive correlation with humidity. Pest population was high during September-January (Puttarudriah and Shastry, 1964; Nadarajan and ChannaBasavanna, 1980) in interior Karnataka, but Pushpalatha and Veeresh (1995) reported maximum population of *O. arenosella* during March-June.

In Karnataka, during 1996-97 the population of *O. arenosella* was significantly higher in the interior than along the coastal area on all ages of coconut palms *i.e.* seedling, young and old palms (Sujatha, 2001). Lowest population was recorded during post-monsoon and summer seasons in coastal and interior zones, respectively. Significant positive and negative correlations of pest population with mean maximum temperature in coastal and interior areas, respectively, indicated that fluctuation is independent of its influence.

Table 2. Natural enemies of *Opisina arenosella* occurring on palmyrah and coconut in interior Karnataka

Species (Order/Family)	Stage attacked	Seasonal occurrence on		% parasitism /No. of predators per palm on	
		palmyrah	coconut	palmyrah	coconut
<i>Apanteles taragamae</i> Viereck (Hymenoptera: Braconidae)	Early instar larva	Throughout the year	July-January	2.0-15.0	1.4-8.3
<i>Goniozus nephantidis</i> Muesebeck (Hymenoptera: Bethyridae)	Late instar larva	Post-monsoon	April	Below 5.0	2.3-12.0
<i>Bracon hebetor</i> Say (Hymenoptera: Braconidae)	Late instar larva	Post-monsoon	summer	Below 5.0	5.0-12.0
<i>Brachymeria nephantidis</i> Gahan (Hymenoptera: Chalcididae)	Pupa	Post-monsoon, Winter	Winter, Summer	5.5-8.0	5.4-15.6
<i>Meteoridae hutsoni</i> Nixon (Hymenoptera: Braconidae)	Larva- pupa	Winter	Throughout the year	2.4-21.5	4.5-22.3
<i>Trichospilus pupivora</i> Ferriere (Hymenoptera: Eulophidae)	Pupa	Winter	Winter	2.0-5.5	2.0-11.0
<i>Cardiastethus exiguus</i> Poppius (Heteroptera: Anthocoridae)	Egg and larva	Throughout the year	Throughout the year	15.0-160.0	6.7-195.0
<i>Mallada astur</i> (Banks) (Neuroptera: Chrysopidae)	Egg and larva	Post-monsoon, Winter	Post-monsoon, Winter	5.0-8.0	5.0-12.0
<i>Jauravia</i> sp. (Coleoptera: Coccinellidae)	Egg	Post-monsoon, Winter	Post-monsoon, Winter	5.0-10.0	4.0-8.0
<i>Phytoseiulus</i> sp. (Acari: Phytoseidae)	Egg	Post-monsoon	Summer	5.0-20.0	20.0- 42.0

Coastal area under study received large amount of rainfall (557.3 to 1715.3 mm) and population of the pest showed significant negative correlation with relative humidity and rainfall, whereas in interior much lower rainfall (58.6 to 363.5 mm) did not show any significant relationship with pest population (Sujatha and Singh, 2004b).

In Sri Lanka, Perera *et al.* (1989) correlated the population outbreaks with climatic and biotic factors. Analysis of records of population outbreaks of *O. arenosella* in Sri Lanka from 1965 to 1985 revealed cycles in the populations of approximately one generation period, giving the population the appearance of partially discrete generations. There was also evidence for longer cycles of six month period. Outbreaks occurred throughout the coconut-growing regions of Sri Lanka, and the number of outbreaks per year in different provinces was sometimes correlated, indicating a common, probably climatic, triggering mechanism. Parasitism remained high throughout the outbreaks and there was some evidence that pupal parasitism increased towards the end of the outbreak.

Description, Biology and Life history of *Opisina arenosella*

The coconut leaf eating caterpillar, *O. arenosella* was first described by Meyrick in 1905. Nirula *et al.* (1951) studied the pest in detail in Kerala. The moth is small, ash grey in colour, measuring 10-15 mm in length with a wing spread of 20-25 mm. The male moth is smaller with a slender abdomen ending in a short brush of scales, while in the female the abdomen is stouter and pointed at the tip. The moths are nocturnal in habit and during day time are found resting on the undersurface of the leaves. They are poor fliers, a fact that may have contributed to their relatively slow rate of spread and the localized nature of infestations. The moths were not found attracted to light and strong wind and rain have

little effect upon the resting moths. In the laboratory with honey as food, the male moth lived for 7 days on an average and the female for 5 days.

Female moths lay eggs in irregular groups in webbed galleries on the underside of the previously attacked leaves of coconut palm. Nirula (1956) noted a fecundity that varies from 59 to 252 eggs, the capacity being influenced by climatic and other factors. The egg is oval in outline, 0.6-0.8 mm long and 0.3-0.4 mm broad, creamy white in colour when freshly laid and turn pinkish before hatching. The surface of the egg is shiny and is covered with irregular faint reticulations. Incubation period varies from 3 to 8 days. Newly hatched larva is about 1.5 mm long. The caterpillar is pink with black head and dark thoracic plates. The abdomen is smooth and shining with long setae on the sides. The caterpillar wanders for some time after hatching and then spins a silken gallery on the abaxial frond surface, remaining in it while feeding. Fully developed larva measures 13-18 mm in length and is greenish in colour with reddish brown stripes on the dorsal side (Nirula, 1956; Menon and Pandalai, 1960).

Regarding the number of instars the larvae undergo, there is difference of opinion among the workers. Nirula *et al.* (1951), Lever (1969) and Mohammed *et al.* (1982a) observed five instars, whereas Antony (1962), Santhosh Babu and Prabhu (1987) reported six and eight instars, respectively. The larvae after feeding voraciously on coconut leaflets enter the prepupal stage. Pre-pupa is 12 -15 mm long and is light pink in colour. It spins cocoons with white silken fiber. The pupa is flattened dorsoventrally, tapering posteriorly; is reddish brown in colour and measures 9-14 mm in length. Life stages of *O. arenosella* are depicted in Figure 2. The results of biology and life history of *O. arenosella* on coconut in different agroclimatic zones in India and Sri Lanka are presented in Table 3.

Table 3. Biology of *Opisina arenosella* on coconut

Location	Developmental period (Days)				No. of eggs per female	Reference
	Egg	Larva	Pupa	Total life cycle		
India						
Andhra Pradesh	4 to 5	-	-	42 to 56	150 to 200	Dharmaraju (1952)
Karnataka	-	-	-	69	-	Puttarudriah and Shastry (1964)
Kerala	5. 3 to 7	40 to 42	12 to 14	57 to 60	130 to 150	Nair (1938); Nirula <i>et al.</i> (1951)
	-	36 to 54	10 to 12	49 to 72	-	Mohammed <i>et al.</i> , (1982a)
South India	3 to 5	35 to 56	9 to 14	60 to 75	140	Lever (1969)
Sri Lanka	3	35	8	46	152	Perera <i>et al.</i> (1989)

Rearing of *Opisina arenosella*

Group rearing of *O. arenosella* on coconut leaf bits to obtain suitable host stage for parasitism is a common practice as the caterpillars do not exhibit cannibalism. However handling of larvae at frequent intervals often results in contamination by pathogens and predatory mites. Artificial diets help to overcome the difficulties encountered in rearing the pests continuously on host plants by reducing the problems of diseases introduced from insect or plant stock and permits the rapid build up of culture. Jayanth and Nagarkatti (1981) formulated an artificial diet for *O. arenosella* where the developmental period and fecundity were found to be 41.12 days and 60 eggs per female, respectively. Murthy *et al.* (1994) reported that palmyrah and coconut leaf powders were suitable for rearing *O. arenosella*.

Nutrients and host plant resistance

In Sri Lanka, role of major plant nutrients and individual amino acids in resistance to *O. arenosella* was studied by comparing plantations with a history of frequent outbreaks and those that had never been attacked. There was no significant difference between mean amounts of foliar potassium, nitrogen, phosphorus, calcium and magnesium between attacked and unattacked sites. Potassium levels were highest in the youngest fronds which are not normally attacked, whereas peak amounts of nitrogen occurred in the fronds which are most susceptible to attack. Amounts of 'amide' were notably higher at unattacked palms at different sites (Cammel *et al.*, 1990)

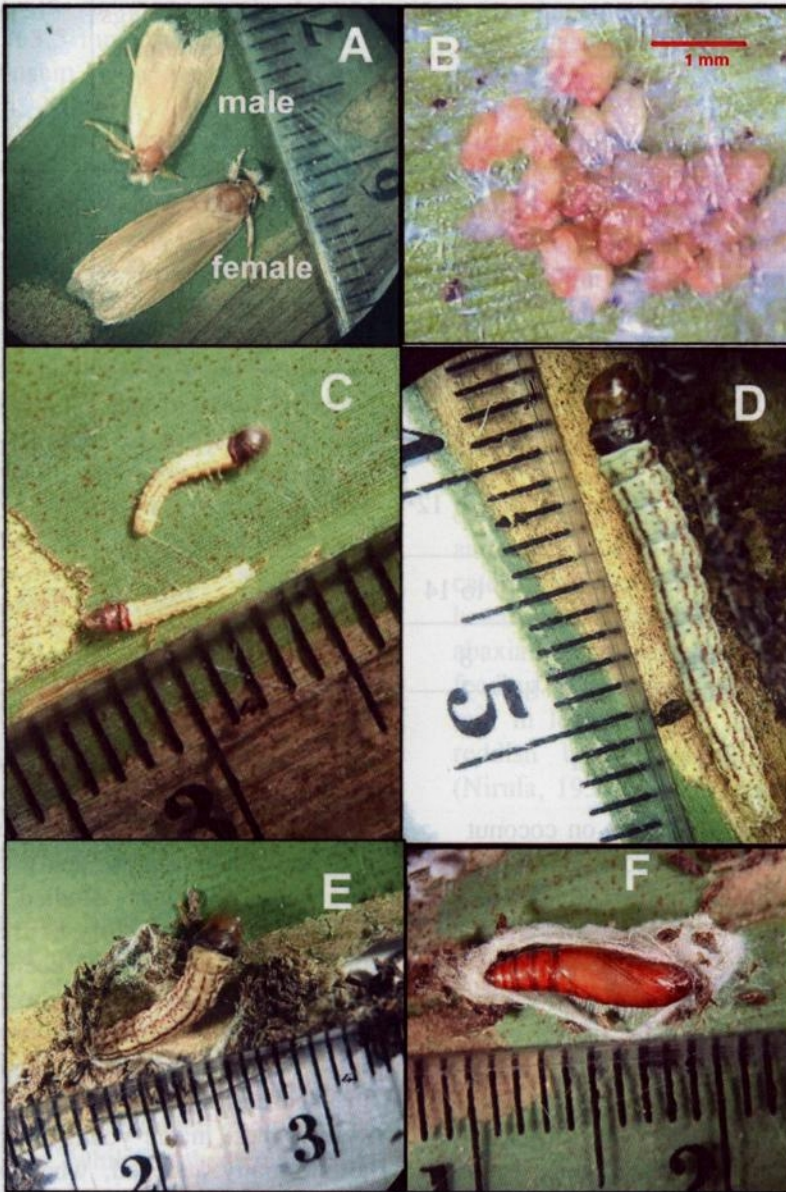


Fig. 2. Life stages of *Opisina arenosella*: A. Adult male and female; B. Eggs; C. Early instar larvae; D. Final instar larva; E. Larva in Prepupal phase; F. Pupa

Pheromones of *Opisina arenosella*

The attraction of males of *O. arenosella* to conspecific virgin females was studied on coconuts at 3 locations in Sri Lanka during November-December 1996. The number of males caught in traps baited with virgin females was significantly greater than the number caught in unbaited traps (Fernando and Chandrasiri, 1997). The existence of a female produced sex pheromone was established by Murthy *et al.* (1995b). Four components of the pheromone of *O. arenosella* were identified by Natural Resources Institute, UK (NRI) using insects from Sri Lanka (Cork and Hall, 1998). In India, Biocontrol Research Laboratories of Pest Control India Limited, Bangalore, Karnataka have initiated work on synthesis of *O. arenosella* pheromone. It is hoped that by end of this year pheromone of this pest will be available for field trial.

