# Natural Enemies of Mealybugs

# 13

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Mealybugs are found attacked by various natural enemies in nature. The outbreak of mealybugs was observed in many instances with the application of broad-spectrum insecticides, which might have disturbed the activity of natural enemies particularly parasitoids and predators. This clearly indicates the importance of natural enemies in the regulatory role of the mealybug population. In fact, there is a very rich natural complex on arboreal mealybugs, but there is a poor natural enemy complex, particularly natural predators or parasites on root mealybugs. Withdrawal of insecticides results in the reappearance of natural enemies, thereby regulating the mealybug population. The natural enemies of the pests can be divided into three categories depending on how they feed on the pests. They are predators, parasitoids or pathogens.

## 13.1 Predators

Insects belonging to Coccinellidae (Coleoptera), Chrysopidae and Hemerobiidae (Neuroptera), Lycaenidae and Noctuidae (Lepidoptera) and Syrphidae, Cecidomyiidae, Chamaeyiidae and Drosophilidae (Diptera) are known to feed on the mealybugs besides the spiders, mantids, ground beetles, assassin bugs, predatory stink bugs, minute pirate bugs and predatory thrips. They are polyphagus feeding on a variety of mealybugs. Naturally occurring predators are capable of suppressing the mealybugs on several occasions.

### 13.1.1 Coleoptera

#### 13.1.1.1 Coccinellidae

Both adults and larvae feed voraciously on all stages of the mealybugs including the egg masses. The larvae of many predatory coccinellids are covered with white waxy filaments very similar to the mealybugs. The adults are brightly coloured. The eggs are oval shaped, yellow and very small. The larvae are voracious feeders though the adults are also known to feed on the mealybugs. Development from egg to adult beetle takes 25–30 days at 25 °C. The species belonging to genera *Cryptolaemus*, *Brumus, Aspidimerus, Stictobura, Orcus, Diomus, Nephus, Sidis, Parasidis, Pseudoscymnus*, *Hyperaspis, Scymnus, Sasajiscymnus, Exochomus, Brumoides, Cleophora, Harmonia* etc. are some of the important predators of mealybugs. Among the coccinellids, *Cryptolaemus montrouzieri* Mulsant was extensively used to control a variety of mealybugs throughout the world.

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### *Cryptolaemus montrouzieri*

*Cryptolaemus montrouzieri* is native of Australia popularly known as the Australian ladybird beetle, often referred to as the mealybug destroyer. Adult beetles are about 4 mm long, oval in shape, black in colour with a light brown head and posterior. *Cryptolaemus* larvae grow up to 13 mm long and are covered with long, white, waxy filaments. The *Cryptolaemus* preys upon several species of mealybugs. It is less effective when the temperature is below 20 °C or when the humidity level is low (<40 % relative humidity (RH)). *Cryptolaemus* prefers a warm and humid climate. The egg to adult development takes about 30 days at a temperature of 25 °C. During her lifespan, a female can lay up to 400 eggs. The eggs are deposited within the egg masses of the mealybugs. *Cryptolaemus* eggs are brighter and quite larger. The larvae are covered with long white wax filaments. At first sight, they very closely resemble the mealybugs. However, *Cryptolaemus* larvae move faster and are more fluffy in their appearance. The larvae will eat each other whenever the food availability is poor. For pupation, the larvae will go to a hidden place. The pupae look very similar to the larvae, quite larger and somewhat more fluffy (Mani et al. 1991).

*Cryptolaemus* on mealybugs

*Nephus includens*

### *Hyperaspis trilineata* Mulsant

*Hyperaspis trilineata* Mulsant is a principal predator of *Saccharicoccus sacchari* (Cockerell). It is reported to have a peculiar type of egg that is at first flat and resembles a whitefly larva. They are laid singly and are hatched in 8–10 days. The young larvae feed for a time on mealybug crawlers before developing their cottony covering. About 3 weeks are required for larval development followed by pupal development and adult emergence.

### *Nephus includens* Kirsch

*Nephus includens* Kirsch is a predator of the citrus mealybug. Adult beetles are dark; they have four orange/yellow spots on their backs. They are about 2 mm in size. Its eggs are laid in the egg mass laid by the mealybug. The female beetle can, during her lifetime, lay from 300 to 400 eggs. The larvae are covered with white waxy filaments, very similar to that of mealybugs. The beetle larvae are fluffier and can run faster. The larvae are often little in the crop because they are very small and often found in the egg mass of the mealybug. The eggs of mealybugs are oval shaped, yellow and very small, but in practice not visible. Both adult beetles and larvae eat mealybugs. When a mealybug is eaten, the dead remains can be seen on trees as white fluffy matter. The larvae mainly feed on eggs and young mealybugs. They can consume up to about 100 eggs per day or about 50 young mealybugs.

### *Scymnus coccivora* Ayyar

*Scymnus coccivora* Ayyar is known to feed on several species of the mealybugs. Adults are light

brown in colour measuring 1.7 × 1.3 mm in size. The pale yellow eggs are deposited singly in the colony of mealybugs. The grub has instars. Long waxy strands develop on the later stage of the grub. The pupa is oval and light brown in colour fringed with short brown hairs. The egg, grub, prepupal and pupal stages occupy 4.1, 4.2, 9.5, 1.2 and 5.2 days, respectively, and the total life cycle is completed in 23 days. The sex ratio is 1:1. A single grub *S. coccivora* was known to consume 308 eggs or 62 nymphs or 6.55 adult mealybugs (Mani and Thontadaraya 1987).


*C. sexmaculata*


*B. suturalis*


*H. octomaculata*


*Nephus regularis*


*S. coccivora*

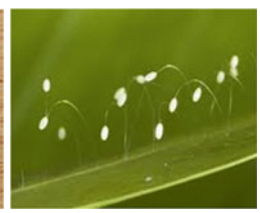
## 13.1.2 *Neuroptera*

### 13.1.2.1 Chrysopidae

Green lacewings are delicate insects 1⁄4- to 1⁄2-in. long with a wingspan of 6 to >65 mm, and the largest forms are tropical. Adults are often seen around the foliage. They are characterized by a wide costal wing venation, which includes the cross veins. The bodies are usually bright green to greenish-brown, and the compound eyes are conspicuously golden in many species. The wings are usually translucent with a slight iridescence; some have green wing veins or a cloudy brownish wing pattern. Eggs are deposited at night, singly or in small groups; each female produces approximately 100–200 eggs. Each egg is hung on a slender stalk about 1 cm in length, usually on the underside of a leaf. Immediately after hatching, the larvae moult, then ascend the egg stalk to feed. The larvae are spindle shaped, some camouflaged within the host mealybugs. They are voracious predators. Larvae of green lacewings found feeding the early stage of mealybug nymphs. A single larva of *Mallada boninensis* is capable of consuming 350–500 nymphs in its development. The species belonging to genera *Chrysopa, Chrysoperla* and *Mallada* are the well-known predators of mealybugs. The stalked eggs of the green lacewings are commonly seen in many plants infested with sucking pests including mealybugs. *Chrysoperla carnea* is used to control the mealybugs in green houses. They carry the trash over their bodies.

Life stages of green lacewing


Adult


Eggs


Larva on mealybugs


Larva carrying trash

#### *Mallada boninensis*

A single larva of *M. boninensis* was able to prey about 345, 490 and 560 nymphs of *Ferrisia virgata, Planococcus lilacinus* and *P. citri*, respectively (Mani and Krishnamoorthy 1990).

#### *Chrysoperla carnea*

The larvae of the *Ch. carnea* grubs were found as active predators on the mealybugs, and the predatory grub preyed on all the stages of the mealybug. A single larva was known to consume 378 eggs or 730 nymphs, or 95 adult females of *P. citri.*

### 13.1.2.2 Hemerobiidae

Hemerobiidae is a family of the Neuropteran insects commonly known as brown lacewings. These insects differ from the somewhat similar Chrysopidae (green lacewings) not only by the usual colouring but also by the wing venation. Hemerobiids have numerous long veins that are lacking in chrysopids. Some of the costal cross veins are forked. The larvae of the brown lacewings belonging to genus *Hemerobius,* and *Sympherobius* prefer to prey the early stage of the mealybugs, though they are known to feed all the three nymphal instars of the female mealybugs. The first-instar larvae of *Sympherobius fallax* consume the second stage of the long-tailed mealybug *P. longispinus* more than any other stages and did not eat the fourth (adult) stage, while the second-stage *S. fallax* preferred the third-stage mealybugs. The third-stage *S. fallax* also preferred the third-stage mealybugs. In the choice experiment, the first-stage larval predators preferred the second-stage mealybugs significantly more than the other two stages, while the second- and third-stage predators preferred the third-stage mealybugs significantly more than the second and the fourth stages. Darkness had a marked effect on the feeding efficiency of all stages of *S. fallax*. The number of mealybugs eaten in the light was significantly greater (Gillani et al. 2009).

Larva of *Sympherobius*

Adult *Sympherobius*

## 13.1.3 *Lepidoptera*

### 13.1.3.1 Lycaenidae

The Apefly *Spalgis epeus* Westwood is a small butterfly found in Asia. It gets its name due to the face resemblance of ape that can be seen from the head-on view of the pupa. The male is dull brown on the upperside and slightly darker towards the apex of the forewing; also a more or less quadrate whitish spot beyond the apex of the cell on the same wing can be seen; in some specimens, this spot is slightly diffused. On the underside, it is pale, silky, brownish-white; fore- and hindwings crossed by numerous, very slender, short, sinuous, transverse, dark brown strigae, which are outwardly slender edged with brownish-white of a shade paler than that of the ground-colour. Both the wings have an anticiliary dark brown line on the inner side with similar edging. Forewing, in addition, has an oval white spot beyond the cell.

The cilia of both the fore- and hindwings are of the same shade as that of the ground colour of the wings. The antenna, head, thorax and abdomen are pale brown in colour, and the club of the antennae is ochraceous at apex; beneath are the palpi and thorax brownish-grey and the abdomen pale brown in colour. In female, the upperside is slightly paler brown. In the forewing, the cell and apex are darker, with a white spot similar to that in the male but larger, beyond the apex of the cell; in most specimens, it is extended diffusely outwards and downwards. The hindwing is similar to that of the male. The underside is as precise as in the male.

Life stages of *Spalgis epeus*

Second instar caterpillar

Third instar caterpillar

Final instar caterpillar

Adult butterfly

The lycaenid predator *Spalgis epeus* was commonly associated with the natural control of the mealybugs *Rastrococcus iceryoides, Planococcus lilacinus, Pl. citri, Ferrrisia virgata, Paracoccus marginatus* etc. The larvae of *Spalgis epeus* were observed to predate on root mealybug colonies especially those at the base of the stems (Devasahayam et al. 2009). Although *Spalgis lemolea* was a common natural enemy of *Phenacoccus madeirensis* infesting cassava in Africa (Herren and Neuenschwander 1991), its potential utility as an effective biological control agent was thwarted by its erratic occurrence. At 25–30 °C and 40–60 % RH, the mean duration of the egg, larval and pupal stage of *Spalgis epeus* on *Pa. marginatus* is 3.5, 12.0 and 10.3, respectively, and the mean duration from egg to adult emergence was 26 days, and it takes 24 days on *Pl. citri* to complete the life cycle (Dinesh et al. 2010). As for the predatory potential of *S. epeus*, the total number of papaya mealybugs consumed during the larval stage was 4,115 eggs, 281 nymphs and 77 female adults.

## 13.1.4 Diptera

Several dipterans are found as predators in the concealed mealybug niche. The insects belonging to Drosophilidae, Cecidomyiidae, Syrphidae etc. are known to attack the mealybugs. The dipteran larvae feed voraciously on the mealybugs.