Natural enemies of *Opisina arenosella*

The coconut leaf eating caterpillar *O. arenosella* in the natural environment is attacked by several species of parasitoids, predators and micro-organisms. Dharmaraju (1962) provided a checklist and distribution of natural enemies of the pest in India and Sri Lanka (Ceylone). Pillai and Nair (1993) reported that the coconut caterpillar supported about 60 insect natural enemies and emphasized the need for systematic surveys throughout the pest infested tracts, which would certainly reveal many more natural enemies and their efficiency in pest suppression. Superiority of the solitary parasitoids over gregarious species in the biological suppression of the pest is well documented in Kerala, India (Pillai and Nair, 1995). There are indications that the relative distribution as well as levels of parasitism of the natural enemies varies considerably in different climatic conditions and localities. Perera (1993) opined that the performance of different parasitoids of *O. arenosella* was

highly variable and is perhaps the reason for the periodic occurrence of pest outbreaks. Survey conducted by Sujatha (2001) in Karnataka revealed 34 insect natural enemies and 17 species of spiders. The promising parasitoids and their rates of parasitism recorded in different states of India and Sri Lanka, respectively, are listed in Tables 4 and 5. Information on the biology of important parasitoids of *O. arenosella* is provided in Table 6.

Parasitoids

Parasitic hymenopterans are regulatory in their action, which in turn gives an advantage of permanency to biocontrol of insect pests. Among the various parasitoids of *O. arenosella* hymenopterans predominate (Nasser and Abdurahiman, 2001). Based on the stage of the pest on which the parasitoids develop they are treated as egg, larval, prepupal, larval-pupal and pupal parasitoids.

Egg parasitoids

Dharmaraju (1952) and Nirula (1956) recorded *Trichogramma chilonis* Ishii as an egg parasitoid of *O. arenosella*. Rao and Azam (1985) released *T. australicum* Girault in *O. arenosella* infested tracts in Andhra Pradesh. However, no reports on recovery from released sites are available. In Sri Lanka, the mass release of *T. brasiliense* Ashmead was not successful (Cock and Perera, 1987). Singh and Jalali (1994) observed that eight species of *Trichogramma* effected 50-98 per cent parasitism of *O. arenosella* eggs in the laboratory. Further studies indicated the superiority of *T. embryophagum* Hartig in parasitising eggs of *O. arenosella* (Jalali et al., 2002, 2005). Sujatha (2001) reported 29.4 per cent parasitism of *O. arenosella* eggs by *T. embryophagum* on pest infested potted coconut seedlings under net house conditions.

Table 4. Promising parasitoids of *Opisina arenosella* in India

Stage attacked	Species (Family)	Geographic location	Per cent parasitism	Reference
Egg	<i>Trichogramma chilonis</i> Ishii (Trichogrammatidae)	South India	-	Dharmaraju (1952); Nirula (1956)
Early instar larva	<i>Apanteles taragamae</i> Viereck (Braconidae)	Andhra Pradesh	5.0	Manjunath (1985)
		Karnataka (Bangalore)	1.7 to 15.0	Nadarajan and ChannaBasavanna (1980)
		Karnataka (coastal) Karnataka (interior)	1.2 to 9.6 1.1 to 12.4	Sujatha (2001)
		North Kerala	1.51 to 15.4	Ghosh and Abdurahiman (1985a)
		South Kerala	4.3 to 59.6	Chandrika (2005)
Late instar larva	<i>Goniozus nephantidis</i> Muesebeck (Bethyridae)	Andhra Pradesh	28.0	Manjunath (1985)
		Gujarat	1.2 to 26.3	Yadav and Dhamalia (1985)
		Gujarat	4.2 to 6.12	Kapadia and Mittal (1986)
		Gujarat (Junagadh)	7.9	Vyas and Butani (1986)
		Gujarat	5.9	Kapadia (1987b)
		Gujarat	30.9	Kapadia and Mittal (1993)
		Karnataka (Bangalore)	9.6	Baburaya Nayak (1970)
		Karnataka (Bangalore)	1.6 to 48.0	Nadarajan and ChennaBasavanna (1980)
		Karnataka (Bangalore)	0.6 to 5.4	Medappa (1983)
		Karnataka (coastal) Karnataka (interior)	2.0 to 18.0 2.0 to 21.0	Sujatha (2001)
		North Kerala	0.15 to 19.6	Mohammed <i>et al.</i> (1982a)
		South Kerala	8.5	George <i>et al.</i> (1977)
		Maharashtra (Ratnagiri)	4.2	AICRP (1997)
	<i>Bracon brevicornis</i> Wesmael (Braconidae)	Gujarat	1.0 to 4.5	Yadav and Dhamalia (1985)
		Gujarat	12.2	Vyas and Butani (1986)
		Gujarat	5.73	Kapadia (1987b)
		Kerala	2.5 to 6.45	Sudheendra Kumar <i>et al.</i> (1982)
	<i>B. hebetor</i> Say (Braconidae)	South Kerala	26.2 to 26.7	Sathiamma <i>et al.</i> (1986)
		Karnataka (coastal) Karnataka (interior)	5.0 to 10.0 2.0 to 30.0	Sujatha (2001)

Table 4. Promising parasitoids of *Opisina arenosella* in India ... Contd.

Stage attacked	Species(Family)	Geographic location	Per cent parasitism	Reference
Larva - pupa	<i>Meteoridea hutsoni</i> (Nixon) (Braconidae)	North Kerala	0.26 to 35.64; 5.71	Sudheendra Kumar <i>et al.</i> (1979b); Ghosh and Abdurahiman (1984)
		Karnataka (interior)	2.6 to 22.3	Sujatha and Singh (1999)
Prepupa	<i>Elasmus nephantidis</i> Rohwer (Elasmidae)	North Kerala Kerala	0.08 to 0.34 5 to 10.0	Mohammed <i>et al.</i> (1982a) Nirula (1956)
Pupa	<i>Brachymeria</i> spp. (Chalcididae)	Goa	3.7 to 30.0	Sunderaraju and Orlando (1985)
		Gujarat	6.3 to 42.8 26.43	Yadav and Dhamalia (1985) Kapadia (1987b)
		Karnataka (Bangalore)	3.0-48.0	Nadarajan and ChannaBasavanna (1980)
		Karnataka -coastal Karnataka-interior	2.4-21.0 2.0-15.6	Sujatha (2001)
		Kerala	14.55	George <i>et al.</i> (1977)
		North Kerala	22.0	Joy and Joseph (1977b)
	<i>B. nephantidis</i> Gahan	Gujarat (Junagadh)	10.5	Vyas and Butani (1986)
	<i>B. nosatoi</i> Habu	Kerala Maharashtra (Ratnagiri)	19.3 2.96	Joy and Joseph (1972b, 1973) AICRP (1997)
	<i>Xanthopimpla punctata</i> (Fabricius) (Ichneumonidae)	North Kerala	43.5	Pillai and Nair (1989)
	<i>X. nana nana</i> Schulz (Ichneumonidae)	South Kerala	27.5	Pillai and Nair (1983)
	<i>Xanthopimpla</i> spp (Ichneumonidae)	Gujarat	5.0 to 20.0	Yadav and Dhamalia (1985)
		Gujarat	10.22	Kapadia (1987b)
		Karnataka	4.0 to 48.0 2.0 to 16.6	Nadarajan and ChannaBasavanna (1980) Sujatha (2001)
		Kerala	-	Pillai and Nair (1987; 1990b)
	<i>Goryphus gibbosus</i> Jonathan and Gupta (Ichneumonidae)	Karnataka (interior)	5.0	Sujatha (2001)
	<i>Trichospilus pupivorus</i> Ferriere (Eulophidae)	Kerala	1.0 to 14.0	Joy and Joseph (1977a)
		Kerala	2.6 to 14.0	Pillai and Nair (1982 c)
Karnataka (coastal)		2.0 to 6.0	Sujatha (2001)	
Karnataka (interior)		2.0 to 12.0		
<i>Tetrastichus howardii</i> (Olliff) (Eulophidae)	Karnataka	11.0	Sujatha (2001)	

Table 5. Natural enemies of *Opisina arenosella* recorded in Sri Lanka

Species	Order/Family	Stage attacked	Place \ Province	Per cent parasitism	Reference
Parasitoids					
<i>Goniozus nephantidis</i> Muesebeck	Hymenoptera: Bethylidae	Late larva	All provinces	19.0 2.0 to 3.0	Dharmaraju (1963) Perera (1993)
<i>Apanteles taragamae</i> Viereck	Hymenoptera: Braconidae	Early larva	Eastern and Southern	13.2	Perera (1993)
<i>Stomatomyia bezziana</i> Baranov	Diptera: Tachinidae	Larva	Eastern and South East	80.0	Dharmaraju (1963)
<i>Brachymeria</i> spp.	Hymenoptera: Chalcididae	Pupa	-	21.1	Jayarathnam (1941)
<i>Brachymeria nephantidis</i> Gahan		Pupa	Southern	65.4	Perera (1993)
<i>B. nosatoi</i> Habu		Pupa	Southern	-	Perera (1993)
<i>Trichospilus pupivora</i> Ferriere	Hymenoptera: Eulophidae	Pupa	West and North west		Dharmaraju (1963)
<i>Eriborus trochanteratus</i> Morley	Hymenoptera: Ichneumonidae	Pupa	Western and Southern	1.0 to 37.0	Dharmaraju (1962)
				5.0 to 54.0	Perera (1977)
				5.0 to 10.0	Perera (1993)
Predators					
<i>Parena nigrolineata</i> Chaudoir	Coleoptera: Carabidae	Larva	Sri Lanka	-	Dharmaraju (1963)
<i>Monomorium</i> sp. <i>Crematogaster</i> sp. <i>Technomyrmex albipes</i> (Smith)	Hymenoptera: Formicidae	Larva	Sri Lanka	-	Way <i>et al.</i> (1989)
<i>Rhene</i> sp. <i>Hyllus</i> sp. <i>Plexippus</i> sp.	Araneae: Salticidae	Larva, pupa and moth	Sri Lanka	-	Cock and Perera (1987)

Table 6. Biology of important parasitoids of *Opisina arenosella*

A) Larval parasitoids	Developmental Period				Fecundity (eggs/ female)	Longevity (days)		Region	Reference
	Egg (hrs)	Larva (days)	Pupa (days)	Life cycle (days)		Male	Female		
<i>Apanteles taragamae</i> Viereck	22 - 27.0	9 - 16.0	6.0	15 - 24.0	-	12.0	14.0	North Kerala	Ghosh and Abdurahiman (1988a)
<i>Bracon brevicornis</i> Wesmæl	24-28.0	1.8	3 - 3.5	7-8.5	71.4	30.0	42.0	Kerala	Remadevi <i>et al.</i> (1980b)
<i>B. hebetor</i> Say	30.0	3.1	4.38	8.7	82.0 in 8 days	20.0	63.0	Kerala	Sathiamma <i>et al.</i> (1986)
<i>Goniozus nephantidis</i> (Muesebeck) on <i>O. arenosella</i> on <i>Corcyra cephalonica</i> on <i>C. cephalonica</i>	30.0 30.0 53.5	3.8 4.0 3.24	7.5 10.0 10.9	19.5 14.5 15.0	28.8 4 29.6	- - 5.7	38.9 30.7 19.7	Tamil Nadu Gujarat	Paul <i>et al.</i> (1979) Kapadia and Mittal (1986)
B) Prepupal parasitoid <i>Elasmus nephantidis</i> Rohwer	20.0	3.5	6.5	11.0	57.0	12-13 in summer	30-60 in winter	Kerala	Pillai and Nair (1982a)
C) Larval-pupal parasitoid <i>Meteoriidea huiisoni</i> (Nixon)	-	-	-	17 - 23.0	-	9.3	12.4	North Kerala	Ghosh and Abdurahiman (1984)