### 13.1.4.1 Cecidomyiidae

In this family, the larvae of a large number of species are predaceous on the mealybugs. These insects are very tiny, usually only 2–3 mm in length. The adults, which are very tiny, fragile midges, locate colonies of appropriate prey. The eggs are laid near the base of the mealybug host; the larva tunnel underneath the host and feed on the eggs or developing coccid nymphs. As the small, maggot-like larvae are incapable of moving to considerable distances, there usually has to be a fair population of the prey present, before the adults will lay eggs. The life cycle is completed in 25 days. The total number of eggs deposited by the female averaged 36 during her very short lifespan, which averaged 2.3 days. The larvae of *Dicrodiplosis manihoti* Harris were found to prey on the egg masses of the cassava mealybug, *Phenacoccus manihoti* in the Congo and Senegal. *Kalodiplosis pseudococci* Felt has given significant control of *D. brevipes* in conjunction with two parasitoids. *Triommata coccidivora* Felt plays a supplementary role in regulating the mealybug population.

#### 13.1.4.2 Chamaeyiidae

Chamaeyiidae is a small family of acalyptratae flies. The larvae are the predators of the mealybugs.

#### 13.1.4.3 Drosophlidae

Larvae of the predatory drosophilids are found feeding on the colonies of nymphs. They play a supplementary role in regulating the mealybug population.

#### 13.1.4.4 Syrphidae

Syrphid larvae are predatory on the mealybugs but are of minor importance (Table 13.1).

### 13.1.5 Other Predators

The rat *Millardia meltada meltada* gnawed through the lower dry leaf sheaths and devoured the mealybugs *Saccharicoccus sacchari* at the nodes of sugarcane.

Pirate bugs feed on the mealybugs

Crab spiders feed on the mealybugs

**Table 13.1** List of predators recorded on the mealybugs

| Predator species | Mealybug species |
|---|---|
| **Coleoptera, Coccinellidae** | *Coccidohystrix insolita* |
| *Anegleis cardoni* (Weise) | |
| *Brumoides suturalis* (Fab.) | *M. hirsutus, P. lilacinus, F. virgata, Ph. solenopsis, Pa. marginatus, Coccidohystrix insolita* (Green) |
| *Cryptolaemus montrouzieri* Mulsant | Many mealybug species |
| *Coleophora pupillata* (Schonherr) | Several mealybugs |
| *Cheilomenes sexmaculata* (Fab.) | *Ph. soleneopsis, F. virgata*, *Pa. marginatus* |
| *Curinus coeruleus* Mulsant | *Nipaecoccus nipae* (Maskell) |
| *Chilocorus stigma* (Say) | *Pl. citri* |
| *Chilocorus nigrita* (Fabricius) | *S. sacchari* |
| *Chilocorus* sp. | *Pa. marginatus* |
| *Chilocorus bipustulatus* L. | *Phenacoccus mespili* Ben-Dov |
| *Decadiomus bahamicus* (Casey) | *Pl. citri* |
| *Diomus notescens* (Blackburn) | Several mealybugs |
| *Diomus hennesseyi* Fiirsch | *Ph. manihoti* |
| *Exochomus flaviventris* Mader | *Phenacoccus manihoti* Matile-Ferrero |
| *Exochomus troberti* Mulsant | *Phenacoccus manihoti* |
| *Exochomus flavipes* (Thunberg) | *Phenacoccus manihoti* |
| *Exochomus concavus* Fursch | *Phenacoccus manihoti* |
| *Exochomus metallicus* Korsch | *Planaococcus citri* (Risso) |

(continued)

**Table 13.1** (continued)

| Predator species | Mealybug species |
|---|---|
| *Exochomus nigripennis* (Erichs.) | *Nipaecoccus viridis* (Newstead) |
| *Exochomus melanocephalus* (Zubkoff) | *Saccharicoccus sacchari* (Cockerell) |
| *Harmonia octomaculata* (F.) | *Phenacoccus solenopsis* Tinsley |
| *Harmonia maindroni* Sicard | *Maconellicoccus hirsutus* (Green), *P. lilacinus, Coccidohystrix insolita* (Green) |
| *Hippodamia convergens* (Guérin-Méneville) | *Ph. solenopsis* |
| *Hippodamia variegata* Goeze | *Ph. solenopsis* |
| *Hyperaspis limbatus* Casey | *Saccharicoccus sacchari* (Ckll.) |
| *Hyperaspis silvestri* Weise | *Dysmicoccus brevipes* (Cockerell) |
| *Hyperaspis trilineata* Mulsant | *Saccharicoccus sacchari* |
| *Hyperaspis onerata* (Mulsant) | *Phenacoccus herreni* Cox and Williams |
| *Hyperaspis egregia* Mader | *Planococcoides njalensis* (Laing) |
| *Hyperaspis marmottani* (Fairm.) | *Phenacoccus manihoti* |
| *Hyperaspis senegalensis hottentotta* Mulsant | *Phenacoccus manihoti* |
| *Hyperaspis raynevali* (French) | *Phenacoccus manihoti* |
| *Hyperaspis aestimabilis* Mader | *Phenacoccus manihoti* |
| *Hyperaspis pumila* Muls. | *Phenacoccus manihoti* |
| *Hyperaspis onerata* (Muls.) | *Phenacoccus manihoti* |
| *Horniolus vietnamicus* Miyatake | *P. lilacinus* |
| *Midas pygmaeus* Blackburn | *Ps. calceolariae* |
| *Nephus vetustus* Weise | *Phenacoccus manihoti* |
| *Nephus regularis* Sicard | *Ph. solenopsis, Coccidohystrix insolita* |
| *Nephus reunion* (Fursch | *Pseudococcus* sp. |
| *Nephus bipunctatus* (Kug.) | *N. viridis* |
| *Nephus bilucernarius* Mulsant | *Nephus bilucernarius* Mulsant |
| *Pesudoscymnus pallidicollis* (Mulsant) | *M. hirsutus* |
| *Platynaspis strictica philippenensis* Korchefsky | *Planococcus kenyae* (LePelley) |
| *Pseudoscymnus pallidicollis* (Mulsant) | *Pl. citri* |
| *Pullus pallidicollis* (Mulsant) | *P. lilacinus, Pl. citri* |
| *Sasajiscymnus quinquepunctatus* (Weise) | *Paracoccus marginatus* Williams and Granara de Willink |
| *Scymnus binaevatus* Mulsant | *Pseudococcus calceolariae* (Maskell) |
| *Scymnus coccivora* Ayyar | *M. hirsutus, P. lilacinus, F. virgata, Ph. solenopsis, Pa. marginatus* |
| *Scymnus nubilus* Muls. | *M. hirsutus* |
| *Scymnus syriacus* | *F. virgate* |
| *Scymnus gratiosus* Wiese | *M. hirsutus* |
| *Scymnus severini* Weise | *P. lilacinus* |
| *Scymnus margipaliens* Muls. | *D. brevipes* |
| *Scymnus couturier* G. | *Ph. manihoti* |
| *Scymnus* sp. | *Geococcus citrinus* Kuwana |
| *Scymnus flavifrons* Blackburn | *Pl. citri* |
| *Scymnus* (Pullus) *uncinatus* Sicard | *D. brevipes* |
| *Scymnus pictus* Gorham | *D. brevipes* |
| **Coleoptera, Nitidulidae** | *S. sacchari* |
| *Carpophilus marginellus* Motsch | |