Table 6. Biology of important parasitoids of *Opisina arenosella* ... continued

Parasitoids	Developmental period				Fecundity (eggs/female)	Longevity (days)		Region	Reference
	Egg (hrs)	Larva (days)	Pupa (days)	Life cycle (days)		Male	Female		
D) Pupal parasitoids <i>Antrocephalus hakonensis</i> Ashmead	36 - 41	6 - 8	8 - 11	15-18(31°C) 17-21(26°C)	150 - 160 in 75 days	46	90	Kerala	Mohandas and Abdurahiman (1994)
<i>Brachymeria niphantidis</i> Gahan <i>B. lasus</i> (Walker)	18 - 28 20-35	5.5 4-8	5 - 17 5-8	- 10-17	- 61-131	10-17	11-18 100.0	Kerala	Joy <i>et al.</i> (1978)
<i>B. nosatoi</i> Habu	24	4 - 5	7 - 8	12 - 14	22	18.55	28.60	North Kerala	Mohammed <i>et al.</i> (1983)
<i>Xanthopimpla punctata</i> (Fabricius)	24	4 - 10	5 - 10	10 - 20	-	1 to 5 months		Kerala	Pillai and Nair (1989)
<i>X. nana nana</i> Schulz	26 - 28	5 - 9	6 - 9	12 - 19	-	24	95	Kerala	Pillai and Nair (1992)
<i>Xanthopimpla</i> sp.	28 - 30	6 - 13	5 - 9	12 - 16	-	1 - 4 months		Kerala	Pillai and Nair (1987)
<i>Tetrastichus israeli</i> Mani and Kurian	45 -50	4.0	7.0	13.0	32-74	-	15 -20	Kerala	Sudheendra kumar <i>et al</i> (1979a)

Larval parasitoids

Early larval parasitoid, *Apanteles taragamae* Viereck is a highly adaptable solitary endoparasitoid of second instar larvae of *O. arenosella* with wide distribution (Rao *et al.*, 1948; Nirula, 1956). The frass of second instar larvae of the host acts as a strong attractant to the female parasitoid for oviposition (Ghosh and Abdurahiman, 1988a, 1996; Chandrika, 2005). Efficiency is reduced by 50.0 per cent due to hyperparasitism. *A. taragamae* was active during March-April and September-October in North Kerala, (Ghosh, 1988) and July and October-November in south Kerala (Chandrika, 2005). Nadarajan and ChannaBasavanna (1980) reported its presence throughout the year in *Opisina* infested tracts in Bangalore, with highest parasitism observed during September, where as Pushpalatha (1992) observed higher level of population during March-June. In Karnataka (Figure 3) peak activity of *A. taragamae* was during winter and summer in coastal and during rainy season in interior area (Sujatha, 2001).

In coastal area parasitism was significantly negatively correlated with high relative humidity whereas in the interior, moderate rain showers favoured its activity. Chandrika *et al.* (2000) had described mass production technique for *A. taragamae* on early instar caterpillars of *O. arenosella*.

Goniozus nephantidis is a gregarious ectoparasitoid parasitising the third to final instar stages of *O. arenosella*. Muesebeck (1934) described the species as *Perisierola nephantidis* on *O. arenosella* in South India. Evans (1978) later transferred it to genus *Goniozus*. It was found effective in several Indian states such as Kerala, Karnataka, Tamil Nadu, Gujarat, Andhra Pradesh, Goa and Sri Lanka. Rao and Cheriyan (1928); Nirula (1956); Antony and Kurian (1960); Kurian and Antony (1961) and Mohammed *et al.* (1982a) studied the systematics, host preference, distribution and life history of *G. nephantidis*. Warm and dry weather favours *G. nephantidis*

(Ramakrishna Iyer and Ananthanarayan, 1935). Dharmaraju and Pradhan (1976), Remadevi *et al.* (1978) and Paul *et al.* (1979) discussed its biotic potential and reproduction. A combination of 30°C and 70% RH is ideal for a short preoviposition period, high parasitisation potential, fecundity and longevity. When host larvae of different age groups were provided for oviposition, the biotic potential of *G. nephantidis* was best in 6 weeks old larvae.

Sundaramurthy and Santhana Krishnan (1978) reported that unmated females of *G. nephantidis* laid eggs on host but produced only males. Nadarajan and ChannaBasavanna (1980) observed it as one of the most effective parasitoid around Bangalore and Mangalore. Remadevi *et al.* (1981) reported that *G. nephantidis* can be cultured on larvae of *Corcyra cephalonica*. Pillai and Nair (1985b) studied the mating and host paralysis behaviour of *G. nephantidis*. Fifth or early sixth instar caterpillars are ideal host stages for successful parasitism. The adult female has up to three cycles of oviposition and brood care, each lasting for 12-13 days and separated by 4-5 days. Medappa (1983) observed the efficacy and dispersion of *G. nephantidis* in interior Karnataka. This parasitoid occurs in field throughout the year with its population peak in summer in Kerala (Pillai and Bhat, 1986). *G. nephantidis* was the most effective parasitoid in the field in Tamil Nadu in suppressing *O. arenosella* (Jayaraj, 1989). In Karnataka, surveillance carried out in interior area by Nadarajan and ChannaBasavanna (1980) and in coastal zone by Sujatha (2001) revealed its occurrence during the months of September, December and February - March. Venkatesan *et al.* (2000) had studied the effect of cold storage of cocoons of *G. nephantidis* and reported that storage of 48 h old cocoons at 15°C for 10 days resulted in maximum adult emergence, fecundity and longevity.

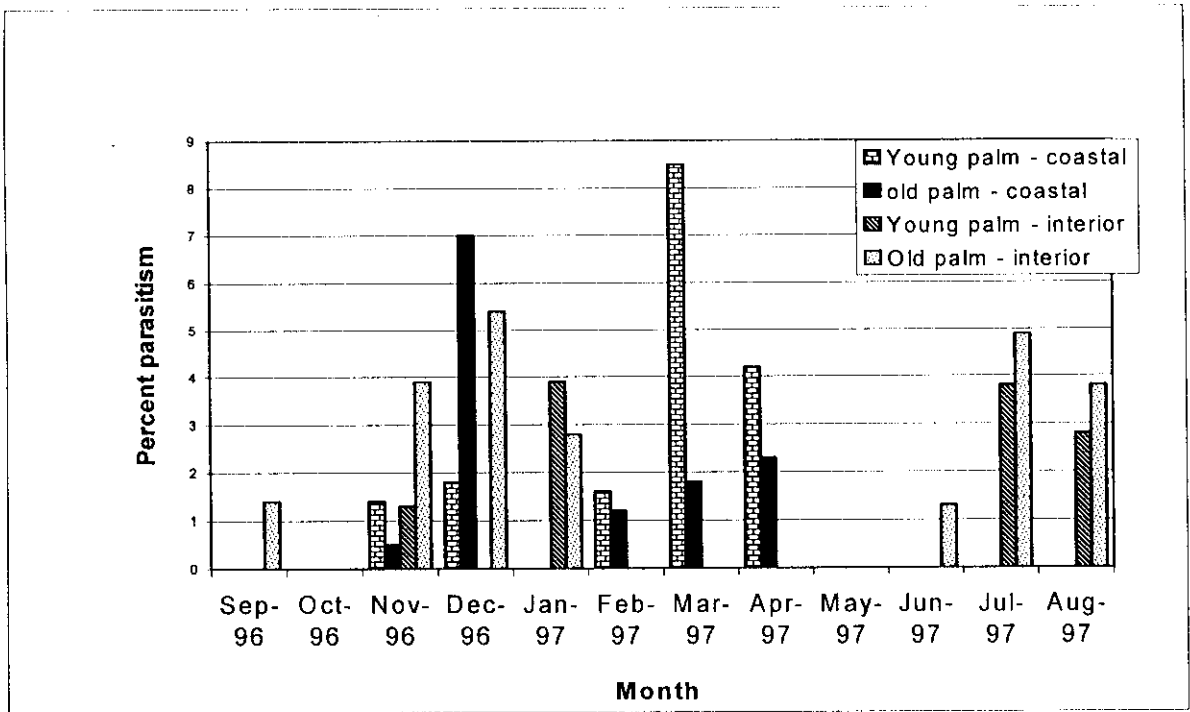


Fig. 3. Parasitism by *Apanteles taragamae* in Karnataka (Sujatha, 2001)

Bracon brevicornis Wesmael is a widely distributed gregarious larval parasitoid of *O. arenosella*. An account of the bionomics of this parasitoid under the name *Microbracon serinopa* Ramakrishna Ayyar was published by Cherian (1929). Rao *et al.* (1948); Dharmaraju (1952) and Nirula (1956) studied the biology of this parasite to some extent. Remadevi *et al.* (1980b) gave an account of the life history and biology. Narendran *et al.* (1981) and Sudheendra Kumar *et al.* (1982) observed the ovipositional sequence in *B. brevicornis*. Ghosh and Abdurahiman (1987) recorded parasitism ranging from 2.50 to 6.45 per cent in North Kerala, where activity was uniform in all four seasons. In interior Karnataka, *B. brevicornis* showed significant positive correlation with mean maximum temperature (34°C) and effected maximum parasitism (11.0 - 30.0 per cent) during summer (Sujatha and Singh, 2003a).

Studies on the bioecology of very closely

related species, *B. hebetor* Say was reported by Sathiamma *et al.* (1986) and noted that a single parasitoid paralysed 14-32 pest larvae (5th instar) during the life span of 20-63 days. Fecundity was 82 eggs in the oviposition period of 8 days. Population was maximum in hot season during February-March and reached its peak during April-May. Though this species is reared and released in the field, the data on the extent of pest suppression obtained is not available (Pillai and Nair, 1993). Pillai and Nair (1993) considered *B. hebetor* and *B. brevicornis* as one and the same species. Puttarudriah and ChannaBasavanna (1952, 1956); Van achterberg and Polaszek (1996) reported the differences between the two species. The activity of *Bracon* spp. in interior Karnataka and coastal South Kerala during the same period (February to June) indicated the possibility of augmentative releases in the pest infested fields during summer for biological suppression of *O. arenosella*.

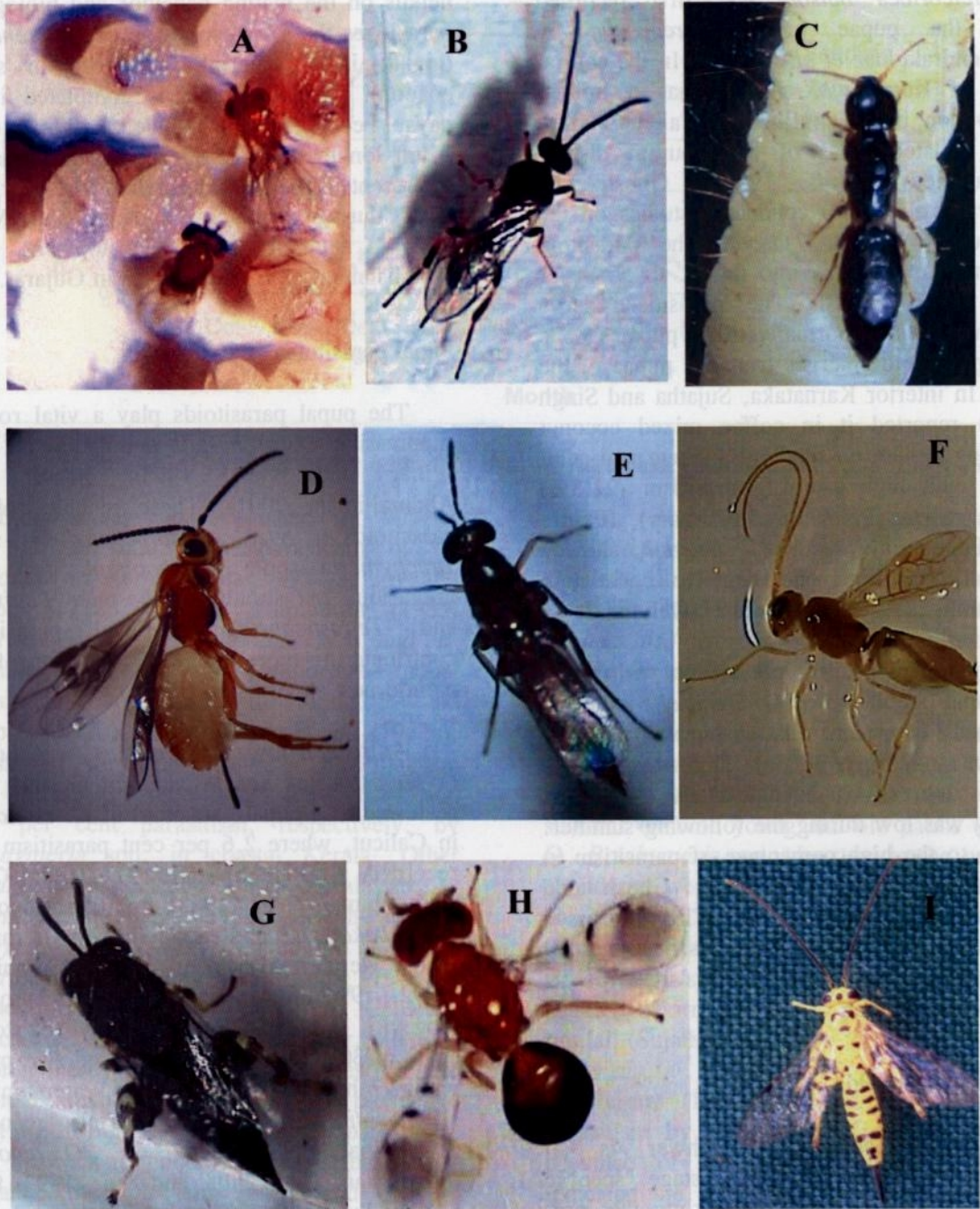


Fig. 4. Parasitoids of *Opisina arenosella*: A. *Trichogramma embryophagum*; B. *Apanteles taragamae*, C. *Goniozus nephantidis*; D. *Bracon hebetor*; E. *Elasmus nephantidis*; F. *Meteoridea hutsoni*; G. *Brachymeria nosatoi*; H. *Trichospilus pupivora*; I. *Xanthopimpla nana nana*

Larval - pupal parasitoid

Meteoridea hutsoni was first recorded from the pupae of *O. arenosella* by Sudheendrakumar *et al.* (1979b). In the coastal areas of Kerala, *M. hutsoni* has a limited distribution being confined to Calicut and to some isolated areas of Malappuram district (Mohammed *et al.*, 1982a). Ghosh and Abdurahiman (1984) conducted studies on the bioethology of *M. hutsoni*. The parasitoid preferred to lay eggs into the 3rd to 5th instar larvae of the pest. The parasitised larva continues to live normally till it pupates. The adult parasitoid emerges from the pupae of the pest. In interior Karnataka, Sujatha and Singh (1999) reported it in coffee mixed coconut cropping system on seedlings, young and adult palms with high rate of parasitism (22.3%) during winter (November-February) (Figure 5). Population of *M. hutsoni* showed significant positive and negative correlation with sunlight and rainfall, respectively.

Significant positive correlation with larval and pupal population of *O. arenosella* indicated its density dependent relationship with the pest (Sujatha and Singh 2003a). Due to continued pupal suppression during winter, the pest density was low during the following summer. Owing to the high percentage of parasitism in the areas of its distribution, Ghosh and Abdurahiman (1987) and Pillai (1994) stressed the need for more research on its mass rearing techniques and release in the areas of its absence.

Prepupal parasitoid

Elasmus nephantidis Rohwer is an efficient, host specific and stage specific gregarious ectoparasitoid attacking the prepupal stage of *O. arenosella*. *E. nephantidis* was first described as a parasitoid of *O. arenosella* from Coimbatore, India (Rohwer, 1921). Rao and Cheriyan (1927) published notes on the life history. Nirula (1956) stated that this parasitoid accounted for 5 to 10 per

cent parasitism on *O. arenosella*. Abdurahiman *et al.* (1981) and Pillai and Nair (1982a) gave details on the mating behavior and biology. It parasitizes the pre-pupal stage of *O. arenosella* (eighth instar caterpillar covered in silken cocoon). The life cycle is completed in 11 days. Fecundity per female is 27-79 eggs. Adult longevity is 12-60 days. The parasitoid is present in the field throughout the year with peak during summer. Kapadia and Mittal (1994) studied the development and establishment of *E. nephantidis* in Gujarat.

Pupal parasitoids

The pupal parasitoids play a vital role in suppressing *O. arenosella* population in India (Pillai and Nair 1993; Nasser and Abdurahiman, 2001). These include solitary parasitoids, *viz.*, *Antrocephalus* spp., *Brachymeria* spp., *Xanthopimpla* spp. and gregarious parasitoids *Trichospilus pupivorus* and *Tetrastichus* spp. Pupal parasitoids contribute to more than 50 per cent of the natural pest suppression (Pillai, 1994).

Antrocephalus hakonensis Ashmead (= *Stomatoceras sulcatiscutellum* Girault) was reviewed as a pupal parasitoid of *O. arenosella* in Calicut, where 2.6 per cent parasitism was recorded. (Joy and Joseph, 1972c and 1977a). Abdurahiman *et al.* (1983) studied the biology of *A. hakonensis* and reported that it is rare in South Kerala. Mohandas and Abdurahiman (1992, 1994) found significant correlation in longevity (60 days) and fecundity (62 to 69 eggs) at 30 °C. Female parasitised five pupae within 2 hours. *A. phaeospilus* Waterston and *A. maculipennis* Cameron were also recorded as pupal parasitoids of *O. arenosella* (Narendran, 1985; Pillai and Nair, 1993) from Kerala. Survey in Karnataka also has revealed the occurrence of these three species and their activity was confined to summer (Sujatha, 2001).

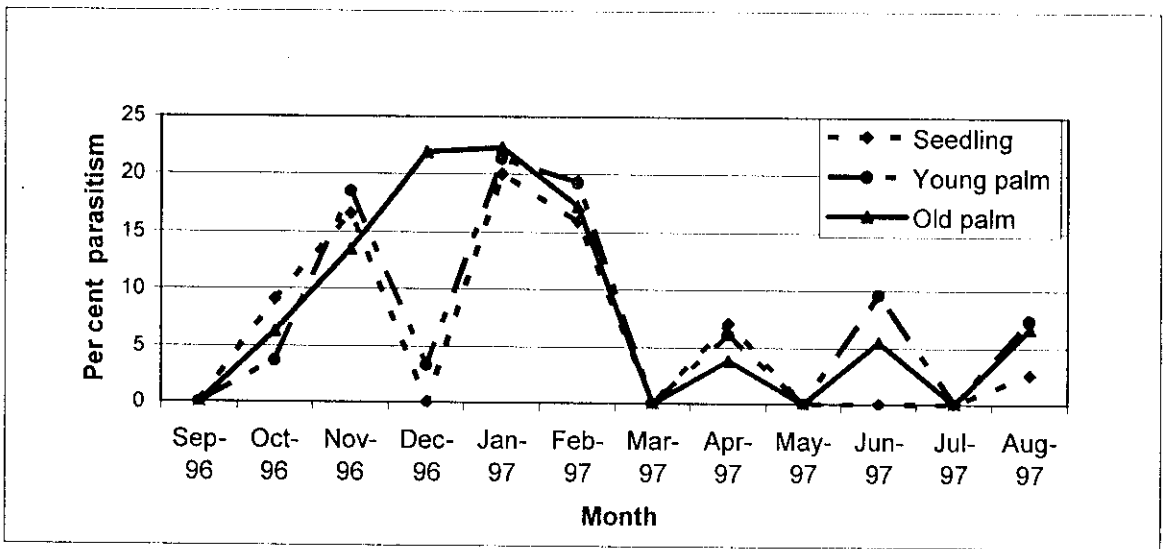


Fig. 5. Parasitism by *Meteoridea hutsoni* in interior Karnataka (India)(Sujatha and Singh,1999)

Brachymeria spp. accounted for 90 per cent of the total pupal parasitism of *O. arenosella* in Kerala (Pillai, 1994). Joy and Joseph (1972b, 1973,); Narendran (1985) reported *Brachymeria nosatoi* Habu and *B. nephantidis* Gahan as important pupal parasitoids in south and north Kerala. Joy and Joseph (1977b), Mohammed *et al.* (1982a), Ghosh and Abdurahiman (1987) and Pillai and Nair (1981) recorded 27.2, 6.90, 6.37 and 45.8 per cent parasitism, respectively, by *Brachymeria* spp. in coastal Kerala. Other *Brachymeria* spp. recorded in Kerala are *B. atteviae* (Narendran, 1989; Joseph *et al.*, 1973), *B. lasus* Walker (Joy *et al.*, 1973), *B. excarinata* Gahan (Joy and Joseph, 1972 b; Kapadia, 1988) and *B. megaspila* Cameron (Narendran, 1985; Pillai and Nair, 1986b). Among these, *B. nosatoi* possesses all the essential attributes of an effective biocontrol agent with higher percentage of parasitism, long life span, good searching ability and tolerance to high temperature and drought (Pillai and Nair, 1993). Biology of *B. lasus*, *B. nephantidis* and *B. nosatoi* has been studied in Kerala (Joy *et al.*, 1978; Mohammed *et al.*, 1983).

Mass rearing methods for *Brachymeria* spp. have been standardised (Pillai and Nair,

1982b). Nadarajan and ChannaBasavanna (1980) recorded *B. nephantidis*, *B. atteviae* and *B. lasus* in interior Karnataka. Yadav and Dhamalia (1985) reported the occurrence of *B. nephantidis*, *B. excarinata*, *B. lasus* and *B. atteviae* in Gujarat.

In coastal and interior areas of Karnataka, *Brachymeria* spp. were in constant association with *O. arenosella* throughout winter and summer on both young and old palms (Figure 6). *Brachymeria* spp. observed in the order of abundance were *B. nephantidis* > *B. lasus* > *B. atteviae* > *B. nosatoi*. Rainfall during September-October reduced the activity of *Brachymeria* spp. as indicated by its significant negative correlation of parasitisation with rainfall (Sujatha, 2001)

Perera (1993) reported 65.4 per cent parasitism by *B. nephantidis* in the southern province of Sri Lanka. All these reports indicated the superiority of *Brachymeria* spp. as biocontrol agents of *O. arenosella*.

Six ichneumonids were reported as pupal parasitoids of *O. arenosella* in India. *Xanthopimpla punctata* was recorded from *O. arenosella* by Ayyar and Margabandhu (1934). It is a solitary parasitoid having life cycle of

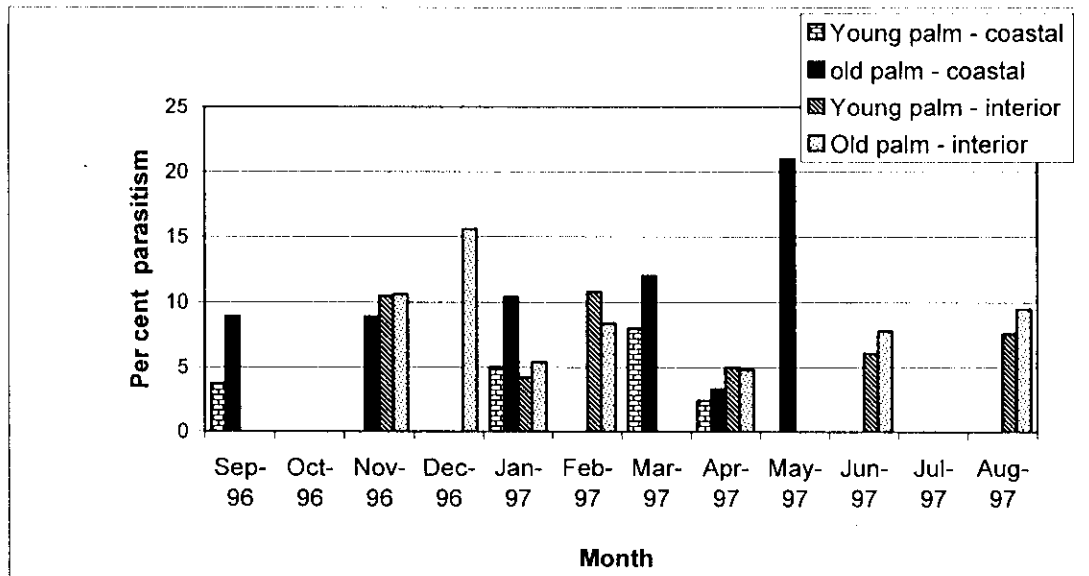


Fig. 6. Parasitism by *Brachymeria* spp. in Karnataka (Sujatha, 2001)

20 days duration and active during summer (Nirula, 1956). Pillai and Nair (1983) recorded *X. nana nana* with a high intensity of natural pupal parasitism in certain localized tracts. *Xanthopimpla* spp. select breeding sites close to water streams and are observed to be present from July to January (Pillai and Nair, 1989). Pillai and Nair (1990b) while discussing the role of six ichneumonid parasitoids in the biological suppression of *O. arenosella* recommended mass release of *X. punctata* in pest infested fields. Sujatha (2001) reported its activity in Karnataka during June-September and November in coastal and interior areas, respectively.