(continued)

**Table 13.1** (continued)

| Predator species | Mealybug species |
|---|---|
| **Coleoptera, Lathridiidae** | *M. hirsutus* |
| *Melanophthalma carinulata* Motsch | |
| **Diptera, Cecidomyiidae** | *Planococcus kenyae*, *Planococcoides njalensis* (Donald) |
| *Coccodiplosis coffeae* (Barnes) | |
| *Coccodiplosis citri* Barnes | *Phenacoccus manihoti* |
| *Cleodiplosis koebelei* (Felt) | *D. brevipes* |
| *Diadiplosis koebelei* (Koebele) | Several mealybugs |
| *Diadiplosis coccidivora* (Felt) | *F. virgate* |
| *Dicrodiplosis manihoti* Harr. | *Phenacoccus manihoti* |
| *Dicrodiplosis* sp. | *Planococcus citri, P. lilacinus, N. viridis* |
| *Gitona* sp. | *F. virgate* |
| *Kalodiplosis koebelei* (Felt) | *Ps. calceolariae* |
| *Kalodiplosis pseudococci* (Felt) | *D. brevipes* |
| *Kalodiplosis coccidarum* (Felt) | *Ph. herreni* |
| *Lobodiplosis pseudococci* Felt | *D. brevipes* |
| *Triommato coccidivora* (Felt) | *P. lilacinus* (Risso) |
| *Vincentodiplosis pseudococci* | *D. brevipes* |
| **Diptera, Chamaeyiidae** | *R. iceryoides, P. lilacinus, Brevennia rehi* |
| *Leucopis luteicornis* Malloch. | |
| *Leucopis* sp. | *F. virgate* |
| *Leucopis ocellaris* Mall | *Pseudococcus comstocki* |
| *Leucopis alticeps* Czerny | *Phenacoccus mespili* Ben-Dov, *P. citri* |
| **Diptera, Drosophilidae** | *P. citri, P. lilacinus, S. sacchari*, *Phenacoccus manihoti* |
| *Cacoxenus (Gitonides) perspicax* (Knab) | |
| *Rhinoleucophenga capixabensis* sp. nov. | *Dysmicoccus brevipes* |
| *Domomyza perspicax* (Knab) | *P. citri, Brevennia rehi* (Lindinger) |
| **Diptera, Syrphidae** | |
| *Ocyptamus argentinus* Curr. | *F. virgata* |
| *Xanthogramma javana* Wd. | *F. virgate* |
| *Allobaccha eclara* (Curran) | *Phenacoccus manihoti* |
| **Diptera, Chloropidae** | *Brevennia rehi* (Lindinger) |
| *Anatrichus pygmaeus* Lamb | |
| **Neuroptera, Chrysopidae** | *M. hirsutus* |
| *Apertochrysa* sp. | |
| *Anisochrysa basalis* Walker | *Pl. citri* |
| *Anisochrysa boninensis* (Okaomota) | *Coccidohystrix insolita* |
| *Brinckochrysa scelestes* Banks | *M. hirsutus* |
| *Ceratochrysa antica* (Wlk.) | *Phenacoccus manihoti* |
| *Chrysopa ramburi* Schneider | *Ps. Calceolariae* |
| *Chrysopa* sp. | *Phenacoccus manihoti, N. viridis* |
| *Chrysoperla carnea* (Stephans) | *P. citri, F. virgate* |
| *Chrysopa lacciperda* (Kimmis) | *P. citri*, *Ph. solenopsis*, *Ph. mespili* |
| *Chrysoperla rufilabris* (Burmeister) | *Ps. longispinus* (Targioni Tozzetti) |
| *Chrysoperla zastrowi* Sillemi (Esben-Petersen) | *Pa. marginatus* |
| *Chrysopa lateralis* Guerin | *Pl. citri* |

(continued)

**Table 13.1** (continued)

| Predator species | Mealybug species |
|---|---|
| *Oligochrysa lutea* (Wlk.) | *Ph. solenopsis* |
| *Mallada boninensis* (Okamota) | Many mealybugs |
| *Plesiochrysa lacciperda* (Kimmins), | *Pl. citri* |
| **Neuroptera, Hemerobiidae** | *Ps. calceolariae* |
| *Sympherobius amicus* Navas | |
| *Sympherobius barberi* (Banks) | *Ps. longispinus, P. citri* |
| *Sympherobius pygamaeus* (Rambur) | *M. hirsutus* |
| *Psectra iniqua* (Hagen) | *Rastrococcus invadens* Williams |
| **Neuroptera, Coniopterygidae** | *M. hirsutus* |
| *Conwentzia psociformis* (Curtis) | |
| *Cryptoscenea australiensis* (Enderlein) | *Pseudococcus viburni* (Signoret) |
| **Lepidoptera, Lycaenidae** | *Planoccuus kenyae, F. virgata, P. manihoti* |
| *Spalgis lemolea* Druce | |
| *Spalgis epeus* West wood | *P. citri, P. lilacinus, Ph. solenopsis, Pa. marginatus, Coccidohystrix insolita, Nipaecoccus nipae* |
| **Lepidoptera,** *Pyralidae* | *P. citri* |
| *Laetilia coccidivora* (Comstock) | |
| **Lepidoptera, Momphidae** | *S. sacchari* |
| *Batrachedra* sp. near *psilopa* Meyrick | |
| **Lepidoptera, Noctuidae** | *P. lilacinus* |
| *Eublemma* sp. | |
| *E. geyri* Rild | *M. hirsutus* |
| *E. trifasciata* Moore | *M. hirsutus* |
| *Autoba silicula* Swinhoe | *M. hirsutus* |
| **Hemiptera, Coreidae** | *M. hirsutus* |
| *Geocoris tricolor* (Fab.) | |
| **Hemiptera, Miridae** | *F. virgate* |
| *Deraeocoris* sp. | |
| **Hemiptera: Anthocoridae** | *Ph. manihoti* |
| *Cardiastethus exiguus* Poppius | |