Trichospilus pupivora is a gregarious pupal parasitoid (Rao *et al.*, 1948). Studies on the biology and culture show that it has a wide host range (Ananthanarayanan, 1934; Dharmaraju and Pradhan, 1976; Pillai and Nair, 1982c; Remadevi *et al.*, 1980a). Development period is 15 days with a short lifespan of 12 days. Each female can parasitise one or two host pupae. Fecundity was high and varied from 45 to 185 eggs. The pupae aestivate between March and May in India. In

the critical assessment of the biological characters of this species, Pillai and Nair (1982 c) concluded that poor searching and dispersal ability, low non-optimal temperature tolerance, inability to recognize parasitised pupae and inability to compete with other parasitoids render *T. pupivora* an ineffective species for the natural control of *Opisina*. Kapadia and Mittal (1994) observed non establishment of *T. pupivora* in *O. arenosella* infested plantation in Gujarat. Sujatha (2001) recorded it during December-February in coastal Karnataka.

The gregarious pupal endoparasitoid, *Tetrastichus israeli* Mani and Kurian has a wide host range. It has been recorded as a regular parasitoid of *O. arenosella* in Tamil Nadu (Ali and Subramanian, 1972; Nadarajan and Jayaraj, 1975; Sudheendrakumar *et al.*, 1979a). Mass production technique was standardised by Nadarajan and Jayaraj (1975). Studies on life tables and intrinsic rate of natural increase of *T. israeli* on various lepidopteran pests, namely, *Spodoptera litura*, *Helicoverpa armigera*, and *O. arenosella* revealed greatest rate of increase on *O. arenosella* (Kumar *et al.*, 1995). Survey carried

out in Bangalore area, revealed that *T. howardii* (Olliff) effected 11.0 per cent pupal mortality on young palms during October-November (Sujatha, 2001). Further laboratory studies confirmed the female biased sex ratio, and its ability to search and parasitise both naked and hidden pupae of *O. arenosella* in pest infested leaf galleries, clearly indicating its suitability to coconut ecosystem.

Hyperparasitoids

At advanced trophic levels hyper parasitoids can disrupt and reduce the regulatory ability of primary parasitoids used in biological control systems. But it is significant to note that introduced parasitoids, which brought about the control of the pest, are successful in that habitat despite the attack by hypers. *O. arenosella* harbours both obligatory and facultative hyperparasitoids in coconut habitat. The important hyperparasitoids of *O. arenosella* and rate of secondary parasitism in India and Sri Lanka are listed in Tables 7 and 8.

Rao *et al.* (1948), Nirula (1956), Dharmaraju (1962) and Mohammed *et al.* (1982a) have recorded the hyperparasitism of *O. arenosella*. Ghosh and Abdurahiman (1985b) and Kapadia (1983) discussed the role of hyperparasitoids in dampening the effect of primary parasitoids. Ghosh and Abdurahiman (1985a) and Sujatha (2001) reported that in India, among the three important primary larval parasitoids, *A. taragamae* recorded maximum hyperparasitoids. Seasonal activity of hyperparasitoids in Karnataka coincided with the peak period of infestation by *O. arenosella* and reduced the efficiency of primary parasitoids. In both coastal and interior areas hypers were active during July-September and January-March. Hyperparasitism ranged 5-45 per cent. Among the six species recorded on *A. taragamae*, *Aphanogmus manilae* Ashmead predominated (Sujatha, 2001). Chandrika (2005) recorded 0.8 to 18.42 per cent hyper parasitism on *A.*

taragamae in south Kerala. Sujatha (2001) reported *Nesolynx dipterae* Risbec, a gregarious eulophid hyperparasitoid from the pupae of *O. arenosella* in Karnataka, which were primarily parasitised by an unidentified dipteran with hyperparasitism below 4.0 per cent during winter. A pupal hyperparasitoid, *Eurytoma albotibialis* Ashmead was active during winter in interior and coastal areas of Karnataka but hyperparasitism was below 20.0 per cent. Chandrika (2005) recorded *Pediobius parrulus* Ferriere from cocoons of *E. nephantidis* in Kerala.

Studies of exotic parasitoids

Many biocontrol successes have involved the introduction of an exotic parasitoid or predator and in most cases a single exotic species has eventually been able to reduce the population to a non-pest status. Systematic efforts to breed the exotic natural enemies of *O. arenosella* and release in pest infested coconut gardens were not successful. Exotic tachinid parasitoids, such as *Stomatomyia (Spoggosia) bessiana* Baranov from Sri Lanka and *Bessa remota* Aldrich introduced from Malaysia, released in India were not successful (Rao *et al.*, 1971; Jayanth and Nagarkatti, 1984, Cock and Perera, 1987). *Eriborus trochanteratus* Morley, a solitary larval endoparasitoid was reported from India and Sri Lanka (Ayyar and Margabandu, 1934; Perera, 1977; Swamiappan and Balasubramaniyan, 1987). Development is completed in 15 days. Field release affected 17.3 to 26.3% parasitism (Pillai and Nair, 1986a). Cock and Perera (1987) attributed the failure of exotic species to the fact that any species introduced would have to be screened in the laboratory and field cages before direct field release.

Table 7. Hyperparasitoids of *Opisina arenosella* in India

Host	Hyper parasitoid (Family)	Per cent hyper parasitism	Place	Reference
<i>Apanteles taragamae</i>	<i>Aphanogmus manilae</i> (Ashmead) (Ceraphronidae)	5.0 - 27.14	North Kerala	Mohammed <i>et al.</i> (1982a)
	<i>Meteoridae hudsoni</i> (Nixon) (Braconidae)	17.4		Ghosh and Abdurahman (1985 b ; 1985c; 1988b)
	<i>Brachymeria nephantidis</i> Gahan (Chalcididae)	2.86		
	<i>Pediobius imbreus</i> (Walker) (Eulophidae)	2.86		
	<i>Eurytoma albotibialis</i> Ashmead (Eurytomidae)	1.42 -7.0		
	<i>E. braconidis</i> Ferriere (Eurytomidae)	-		
<i>Apanteles rubripes</i>	<i>Pediobius bruchicida</i> (Rondani) (Eulophidae)	25.0 - 35.0	Gujarat	Kapadia (1983)
<i>Bracon brevicornis</i>	<i>P. imbreus</i> (Walker) (Eulophidae)	29.8	North Kerala	Ghosh and Abdurahman (1985b)
	<i>P. bruchicida</i> (Eulophidae)	42.62	Gujarat (Junagadh)	Kapadia (1983)
		20.2		Vyas and Butani (1986)
<i>Goniozus nephantidis</i>	<i>P. imbreus</i> ; <i>P. bruchicida</i> (Eulophidae)	31.82 - 90.14	Gujarat (Mahuva)	Kapadia and Mittal (1986)
	<i>A. manilae</i> (Ceraphronidae)	18.0 - 28.0	InteriorKarnataka	Kapadia (1983)
	<i>E. albotibialis</i> , <i>E. braconidis</i> (Eurytomidae)	--	--	Sujatha (2001)
<i>Brachymeria</i> spp.	<i>E. albotibialis</i> (Eurytomidae)	13.11 - 43.48	South Kerala	Pillai and Nair (1985a)
		8.3 -12.5	Karnataka	Sujatha (2001)
<i>Meteoridae hudsoni</i>	<i>E. albotibialis</i> (Eurytomidae)	Negligible parasitism	North Kerala	Ghosh and Abdurahman (1984)

Table 8. Hyperparasitoids on *Opisina arenosella* in Sri Lanka

Host parasitoid	Hyper parasitoid (Family)	Per cent hyper parasitism	Reference
<i>Apanteles taragamae</i>	<i>Aphanogmus manilae</i> Ashmead (Ceraphronidae) <i>Eurytoma</i> sp. (Eurytomidae)	15.0 to 20.0 -	Dharmaraju (1962)
<i>Goniozus nephantidis</i>	<i>Aphanogmus goniozi</i> Dessart (Ceraphronidae) <i>Eurytoma</i> sp. (Eurytomidae) <i>Pediobius imbreus</i> Walker (Eulophidae) <i>P. detrimentosus</i> Gahan (Eulophidae)	- - 6.0 to 8.0 -	Dessart (1988) Dharmaraju (1962) Perera (1993)
<i>Eriborus trochanteratus</i>	<i>A. manilae</i> (Ceraphronidae) <i>G. nephantidis</i> (Bethyridae) <i>Eurytoma</i> sp. (Eurytomidae) <i>Brachymeria nephantidis</i> Gahan (Chalcididae) <i>P. imbreus</i> (Eulophidae)	- - - - -	Dharmaraju (1962) Perera (1977)
<i>Stomatomyia bezziana</i>	<i>B. nephantidis</i> (Chalcididae) <i>Eurytoma albotibialis</i> Ashmead (Eurytomidae) <i>P. imbreus</i> (Eulophidae) <i>Trichospilus pupivorus</i> Ferriere (Eulophidae)	- - - -	Dharmaraju (1962) Perera (1987)

Predators

The efficiency of the predators is neither fully assessed nor widely used in the biological control programme of *O. arenosella* (Pillai and Nair, 1993). Insect and spider predators are abundant in the coconut ecosystem. The dominant insect predators are the carabid beetles *Parena nigrolineata* Chaudoir, *Calleida splendidula* Fabricius, anthocorid *Cardiastethus* spp., chrysopid *Ankylopteryx octopunctata candida* Fabricius, coccinellids (Pillai and Nair, 1986b, 1993). Species of *Cheiracanthium*, *Rhene* and *Sparassus* are the important spider predators (Sathiamma *et al.*, 1987a, b). Surveillance in Karnataka revealed the occurrence of efficient insect predators, viz., *C. exiguus*, *Buchananiella sodalis* Buchnan-White, *Mallada astur* (Banks), *Jauravia* sp., *Phytoseiulus* sp., and ants; namely, *Tapinoma* sp., *Monomorium pharaonis* (Linnaeus), *M. latinode* Mayr,

Crematogaster sp. and *Tetraoponera rufonigra* (Jerdon) (Sujatha and Singh, 1999). Promising predators of *O. arenosella* and their efficiency/feeding potential are provided in Table 9. Biology of important predators is depicted in Table 10.

Carabids

Parena sp. was found effective in India in the states of Kerala, Karnataka, Andhra Pradesh, Tamil Nadu and Goa. Rao (1924) and Venkatasubban (1932) observed *Parena* sp. predating on larvae and pupae of the pest in coastal south India. In north Kerala, Mohammed *et al.* (1982b) studied the life history and predatory behaviour of two species of carabids. Pillai and Bhat (1987) and Pillai and Nair (1990a) studied the biocology and feeding potential of *Parena nigrolineata* and *Calleida splendidula*, respectively. In Karnataka, studies have been conducted on the

biology and feeding (Gulagannavar, 1987) and field efficacy of *P. nigrolineata* (= *Parena laticincta* Bates). in Tamil Nadu at Coimbatore (David *et al.*, 1975) and in Andhra Pradesh (Rao *et al.*, 1978) revealed the efficiency of the predator. Sujatha (2001) reported that the intense activity of *P. nigrolineata* (8 to 15 per palm) throughout April-August proved effective in pest suppression in coastal Karnataka.

Anthocorids

Anthocorid bugs have been reported as egg predators of *O. arenosella* (Rao *et al.*, 1948; Abdurahiman *et al.*, 1982) (Figure 7A). Nasser and Abdurahiman (1990) recovered three anthocorid bugs, *viz.*, *Cardiastethus exiguus*, *C. affinis* Poppius and *B. sodalis* from pest infested leaflets of coconut in north Kerala. Among these, *C. exiguus* was found to be an efficient predator. Studies on aspects such as biology, population dynamics, feeding potential and predatory behaviour were conducted. The bugs feed on 200-250 eggs of the pest in a life time. Fecundity was high during May-October (rainy season). Srinivasa (1996) in his studies on the predatory potential and biology of *C. affinis* on *O. arenosella* in interior Karnataka reported non significant relationship between its population and pest population. The density of *C. exiguus* showed significant positive correlation with early larval population of *O. arenosella*, in interior and coastal zones of Karnataka (Sujatha, 2001, 2005).