## 13.2 Parasitoids

### 13.2.1 Hymenoptera

The parasitoids belonging to families Encyrtidae, Aphelinidae, Platygastridae, Pteromalidae, Braconidae, Eucoilidae, Signiphoridae and Eulopidae are known to attack the mealybugs. Among them, encyrtids, aphelinids and platygastrids play a major role in the regulation of mealybugs.

#### 13.2.1.1 Encyrtidae

Major parasitism in the mealybugs involves members of the wasp family Encyrtidae. The encyrtids are koinobiont endoparasitoids, so that the parasitized mealybug continues to live for a few days, to grow and even to reproduce to some extent. This time gap between parasitization and deterioration of the physiological condition enables the mealybug to confront the immature individual parasitoid by encapsulation. The encapsulation is a common immune defense mechanism that involves the formation of a capsule around the parasitoid egg or

larva; it is usually composed of host blood cells and the pigment melanin. The capsule may kill the parasitoid and thus prevent successful parasitism (Blumberg 1997). Various levels of encapsulation have been shown to occur in different mealybug species, in response to parasitism by encyrtids (Blumberg 1997; Blumberg and van Driesche 2001; Chong and Oetting 2007; Giordanengo and Nenon 1990; Sagarra et al. 2000). Conversely, encyrtid parasitoids may use superparasitism as a strategy to overcome the immune response of unsuitable hosts (Blumberg et al. 2001). Besides superparasitism, other factors also affect the frequency of parasitoid encapsulation including: (a) host and parasitoid species; (b) the host's physiological age and condition; (c) the host and parasitoid origins (or strains); (d) the rearing and/or ambient temperature; and (e) the host plant species and stress conditions (Blumberg 1997; Calatayud et al. 2002).

Noyes and Hayat (1994) recorded 49 encyrtid species as parasitoids of mealybugs in India. The family Encyrtidae dominates the parasitoid complex of mealybugs. *Anagyrus*, *Apoanagyrus, Adolescentus*, *Aenasius*, *Leptomastix, Leptomastidea*, *Blepyrus, Gyranusoidea, Praleurocerus, Mahencyrtus, Acerophagus, Coccidoxenoides, Epidinocarsis, Neodusmetia, Hambletonia, Pseudaphycus* and *Alamella* are some of the important genera under encyrtidae attacking the mealybugs. They are sexually dimorphic and both males and females are different from each other. The males are smaller than the females and have hairy antennae. The females have a bright band across the abdomen. The encyrtids are known to attack nymphs and adults of mealybugs. Each species tends to specialize in terms of the stage of development of the host. Certain species like *Blepyrus insularis*, *Coccidoxenoides perminutus*, *Acerophagus papayae* prefer earlier stage that is 5–8-day-old nymphs (early Second instar) for parasitization, whereas species like *Anagyrus dactylopii*, *Leptomastix dactylopii* etc. prefer 15–20-day-old mealybugs (third instar and young adult female). They breed very well when they are exposed to the preferred stage. The duration of the life cycle is about 3 weeks at 25 °C. Mealybugs that are parasitized turn into small cocoons, a little darker in colour than live mealybugs. The young full-grown parasitoid emerges through an exit hole at the distal part of the cocoon, leaving the lid behind. Full development of the parasitoid takes place inside the mealybug. Adult parasitoids feed themselves by piercing the young instars of the mealybugs and sucking from their bodies. By doing so, they can extend their lifespan. This feeding behaviour kills the young mealybug-instars. Parasitized mealybugs turn into a yellow/orange cocoon and become hard (like mummies). These mummies are difficult to see, because of their small size. In this period, a female can lay about 80 eggs, most of them in the first weeks of her life.

*Anagyrus* is a large genus of the family Encyrtidae that attacks the mealybugs. Some important species like *Anagyrus aegyptiacus, A. dactylopii, A. kamali, A. pseudococci* play the major role in suppressing the mealybugs. Other encyrtids, namely *Leptomastidea abnormis*, *Leptomastix dactylopii*, *Acerophagus papayae, Apoanagyrus lopezii, Aenasius bambawalei* and *Aenasius advena* Comp., are found to be very effective parasitoids of mealybugs.

#### *Anagyrus antoninae* (Timberlake)

It is an internal gregarious parasite of *Antonina graminis*. It is oriental in origin but common in Hawaii. It is active in cooler and high-humid areas. The female mates soon after the emergence and starts laying eggs immediately. Attack is on the gravid female mealybugs. The stalked eggs are unattached and free in the body fluids of the mealybug and are hatched in 3–4 days. The larval and prepupal stages cover 8–10 days. The pupal stage takes about 6–8 days, and the total life cycle is completed in 18 days. Up to seven adult parasites emerge per mealybug and the sex ratio is 1:1. It is carried out very well under Florida conditions.

#### *Neodusmetia sangwani* (Subba Rao)

It is an internal gregarious parasitoid of *Antonina graminis* and is native to India. Adult females are brachypterous and males are winged. They live only for 2 days. The female produces up to 55 progeny. The sex ratio is 1:7. Life cycle is completed in 17–23 days. Normal dispersal is very slow since the females are wingless. It has done very well under Texas conditions.