Numerical abundance during summer and post monsoon in coastal and interior areas, respectively revealed its perfect synchronization with peak population of the host. Further studies on feeding potential revealed that during nymphal period *C. exiguus* consumed 102 eggs/36 neonatal larvae of *O. arenosella*. Seasonal fluctuations in the population were dependent more on biotic factors than abiotic (Nasser, 1992; Sujatha, 2001, 2005). The high fecundity and amenability to laboratory rearing make

C. exiguus an ideal predator for mass release in the field (Nasser and Abdurahiman, 2001). Ballal *et al.* (2003) studied the biological parameters of *C. exiguus* on alternate host, *Corcyra cephalonica* Stainton and standardized a method for mass rearing of this predator

Chrysopids

Among the chrysopids, *Ankylopteryx octopunctata candida* Fabricius was recorded as an egg and early larval predator on *O. arenosella* in Kerala, which appeared in the field from April to October with a peak in population during June-July (Sathiamma *et al.*, 1985). It consumed 160-230 eggs of *O. arenosella* during its development.

Chrysopa sp. and *Chrysopa scelestes* Banks were recorded as egg and early larval predators in Gujarat (Yadav and Dhamalia, 1985). Krishnamoorthy (1988) described the life history of *Chrysopa scelestes* Banks feeding on the neonate larvae of *O. arenosella*. Srinivasa (1996) recorded *Chrysopa* sp., in interior Karnataka on young palms during monsoon season.

In interior Karnataka *Mallada astur* was recorded on tall palms in coffee mixed coconut cropping system feeding on eggs and neonatal larvae of *O. arenosella* (Sujatha, 2001) (Figure 7 B, C). *M. astur* larva, during its development, fed on an average 70 neonatal larvae of *O. arenosella*. Combined diet of eggs and neonate larvae (143) resulted in shorter developmental period. Its predominant presence on coconut and palmyrah palms of 30m height, high oviposition period and fecundity rate and its ability to thrive in the larval galleries of *O. arenosella*, strongly support its utilization as a biocontrol agent during peak period of infestation during September-February in interior Karnataka (Sujatha and Singh, 2003b).

Table 9. Promising predators of *Opisina arenosella*

Species (Order/Family)	Stage attacked	Place	Remarks/ feeding potential	Reference
<i>Calleida splendidula</i> (Fabricius) (Coleoptera: Carabidae)	Larva	Kerala	One mature larva in every three days	Pillai and Nair (1990a)
<i>Parena nigrolineata</i> Chaudoir (= <i>Parena laticincta</i> Bates) (Coleoptera: Carabidae)	Larva	Andhra Pradesh	Active	Rao <i>et al.</i> (1978)
<i>Parena nigrolineata</i> Chaudoir (Coleoptera: Carabidae)	larva	Tamil Nadu	Important predator	David <i>et al.</i> (1975)
		Kerala	0.32 4th instar larvae/day	Pillai and Bhat (1987)
		Karnataka	0.46 larvae / day	Gulagannavar (1987)
		North Kerala	-	Mohammed <i>et al.</i> (1982b)
<i>Jauravia</i> sp. (Coleoptera: Coccinellidae)	Egg	Karnataka	3.5 eggs/day	Sujatha (2001)
<i>Cardiastethus exiguus</i> Poppius (Heteroptera: Anthocoridae)	Egg	North Kerala	4.02 to 5.71 eggs / day	Nasser and Abdurahman (1990)
		Karnataka	7.20 eggs/day	Sujatha (2001)
<i>C. affinis</i> Poppius (Heteroptera: Anthocoridae)	Egg	-	5.0 eggs / day	Nasser and Abdurahman (1990)
<i>Buchananiella sodalis</i> Buchnan-White (Heteroptera: Anthocoridae)	Egg	-	9.6 eggs/day	Sujatha (2001)
<i>C. affinis</i> Poppius (Heteroptera: Anthocoridae)	Egg and larva	Karnataka	0.72 larva / day	Srinivasa (1996)
<i>Ankylopteryx octopunctata candida</i> (Fabricius) (Neuroptera: Chrysopidae)	Egg and larva	Kerala	2 to 3 eggs / day	Sathamma <i>et al.</i> (1985)
<i>Chrysopa</i> sp. (Neuroptera: Chrysopidae)	Egg	Gujarat	Important predator	Yadav and Dhamalia (1985)

Table 9. Promising predators of *Opisina arenosella* Contd

Species (Order/Family)	Stage attacked	Place	Remarks/ feeding potential	Reference
<i>Mallada astur</i> (Banks) (Neuroptera: Chrysopidae)	Egg and larva	Karnataka (interior)	376.0 eggs/ 70 neonatal larvae	Sujatha and Singh (2003b)
<i>Monomorium floricola</i> Jerdon (Hymenoptera: Formicidae)	-	-	-	Veeresh <i>et al.</i> (1995)
<i>Anoplolepis longipes</i> Jerdon (Hymenoptera: Formicidae)	Egg, larva and pupa	Karnataka Karnataka (coastal)	Efficient predators	Sujatha (2001)
<i>Monomorium</i> spp. (Hymenoptera: Formicidae)	-	-	-	-
<i>Crematogaster</i> sp. (Hymenoptera: Formicidae)	-	-	-	-
<i>Tapinoma</i> sp. (Hymenoptera: Formicidae)	-	-	-	-
<i>Cheilomenes sexmaculata</i> (Fabricius) (Coleoptera: Coccinellidae)	-	-	-	-
<i>Micraspis discolor</i> (Fabricius) (Coleoptera: Coccinellidae)	Egg	Kerala	-	Pillai and Nair (1986b)
<i>Propylea fallax</i> Khnzorian (Coleoptera: Coccinellidae)	-	-	-	-
<i>Jauravia pubescens</i> (Fabricius) (Coleoptera: Coccinellidae)	-	-	-	-
<i>Cheiracanthium</i> sp., (Arenae: Clubionidae)	-	-	-	-
<i>Rhene</i> spp., (Arenae: Salticidae)	-	-	-	-
<i>Sparassus</i> sp., (Arenae: Sparassidae)	Egg, larva and pupa	Kerala	0.70 to 1.54 larvae per day	Sathiamma <i>et al.</i> (1987a)

Table 10. Biology of important predators of *Opisina arenosella*

Predators	Developmental period (days)		Fecundity (eggs/Female)	Longevity (days)		Reference
	Egg	Nymph/grub		Male	Female	
A) <i>Anthocorids</i> <i>Cardiastethus</i> sp.	4 - 5.0	18.2	17-20	One month		Abdurahiman <i>et al.</i> (1982)
<i>C. exiguus</i> Poppius on <i>C cephalonica</i>	3 -5.0	14.0 - 20.0	75-250	101.4	126.6	Nasser and Abdurahiman (1990); Bellal <i>et al</i> (2003)
	3.57	16.71	40.36 nymphs	35.7	66.1	
<i>C. affinis</i> Poppius	3 - 4.0	17 - 19.0	58-38 in its life time	125.0	156.0	Nasser and Abdurahiman (1990)
<i>C. nazarenus</i> Reuter	2 - 5.0	15.6	8-23.0	15.6	39.4	Kapadia (1987a)
	4 - 7.0	16 - 26.5	35-45.0	20.3	38.9	
B) <i>Carabids</i> <i>Parena nigrolineata</i> Chaudoir. (= <i>P. laticincta</i> Bates)	4 - 9.0	6 - 16.0	25-63 eggs\50 days	214.0	196.0	Pillai and Bhat (1987)
	5 - 9.0	11 - 18.0	-	-	-	Rao <i>et al.</i> (1978)
<i>Calleida splendidula</i> (Fabricius).	4 - 5.0	-	32-72/month	2-3 months		David <i>et al.</i> (1975)
	4 - 8.0	13 - 18.0	-	180.0	420.0	Pillai and Nair (1990a)
C) <i>Chrysopids</i> <i>Ankylopteryx</i> sp. <i>Mallada astur</i> (Banks)	2.0	9 - 11.0	-	17-35	50-72	Sathamma <i>et al.</i> (1985) Sujatha and Singh (2003b)
	5.0	11.5	8.5	-	-	

Ants

In Sri Lanka, Way *et al.* (1989) observed at least 11 species of ants nested in coconut palm crown and some of these like *Monomorium floricola* (Jerdon), *Technomyrmex albipes* (Smith) and *Crematogaster* sp. were very effective in locating and removing eggs of *O. arenosella* by foraging activity. Further surveys carried out by them on ants have confirmed the presence of *Monomorium* spp. in non-outbreak areas. Veeresh *et al.* (1995) have suggested the effective utilization of ants, *M. floricola* and *Anoplolepis longipes* (Jerdon) against *O. arenosella* in coconut. Sujatha (2001) observed that in coastal Karnataka predatory ant colony (*Tapinoma* sp., *Monomorium* spp., and *Crematogaster* sp.) migrate from ground to pest infested tall palms soon after the initial showers of monsoon rains, nest in the folded coconut leaflets and contribute effectively not only to the mortality of eggs of *O. arenosella* but also in wiping out its population from infested palms in the areas of its occurrence.

Spiders

Spiders are the most dominant group of predators on *O. arenosella*. Rao *et al.* (1979)

reported four species of spiders (*Cheiracanthium melanostoma* (Thorell), *Olios lamarcki* (Licrielle), *Heteropoda leprosa* Simon, *Marpissa calcuttaensis* (Tikader)) in association with *O. arenosella* in East Godavari district of Andhra Pradesh. Twenty six species of spiders belonging to 12 genera and 6 families have been recorded in Kerala, where *Cheiracanthium*, *Rhene* and *Sparassus* are some of the major predacious species on *O. arenosella*.

Spider population was high during July-August and low during February-March. Biology of *R. indicus* and *Cheiracanthium* sp. is given by Sathiamma *et al.* (1987a, b). In interior Karnataka, 14 species of spiders were recorded (Gulagannavar, 1987). Sujatha (2001) reported the occurrence of 17 species of spiders on *O. arenosella* in Karnataka, where they were active during July-August. *Cheiracanthium* sp., *Marpissa* sp., *Rhene* sp., *Sparassus* sp., *Tetragnatha andamanensis* Tikader, and *Zygoballus* sp. were commonly observed in both coastal and interior regions. *Poecilochroa* spp. and *Phidippus* spp. were specific to coastal and interior areas, respectively. Spider fauna recorded on *O. arenosella* is presented in Table 11.

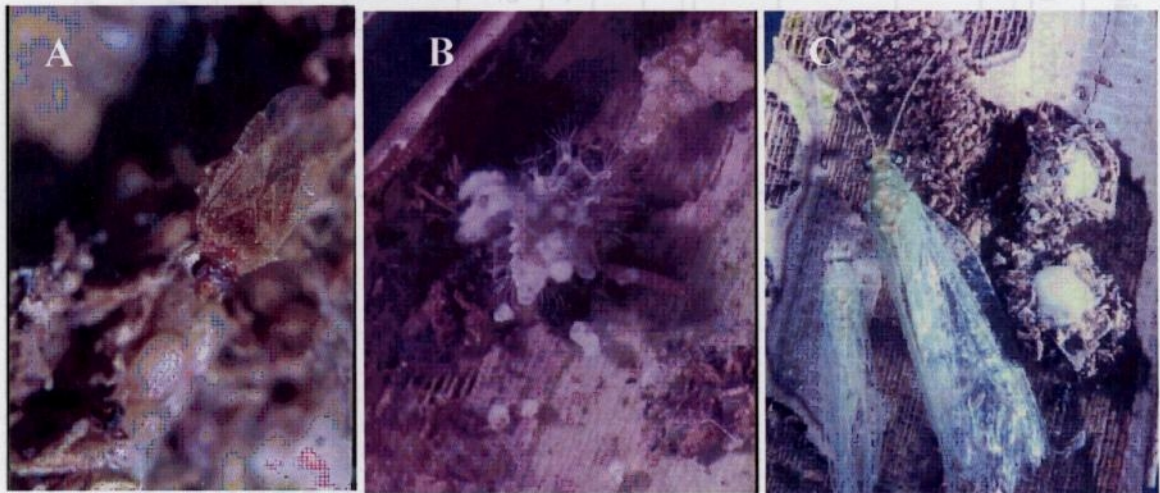


Fig. 7. Predators of *Opisina arenosella*: A. *Cardiastethus exiguous*; B. *Mallada astur* larva; C. *Mallada astur* cocoons and adults