*Neodusmetia sangwani*

*Hambletonia pseudococcina*

### *Pseudaphycus mundus* Gahan

It is mainly a parasitoid of *Dysmicoccus boninensis,* native of Lousiana. It attacks all stages of the mealybug except the first-instar nymphs. It deposits eggs in the body fluids of the mealybug. From 2 to 15 min is required for oviposition. It takes 16–18 days to complete the life cycle. It is solitary in small mealybugs but lays up to 19 eggs on larger mealybugs. It did very well against *D. boninensis* in sugarcane fields at Hawaii.

### *Hambletonia pseudococcina* Compere

It is bisexual in Brazil and unisexual in Columbia. The unisexual race was found to be relatively successful against *D. brevipes* in Hawaii. It is a solitary parasitoid. The females attack half-grown mealybugs and takes 24–30 days to complete the life cycle.

### *Aenasius advena*

*Aenasius advena* Comp is a solitary internal parasitoid of *Ferrisia virgata*. It occurs in large numbers at times on *F. virgata* in guava and other crop ecosystems in India and elsewhere. It prefers 15-day-old mealybugs and the lifecycle is completed in about 18 days. Along with *C. montrouzieri*, *A. advena* gives the perfect control of *F. virgata* on guava and other crop ecosystems in India.

### *Blepyrus insularis*

It is also another internal parasitoid of *F. virgata*, preferring to parasitize the early instars of the mealybugs. It performs very well in glasshouse crops infested with *F. virgata* (Mani and Krishnamoorthy 1991).

### *Coccidoxenoides perminutus*

*Coccidoxenoides perminutus* Girault (*Pauridia peregrina* Timberlake, *Coccidoxenoides peregrinus* (Timberlake)) is an endoparasitoid of *Planococccus citri* widely present throughout the world. *Coccidoxenoides perminutus* alone or along with other natural enemies is capable of suppressing *P. citri*. Besides *Pl. citri*, it also attacks *Pseudococcus longispinus*, *Pl. ficus* and *Pseudococcus viburni*. Adult parasitoids are black in colour with noticeable translucent wings, with relatively long antennae and are approximately 3 mm long. Females lay their eggs into the first three instars but prefer the second instar of *Pl. citri* and are able to lay 60–90 eggs each. The eggs develop into pupae within the mealybug slowly feeding off the host. About 16 days after egg laying, adult *C. perminutus* wasps emerge from pupae, and are immediately ready to mate and continue the cycle. The speed of the lifecycle is dependent on temperature and humidity. Generally, *C. perminutus* adults are active for about 7 days and are most effective at temperatures between 20 and 30 °C and humidity between 50 and 90 %. Each female lives for approximately 7 days.

### *Anagyrus fusciventris* (Girault)

It is a parasitoid of *Pseudococcus longispinus*. Females are grey-brown in colour and have bright blue eyes. Males are black in colour. Both sexes are about 3 mm in size. Mealybugs that are parasitized turn into small cocoons, a little darker in colour than the live mealybugs. It prefers larger instars for parasitization. The females lay one egg per host; from each parasitized mealybug, one adult wasp will emerge. The lower temperature threshold for the parasitoid is 18 °C. The parasitoid development from egg to adult takes about 3 weeks at a temperature of 25 °C. Full development of the parasitoid takes place inside the mealybug. Adult parasitoids feed themselves by piercing the young instars of the mealybugs and sucking from their bodies. By doing so, they can extend their life span to about 2 months. This feeding behaviour kills the young mealybug instars.

*Coccidoxenoides perminutus*

*Anagyrus fusciventris*

### *Anagyrus pseudococci* (Girault)

*Anagyrus pseudococci* (Girault) is native of Mediterranean areas. It is known to attack *Pl. citri* and *Ps. citriculus.* It attacks all the nymphal stages and the adult females but prefers the third instar of the mealybug. About 45 eggs are laid per female at the rate of three to four per day. The eggs hatch in 44 h and the lifecycle is completed in 18 days at 27 °C.

### *Leptomastix dactylopii* Howard

It is widely used against *Planococcus citri*. Besides *P. citri*, it also breeds well on *Pl. ficus.*

It is a small yellow-/brown-coloured parasitic wasp with distinctively long dark antennae. It is about 3 mm long. Males are smaller and darker than females. The antennae of the females are bended; the antennae of the males are hairy. Eggs are laid in the third instar and in the young adult female mealybug. The females deposit one egg inside the mealybug body. A female lays about 100 eggs. After hatching, the young larva of the parasitoid eats the mealybug from inside out. The parasitized mealybugs turn into a yellow-brown cocoon and become hard (like mummies). The lower temperature threshold for *Leptomastix dactylopii* is 20 °C, but the optimal temperature is 26 °C. At 25 °C, this development takes about 15–17 days.

*Anagyrus pseudococci*

*Leptomastix dactylopii*

### *Leptomastix epona*

It is a parasitoid of *Pseudococcus viburni* (*Ps. affinis*) and *Spilococcus cactearum*. Adult wasps are brown-black with thin, long, black antennae. Their wings are mainly translucent with slight dark bands. *Leptomastix epona* is 3 mm in size. Mealybugs that are parasitized turn into yellow cocoon like 'mummies', easily distinguishable from live mealybugs. The adult parasite emerges from a circular exit hole at the proximal end of the cocoon, leaving a 'lid' on the mummy. It mainly parasitizes older instars of *Ps. viburni* and *Spilococcus cactearum*. It lays one egg per mealybug. Mealybugs are killed by the growing larva approximately 10 days after parasitization. Lower temperature threshold for *Leptomastix epona* is 15 °C.


*Leptomastix epona*

*Pseudaphycus maculipennis*

### *Acerophagus maculipennis*

*Pseudaphycus maculipennis* (*Acerophagus maculipennis*) was shown to be an arrhenotokous, synovigenic, gregarious endoparasitoid of *Pseudococcus viburni*. Both females and males lived for 16 and 11 days, respectively, when fed either honey-agar or mealybug honeydew. Relatively, large instars (third instar or adult females) were preferred for oviposition; mated females parasitized more mealybugs than unmated females, and the progeny sex ratio favoured females by 3:1. Egg load increased with age from emergence to day 8, averaging 23 mature eggs per female. Mean realized daily fecundity never exceeded 5, with a mean lifetime fecundity of 46 eggs per female. Parasitized mealybugs remained alive for about 5 days and then mummified. Total development period was 20–21 days (larva 4–5 days, prepupa 3 days, pupa 8–9 days). A mean of 3.0 parasitoids per mealybug were reared after individual parasitism events, increasing through superparasitism (either self or conspecific) to nine parasitoids per mealybug when hosts were exposed to competing females.

### *Pseudaphycus malinus*

It is an internal parasitoid of *Pseudococcus comstocki* believed to be a native of Japan. It develops as a solitary parasite in smaller mealybugs but gregarious in larger mealybugs. Females deposit about 100 eggs in 4–10 days. Incubation is completed in 3 days, larval development in 8 days and pupal stage in 10 days.

### *Leptomastidea abnormis*

*Leptomastidea abnormis* mainly parasitizes *Planococcus citri*. It is a grey-yellow parasitic wasp, 0.75–1.5 mm in size; dark bands are clearly visible across the wings. Males are smaller than females and have hairy antennae. The females have a bright band across the abdomen. The parasitized mealybugs turn into a yellow/orange cocoon and become hard. Leptomastidea emerges from a circular hole in the proximal end of the mummy. Eggs are laid in the first and second instars of its host, one egg per mealybug. The inconspicuously stalked eggs are laid in the body fluid of the mealybugs and are hatched in 3 days. The tailed larva complete the development in 8 days and the lifecycle is completed in 17 days at

26 °C. Mealybugs are killed by the larva of the parasitic wasp, growing inside the mealybug. Leptomastidea can survive temperatures up to 40 °C.

### *Acerophagus papayae*

It is a solitary endoparasitoid of papaya mealybug *Paracoccus marginatus* A. It parasitizes the early-stage (II instar) nymphs of the mealybug. It is a tiny small wasp with yellowish body, transparent wings and grey/bluish eyes with three black triangular spots in the forehead. The male parasitoid is much smaller than the female parasitoid. This parasitoid affects mainly the second stage after hatching from the egg. Each female is capable of laying 50 eggs in its lifetime of 35 days. Normally, single egg is laid inside a mealybug; occasionally more than one egg is also laid.

*Acerophagus papayae*

*Leptomastidea abnormis*

### *Anagyrus dactylopii*

It is the principal parasitoid of *Nipaecoccus viridis* and *Maconellicoccus hirsutus*. It parasitizes all the nymphal instars but prefers third-instar nymph and adult female. They are sexually dimorphic. Males are small, black with branched antennae. Females are larger and brown in colour; complete their life cycle in 15 days.

### *Anagyrus aegyptiacus*

It is a solitary parasitoid of *N. viridis*. Females deposit eggs in all the three nymphal instars and hatch them in 4 days. There are six larval instars. The complete life cycle covers 16 days.

### *Anagyrus kamali*

It is a solitary internal parasite of *Maconellicoccus hirsutus.* The female deposits stalked eggs; the attachment to the host derm is visible as an external protrusion. The eggs hatch in 4 days. There are six larval instars. The combined prepupal and pupal stages cover only 3 days. The life cycle is completed in 18 days at 25 °C.

### *Anagyrus indicus*

The gregarious encyrtid parasitoid, *Anagyrus indicus*, oviposits in all three nymphal stages and in the adult female stage of the spherical mealybug, *Nipaecoccus viridis*. But it prefers to the third nymphal and the adult female mealybugs. The parasitoid development was the fastest, the number of parasitoids emerging was the greatest and the ratio of female to male parasitoids was the highest following oviposition in the third nymphal and the adult female hosts.

### *Anagyrus ananatis*

The encyrtid *A. ananatis* (Subba Rao) prefers to parasitize adult females of *Dysmicoccus brevipes*. It is capable of parasitizing up to 27 mealybugs. It can be found attacking the mealybugs in the presence of ants, although its impact on mealybug mortality is low. When ants are absent, the parasitoid is highly effective in lowering the mealybug populations in pineapple plantings.

*Anagyrus indicus*

*Gyranusoidea tebygi*

### *Gyranusoidea tebygi*

It is a native parasitoid of *Rastrococcus invadens* Williams in India. The introduction of *Gyranusoidea tebygi* Noyes into Togo and Benin was capable of eliminating *R. invadens*. It reproduced on first, second and third instars and it avoided hosts that were already parasitized. Host feeding was occasionally observed. Sex ratios of the offspring were male biased in smaller hosts, as opposed to being female biased in larger hosts. Females had longer developmental times than males, developed faster in larger mealybugs than in smaller ones and were always larger than the males emerging from the same host instar. Their size increased with the instar of the host at oviposition. About 90 % of all ovipositions in second- and third-instar nymphs resulted from an attack with multiple stings, starting with a sting in the head of the host for the most part.

### *Apoanagyrus lopezii*

*Apoanagyrus (Epidinocarsis) lopezi* (De Santis) is a species of the parasitic wasp native to Central America. It is used as a biological control agent against the cassava mealybug *Phenacoccus manihoti* Matile-Ferrero in Africa. The parasitoid is found to parasitize and complete development in all developmental instars of *Ph. manihoti*. However, the parasitoid mortality was high (15 %) when the development took place in the first nymphal instar of the host. Complete development from egg to adult emergence was prolonged in smaller hosts, and the developmental periods recorded were 18, 17, 16 and 14 days for the first, second, third and fourth nymphal instars, respectively. Oviposition commenced within 24 h of emergence and lasted effectively for 6 days, during which 95 % of its eggs were laid and 10–12 large hosts were killed through host feeding. Sex ratio is 1:3.