Table 11. Spider fauna on *Opisina arenosella*

Species		Family
Karnataka (Sujatha, 2001)	Kerala (Sathiamma <i>et al.</i> , 1987a)	
<i>Argiope pulchella</i> Thorell	<i>Argiope catenulate</i> (Doleschall)	Araneidae
<i>Gasteracantha</i> sp.	<i>Larinia jayasankari</i> Biswas	
<i>Neoscona mukerjei</i> Tikader	<i>Neoscona bengalensis</i> Tikader & Bal	
<i>Neoscona</i> sp.	<i>N. elliptica</i> Tikader & Bal	
<i>Cheiracanthium</i> sp.	<i>Cheiracanthium</i> spp.	Clubionidae
	<i>C. melanostoma</i> Thorell	
	<i>Clubiona drassodes</i> Cambridge	
<i>Poecilochroa barmani</i> Tikader	<i>Poecilochroa barmani</i> Tikader	Gnaphosidae
<i>Poecilochroa</i> sp.	-	
<i>Marpissa</i> sp.	<i>Marpissa anusuae</i> Tikader & Biswas <i>M. dhakuriensis</i> Tikader, <i>M. tigrina</i> Tikader, <i>Marpissa</i> spp.	Salticidae
<i>Phidippus indicus</i> Tikader	<i>Phidippus bengalensis</i> Tikader	
<i>Phidippus pateli</i> Tikader	<i>Phidippus</i> spp.	
<i>Phidippus</i> sp.	-	
<i>Plexippus paykullii</i> (Audnovin)	<i>Plexippus paykullii</i> (Audnovin)	
<i>Rhene</i> sp.	<i>Rhene danieli</i> Tikader, <i>R. indicus</i> Tikader, <i>R. khandalensis</i> Tikader,	
<i>Zygoballus</i> sp.	-	
<i>Sparassus</i> sp.	<i>Sparassus</i> sp.	Sparassidae
<i>Tetragnatha andamanensis</i> Tikader	<i>Tetragnatha andamanensis</i> Tikader	Tetragnathidae
<i>Theridion</i> sp.		Therididae

10.2.6. Mites

Pyemotes ventricosus Newport belonging to Pymotidae family was a gregarious ectoparasitic mite collected from the field. It parasitises mostly the larval and pupal stages and occurs during rainy season (Mathen *et al.*, 1968). A predatory mite, *Phytoseiulus* sp was recorded in both coastal and interior zones of

Karnataka (Sujatha, 2001). Studies on seasonal variation revealed their numerical abundance during summer and post-monsoon in coastal area. Population of the mite ranged 86.25-261.25 per 20 per cent sample leaflets/palm. *Phytoseiulus* sp. and *C. exiguus* in the ratio 2:1 were associated with low population of *O. arenosella* during summer in interior Karnataka.

Pathogens

Bacillus thuringiensis Berliner, *Serratia marcescens* Bizio, and *Aspergillus flavus* Link are observed to be pathogenic to the pest in the field (Antony and Kurian, 1961; Muthukrishnan and Rangarajan, 1974; Oblisami *et al.*, 1969; Kanagaratnam *et al.*, 1983 and Gopal *et al.*, 2000). Philip *et al.* (1982) and Narayanan and Veenakumari (2003) reported a nuclear polyhedrosis virus affecting the caterpillars in Kerala and Karnataka, respectively. Sujatha (2001) observed 15.0 per cent larval mortality due to bacterial and fungal pathogens soon after the monsoon rains (October) in coastal Kerala

Management of *Opisina arenosella*

Since 1960, detailed investigations have been taken up on the ecology and management of the *O. arenosella* by cultural, mechanical, chemical and biological methods. Cutting and burning the heavily infested and fully dried outermost 2-3 leaves removes the pupae and other pest stages. The pest can be well managed by biological control methods. However, an integrated pest management strategy is to be adopted in an epidemic outbreak. Kurian *et al.* (1974) evaluated the use of integrated control for coconut pests, which is both effective and economical. In coconut based system, IPM strategies involving the discrete application of small quantities of plant protection chemicals through proper timing, selective placement and dosage reduction combined with biological methods of control could be effective to bring about the desired results. As the perennial nature of the crop permits a continuous interaction between the natural enemy and the pest without ecological upheavals, IPM has been recommended against coconut caterpillar (Nadarajan, 1977; Sathiamma *et al.*, 1982; Pillai, 1987; Jayaraj, 1989; Perera, 1993; Nair *et al.*, 1998).

Chemical control

Among the various insecticides evaluated

against *O. arenosella* in the laboratory, lead arsenate, malathion and dichlorvos were found effective (Sathiamma and Kurian 1967; 1970; 1972). In severe outbreak conditions, spraying the undersurface of the leaves with 0.02 per cent dichlorvos and administering a systemic insecticide (monocrotophos 10 ml/palm) through the root has been recommended (Rao *et al.*, 1980, 1981). Nadarajan and ChannaBasavanna (1981) reported that in the cases of severe infestation trunk injection of monocrotophos 3.5 to 7.0 ml per palm was effective. Kanagaratnam and Pinto (1985) reported that monocrotophos (5-10ml) injected into the trunk gave complete pest suppression within 85 days after injection and the effect persisted in leaves for about 4-6 months. Pushpalatha (1986) recommended root feeding of monocrotophos against the pest. Nair *et al.* (1997) suggested that all the mature nuts may be harvested before root feeding/ trunk injection treatment with systemic insecticides and plucking tender coconuts or harvesting of nuts should be strictly avoided for forty days after treatment to overcome the residue problem in edible parts. Nair *et al.* (1998) while discussing the newer approaches in the IPM in coconut felt that insecticides destroyed the natural enemies in coconut ecosystem which in turn resulted in pest outbreaks.

Application of systemic insecticide through a cavity at the base of the petiole (petiolar wells) has been found useful in the control of *O. arenosella* (Perera *et al.*, 1989). In Sri Lanka, while biological control is encouraged, chemical treatments using systemic insecticides is recommended to control the pest outbreaks (Perera, 1993).

Biological control

Biological control provides the best solution for the management of *O. arenosella* on a perennial crop like coconut (Rao *et al.*, 1948; Nirula, 1956; Nagarkatti, 1973; Perera, 1984, 1987; Cock and Perera, 1987; Pillai and Nair, 1993, Singh, 1999 and Sujatha 2001).

Nagarkatti (1973) opined that a systematic survey for natural enemies in all coconut growing areas in the country is essential and further stated that systematic effort to breed the exotic and indigenous natural enemies and perfectly timed release of host specific and stage specific parasitoids and predators would be effective in successful pest suppression.

Abraham (1994) while reviewing the pests of coconut and arecanut felt that the information available on the population dynamics of *O. arenosella* in relation to its natural enemies in time and space was very scanty and suggested for an integrated management effort with a very strong element of biocontrol. Muraleedharan (1998) concluded that biosuppression with the release of stage-specific parasitoids at different intervals has been proved to be one of the most promising management tactics for *O. arenosella*.

Singh (2000) pointed out that the bioagents selected in augmentative biocontrol should be the effective species amenable to mass production, compatible with crop production inputs, high reproductive potential and host searching capacity, and tolerant to most common pesticides. In Karnataka, the combined action of stage specific natural enemies and extreme weather conditions brought down the pest population to acceptable levels (Sujatha and Singh, 2004a). In the coastal Karnataka heavy monsoon rains (1030-1714 mm) and activity of egg and early larval predators, viz., anthocorids, mites and ants wiped out the pest population as evidenced during post monsoon. In the interior area, parasitism by braconids viz., *A. taragamae* (early larval), *B. hebetor* (late larval) and *M. hutsoni* (larval-pupal) during rainy, summer and winter seasons, respectively, besides the favourable coexistence of predators, namely, anthocorids and mites regulated the pest population.

Kairomones could be used to enhance the efficiency of potential parasitoids

(Bakthavatsalam and Singh 1996). Hexane wash of gallery and body of *O. arenosella* elicited positive response from the efficient parasitoids namely, *G. nephantidis*, *E. nephantidis* and *B. nephantidis*. Analysis of infochemicals using GCMS revealed the presence of dodecane, pentadecane, hexadecane, heptadecane, eicosane and tricosane in the gallery of *O. arenosella* and larval wash showed terpenoids (Bakthavatsalam *et al.*, 1999).

Field release of natural enemies

Management of *O. arenosella* by employing the indigenous natural enemies in India was known as early as 1920s. During 1926 and 1930, Madras Government had set up parasite breeding centres at Mangalore, Calicut and Ponnani. In these breeding stations the parasitoids viz., *Trichospilus pupivora*, *Goniozus (Perisierola) nephantidis* and Bracon (*Microbracon*) *brevicornis* were bred in large numbers for liberation in the infested areas. In 1929 a boat laboratory was started to breed and transport parasitoids in the Trivandrum and Cochin belt. The result was successful but this work was stopped in 1931. Several similar efforts have since been made in areas of southern India with varying degrees of success (Nirula *et al.* 1951). An area of 600 ha of coconut plantation in Badagara (Kerala) was under epidemic out break of the pest during 1970 and with the release of parasitoids this was brought under check (Joy and Joseph, 1972a). Joy and Joseph (1977a) and Pillai and Nair (1981) recognized the importance of release of pupal parasitoids against *O. arenosella* in an effective manner. In interior Karnataka, Medappa (1983) found that fortnightly releases of ten numbers of *G. nephantidis* per palm raised the level of parasitism by 10 per cent. Studies carried out on the release of *G. nephantidis* in Gujarat revealed an overall per cent parasitism of 30.97 (Kapadia and Mittal, 1993). The techniques were standardized for the mass multiplication of twelve parasitoids including

two exotic species and two predators (Singh, 1994b). Studies on mass release at Tamil Nadu revealed that the natural parasitism of *G. nephantidis* and *B. brevicornis* were increased from 0.65 and 3.25, respectively, to 12.72 and 21.56 after the release. Release of *G. nephantidis* in Ratnagiri (Maharashtra) resulted in 21.43 per cent parasitism after nine months (AICRP, 1997). Sathiamma *et al.* (1999) have discussed the techniques for mass multiplication of the promising parasitoids *viz.*, *G. nephantidis* (larval), *E. nephantidis* (pre-pupal) and *B. nosatoi* (pupal), which are recommended for field release.

Sampling technique and norms for field release

Initial assessment of the pest population is necessary for the release of known doses of larval and pupal parasitoids for the control of *O. arenosella*. Also the stage of the pest is to be ascertained for the release of the stage specific parasitoid. For this purpose a sampling technique was evolved by George *et al.*, 1982 (Table 12).

Table 12. Sampling formula for estimation of *O. arenosella* population (George *et al.*, 1982)

Period	Sampling formula
February to March	$Y = 22.59 + 5.75 x$
April to June	$Y = 38.40 + 9.70 x$
July to October	$Y = 20.87 + 6.20 x$
November to January	$Y = 6.36 + 8.99 x$
Y = Estimated population, x = Population count on sample leaflets	

Arbitrary release of parasitoids often failed to bring about effective control of the pest and at other times the released parasitoids were unable to reach the proper target stages of the host. Dosages were worked out for the release

of *G. nephantidis*, *E. nephantidis* and *B. nosatoi* based on the estimated population of the larvae, prepupae and pupae of *Opisina*.

Releases are to be done at fortnightly intervals. Release *G. nephantidis* @ 20.5% at or above the third instar larval stage, *E. nephantidis* @ 49.4% at the pre-pupal stage and *B. nosatoi* @ 31.9% at the early pupal stage of the pest. In a multistage condition of the pest, a combined release of all the parasitoids @40% of each of the target pest stage is required (Sathiamma *et al.*, 1987c).

Sujatha (2001) reported that the release of 2 nymphs (5 day old) of *C. exiguus* per infested leaflet hosting on an average 50.0 eggs of *O. arenosella* resulted in desired pest suppression. Release of one larva of *M. astur* (4 day old) per leaflet having 35-45 neonatal larvae of *O. arenosella* effectively reduced the pest population in early stages of infestation (Sujatha and Singh, 2003b).

Field performance in India

Thodiyur (Kollam Dist. Kerala)

Studies conducted in an endemic area at Thodiyoor (Kollam District, Kerala, India) with the field release of the three stage specific parasitoids *viz.*, *G. nephantidis*, *E. nephantidis* and *B. nosatoi* at fixed norms and intervals in a heavily infested coconut garden (2.8 ha) for a period of five years resulted in highly significant reduction (94%) in *Opisina* population (Sathiamma, *et al.*, 1996) (Figure 8) The control plot where no release was made, the pest population was very much fluctuating. In the released plot the percentage of parasitism also remained high 3.7 to 47.6 (*G. nephantidis*), 0 to 55.6 (*E. nephantidis*) and 0 to 71.4% (*B.nosatoi*) and the parasitoids continued to exert check on the build up of the population (Sathiamma, *et al.*, 1996). Follow up observation revealed no build up of the pest in the released site even after eight years.

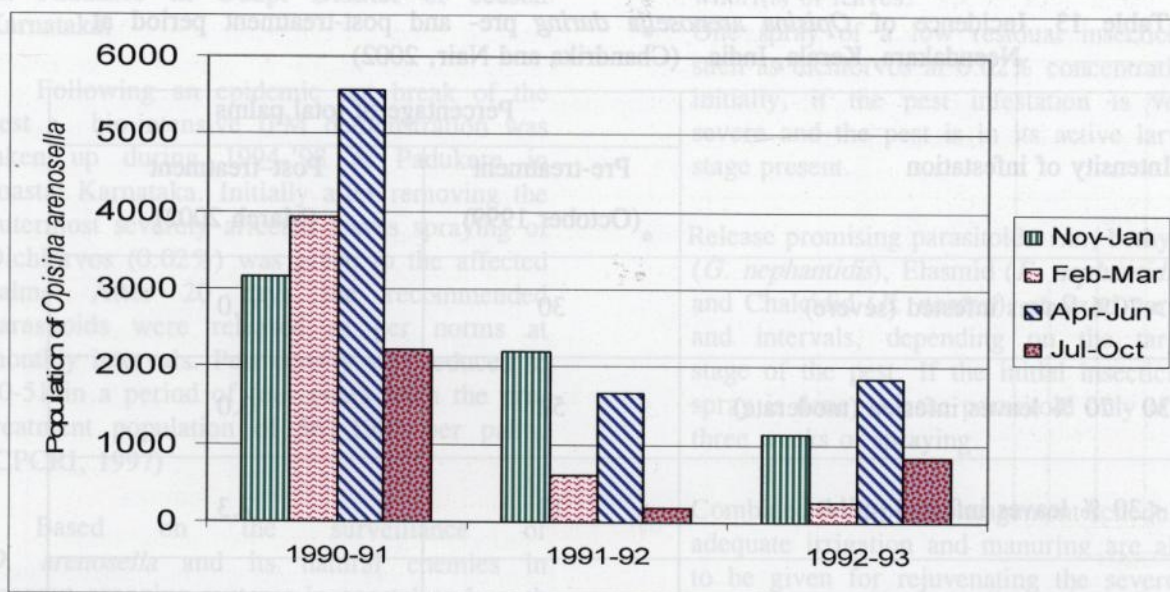


Fig. 8. Estimated total population of *Opisina arenosella* at Thodiyoor Sathiamma, et al., 1996)

Neendakara (Kollam Dist., Kerala)

A front line demonstration on bio-intensive IPM against coconut leaf eating caterpillar was conducted in 1999 - 2002 at Neendakara Krishi Bhavan area, Kollam District, Kerala (Chandrika and Nair 2002). This demonstration was implemented with the support of Dept. of Agriculture, Kerala. Highly affected and fully dried one or two leaves were removed from severely infested palms. Parasitoids were mass multiplied in the laboratory and were released in the field after assessing the population of the target stage of the pest at monthly intervals as per the norms. Bethylid (*G.nephantidis*), Elasmid (*E. nephantidis*), and Chalcidid (*B. nosatoi*) parasitoids were released at 21, 49 and 32% to the larval, pre-pupal and pupal stages of the pest respectively. A total of eight releases of parasitoids were made.

Another *Opisina* endemic area viz., Ayiramthengu in the same district was monitored and population of the pest was recorded during the same period to study the natural build up of pest population in an unreleased plot. Regular monitoring and release of stage specific parasitoids resulted in

52.6 and 94.7 per cent reduction in pest population after one -year and two-year respectively of parasite release. Pest incidence on palms was reduced to nil from 30% severe and 52% moderate infestation levels (Table 13).

There was a steady decline in *O. arenosella* population and the biocontrol agents alone could effect significant reduction in population of the pest. The pest population showed a decrease of 95% when compared to the pre-treatment condition. There was a build up of the released parasitoids in the field. This was evidenced by the observations during post-release period showing *E. nephantidis*, *G. nephantidis* and *B. nosatoi* parasitising the pest population. Observations on pest population from the non-release plot (Ayiramthengu) showed a steady stage with peak population during March-July. The pest population always remained on a higher level during peak periods (Figure 9).

Table 13. Incidence of *Opisina arenosella* during pre- and post-treatment period at Neendakara, Kerala, India (Chandrika and Nair, 2002)

Intensity of infestation	Percentage of total palms	
	Pre-treatment (October 1999)	Post-treatment (March 2002)
> 70% leaves infested (severe)	30	0.0
30 - 70 % leaves infested (moderate)	52	0.0
< 30 % leaves infested (mild)	10	7.3
Negligible to no leaf damage	8	92.7

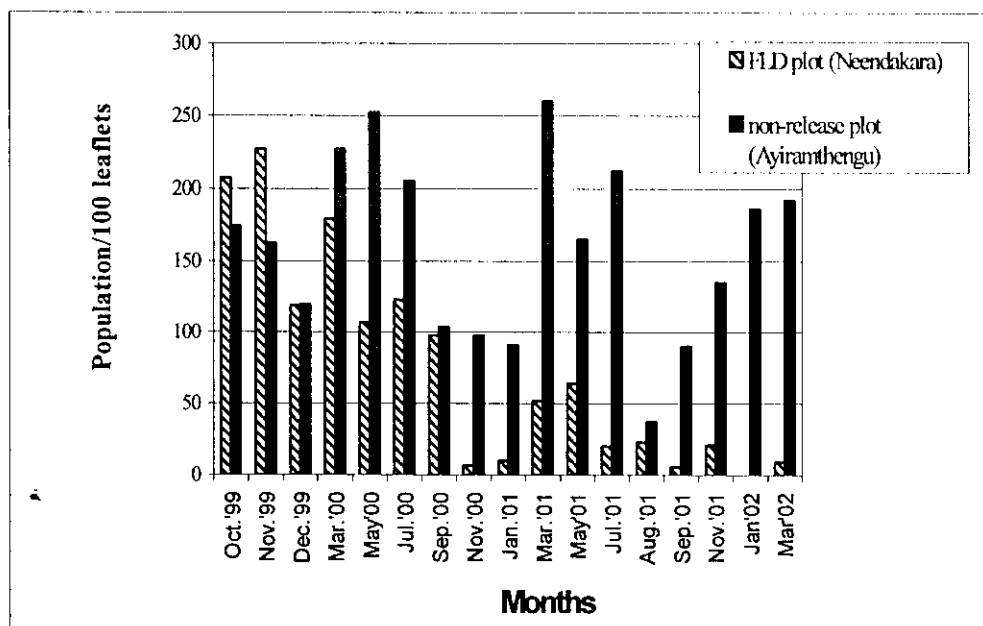


Fig. 9. Population of *Opisina* in the experimental and control plots in Kerala, India (Chandrika and Nair, 2002)

At Padukere in Udupi District of coastal Karnataka:

Following an epidemic out break of the pest a bio-intensive IPM demonstration was taken up during 1994-'98 at Padukere in coastal Karnataka. Initially after removing the outermost severely affected leaves spraying of Dichlorvos (0.02%) was given to the affected palms. After 20 days the recommended parasitoids were released as per norms at monthly intervals. Pest density was reduced to 30-51 in a period of four years from the pre-treatment population of 567-1901 per palm. (CPCRI, 1997)

Based on the surveillance of *O. arenosella* and its natural enemies in coconut cropping systems in coastal and south interior Karnataka, time of release of important stage-specific indigenous natural enemies, based on their seasonal abundance has been suggested (Table 14).

IPM Schedule

All integrated control programmes have as their goal the preservation of natural enemy reservoirs, while simultaneously destroying a satisfactory portion of the pest species by selected insecticide treatment. For best results natural enemy reservoirs maintained within the treated area so that the beneficial species are immediately available as a restraint against pest increase (Bartlett, 1964). Singh (1999), while reviewing the use of safe pesticides to conserve the natural enemies of several crop pests has pointed out the need for developing technology for selective use of pesticides in different crop ecosystems. Selection of suitable bio agents tolerant to insecticides is an objective in the augmentative bio control

The IPM module now recommended by Nair *et al.* (2002) consists of the following components *viz*,

- Cut and burn fully dried one or two outer

whorl(s) of leaves.

- One spray of a low residual insecticide such as dichlorvos at 0.02% concentration initially, if the pest infestation is very severe and the pest is in its active larval stage present.
- Release promising parasitoids *viz.*, bethylid (*G. nephantidis*), Elasmid (*E. nephantidis*), and Chalcidid (*B. nosatoï*), at fixed norms and intervals, depending on the target stage of the pest. If the initial insecticide spray is done, release parasitoid only after three weeks of spraying.
- Combined with pest management schedules adequate irrigation and manuring are also to be given for rejuvenating the severely infested coconut palms during epidemic outbreaks.

Growing inter/mixed crops in coconut garden support the farmers economically when pest out break occurs as this can generate more income per unit area.

Conclusion

In coconut ecosystem, extensive monocropping provides a relatively stable and uniform environment, which leads to the development of its own spectrum of pests. Increasing ill effects of chemical control methods such as stem injection, root feeding by monocrotophos and spraying by dichlorvos, have prompted the research workers to accept the biological control as a long term strategy to curb the pest population. All the proven cases with the very promising bioagents with regular monitoring have confirmed a meaningful way of pest management utilizing the indigenous biocontrol agents for the biological suppression of *O. arenosella*.

Table 14. Suggested time of release of important natural enemies of *Opisina arenosella* in Karnataka (India)

Species (Order:Family)	Stage attacked	Time of release	
		Coastal	Interior
<i>Apanteles taragamae</i> Viereck (Hymenoptera: Braconidae)	2 nd instar larva	Winter, Summer	Rainy, Post monsoon
<i>Bracon hebetor</i> Say (Hymenoptera: Braconidae)	Late instar larva	November-December	Summer
<i>Goniozus nephantidis</i> (Muesebeck) (Hymenoptera: Bethyridae)	Late instar larva	Winter, Summer	Summer
<i>Brachymeria</i> spp. (Hymenoptera: Chalcididae)	Pupa	Winter, Summer	Winter, Summer
<i>Meteoridea hutsoni</i> Nixon (Hymenoptera: Braconidae)	Larval- pupal	-	Winter
<i>Antrocephalus</i> spp. (Hymenoptera: Chalcididae)	Pupa	Summer	Summer
<i>Xanthopimpla punctata</i> Fab (Hymenoptera: Ichneumonidae).	Pupa	Rainy, Post-monsoon	Post-monsoon
<i>Cardiastethus exiguus</i> Poppius (Heteroptera: Anthocoridae)	Egg and neonatal larva	Winter, Summer	Rainy, Post-monsoon
<i>Mallada astur</i> (Banks) (Neuroptera: Chrysopidae)	Egg and first instar larva	-	July-January
<i>Jauravia</i> sp. (Coleoptera: Coccinellidae)	Egg and neonatal larva	-	July-January
<i>Parena nigrolineata</i> Chaudoir (Coleoptera: Carabidae)	Larva	Summer, rainy	Post-monsoon, Winter

It is of utmost importance that the parasitic fauna of a locality is to be studied before initiating the biological control programme. Role of solitary parasitoids in pest suppression is well documented. Clipping off the pest at the very initial stage and releasing appropriate dose of parasitoids synchronizing with the stages of the pest during lean periods in the field could check the pest from attaining a severe infestation level. Monitoring the infested field during successive years is the most important step for regulating further releases and for reducing the cost of application.

Conservation of promising predators (anthocorids, chrysopids, coccinellids and ants) help a long way in natural suppression of the pest and hence, spraying of palms has always been harmful to the natural enemies. Palmyrah can serve as an alternate host for the conservation of promising natural enemies of *O. arenosella*. Available records indicate the need for the mass production and release of stage specific parasitoids, namely, *A. taragamae*, *Bracon* spp. *G. nephantidis*, *Antrocephalus* spp. *Brachymeria* spp., *Xanthopimpla* spp., and *M. hutsoni* which are quite effective in controlling the pest population in the field during winter and summer. The IPM technology should become more cost-effective and farmer friendly. Integrated management programme also advocates a community effort to bring down the pest attack especially in the case of coconut where the plantations are contiguous.

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