### *Aenasius bambawalei*

It is a solitary endoparasitoid of *Phenacoccus solenopsis* Tinsley in India and Pakistan. Egg and larval stages of the parasitoid are not visible being an internal feeder, but swelling and poor movement of the parasitized mealybugs were observed after 2–3 days of parasitization. The parasitized mealybugs transformed into dark-brown mummies within 4–7 days. The pupae of *A. bambawalei* Hayat were barrel shaped with dark-brown colour. Duration of the pupal period ranged from 5 to 8 days. Adults emerged by cutting a circular small hole on the mummies after completion of the pupal period. The adults of both the sexes are shiny black in colour. Males were smaller than females. The maximum developmental time was recorded for the second-instar host nymph as compared to the third instar. The males developed faster than the females in all host stages. The overall sex ratio was 1:2. The maximum number of female wasps developed at third-instar nymph (59.6 %), and it was concluded that the third-instar host nymph appeared to be the most suitable host stage for mass rearing.

#### *Clausenia purpurea* Ishii

It is a known parasitoid of *Ps. citriculus* and *Ps. comstocki.* It attacks the first and second mealybug instars. Males are rare. Each female deposits about 200 eggs in 15–20 days. Life cycle is completed in 25–30 days.

#### *Hungariella* spp.

*H. pretiosa* (Timverlake) is known to attack *Ps. fraglis*. It is a solitary internal parasitoid of the second-instar mealybug nymphs. Most of 100–200 eggs per female are laid during the first day of its life. The egg enlarges eightfold before hatching. Incubation and larval period are 6 and 17 days, respectively. The life cycle is completed in 23 days. Sex ratio is 1:1. *H. peregrina* (Compere) is attacking *Ps. longispinus*.

#### *Anarhopus sydneyensis* Timberlake

It is native of Australia known to parasitize *Ps. longispinus*. It is a solitary parasitoid preferring to attack the third-instar nymphs and the life cycle covers 1 month.

#### *Tetracnemoidea inica* (Ayyar)

It is a solitary parasitoid of *Planococcus lilacinus.* It attacks all the nymphal instars but prefers 5-day-old nymphs, which yielded higher number of parasitoids and also female progenies. It takes 26–33 days to complete the life cycle (Mani and Krishnamoorthy 1995).

### 13.2.1.2 Platygastridae

Parasitoid wasps, belonging to the hymenopteran family Platygastridae (sometimes incorrectly spelled Platygasteridae), are mostly very small (1–2 mm), black and shining, with elbowed antennae that have an eight-segmented flagellum. The wings most often lack venation, though they may have slight fringes of setae. Several species of the genus Allotropa are known to attack mealybugs. They complete the life cycle in 25 days at 25 °C. It oviposits on all the three nymphal stages and on the adult female mealybugs. It prefers 10–15-day-old mealybugs (second and early third instar nymphs) for parasitization. Adults are small and short lived (Mani and Krishnamoorthy 1989; Clancy 1944; Gilliat 1939). They play a supplementary role in suppressing the mealybugs.

#### *Allotropa burrelli*

*Allotropa burrelli* Mues. is a gregarious parasitoid of *Pseudococcus comstocki* (Kuw.), with incubation stage averaging 9.5 days and larval stage averaging 6.5 days. There is a single larval instar; prepupa averaging 2.0 days; pupa averaging 13.0 days. The sex ratio has ranged from 2:1 to 3:1, with females predominating. The adults are small and short lived, and oviposit at random in the host body cavity. There is no preoviposition period. All nymphal stages of the mealybugs are attacked, but a preference is shown for those at least half grown. The life cycle ranges from 26 to 38 days, with an average of 31 days.

#### *Allotropa citri*

It can parasitize all stages of *Pseudococcus cryptus*. It prefers the first- and the second-instar nymphs. The lower developmental threshold temperature and thermal constant of *A. citri* for the first- and second-instar nymphs of *P. cryptus* were 10.1 °C and 518.1 degree-days (DD), respectively.

#### *Allotropa suasaardi*

*Allotropa suasaardi* Sarkar and Polaszek is a parasitoid of *Phenacoccus manihoti* Matile-Ferrero on cassava in Thailand. The mean developmental time was shorter and a higher number of progeny were produced in *Dysmicoccus neobrevipes* followed by *Ph. manihoti*.

#### *Allotropa japonica*

*Allotropa japonica* is a platygastrid parasitoid of *Maconellicoccus hirsutus* (Green). It oviposits on all the three nymphal stages and the adult female mealybugs. Freshly laid eggs of *A. japonica* are very small, elongated, whitish and transparent. They become more or less spherical after 24 h. Incubation period ranges from 4 to 6 days, the average being 5.5 days. Usually one to three eggs are found in a parasitized mealybug. The larval development is completed in 4–6 days, there is but one larval instar with ten body segments. Prepupal and pupal periods last for 2–3 days and

12–90 days, respectively. The total life cycle of *A. japonica* sp. n. is completed in 25.5 days. Adults are small and short-lived. Longevity of the adults ranges from 7 to 11 days. The males have long, hirsute, moniliform antennae, while the females have shorter and distinctly clavate antennae. Mating and oviposition takes place readily. The adults exhibit a very good searching capacity. A maximum of 238.16 parasitoids was obtained when the third-instar nymphs of 15 days old were offered to *A. japonica* sp. n. for parasitization (Mani and Krishnamoorthy 1989)

#### *Allotropa utilis* Muesbeck

It is an internal, solitary parasitoid of nymphs of *Phenacoccus aceris* (Signoret) and *Ph. pergandi* Ckll, native of Nova Scotia. It is reported to have a single generation. It attacks the smaller nymphs from July to October. Eggs laid in the body fluid of the mealybugs increase sixfold during incubation. Overwintering is by immature larvae in the parasitized mealybugs. Pupation occurs in the spring. The adult emergence takes place in May from the overwintering host nymphs.

### 13.2.1.3 Aphelinidae

Along with Encyrtidae, this 'family' provides most of the biocontrol agents. Aphelinids are small, soft-bodied parasitic wasps, yellow or brown in colour and do not typically exceed 1.5 mm in length. The larvae of the majority are the primary parasitoids on mealybugs. They are found throughout the world in virtually all habitats and are extremely important as biological control agents. With regard to their biology, Aphelinidae more closely resemble Encyrtidae. Characters uniting the family Aphelinidae are not apomorphic; that is, they are not uniquely derived. The characters of Aphelinidae are complete notaular lines of the mesoscutum; transverse or broad petiole (propodeum); long marginal; short stigma; and short or absent postmarginal wing veins; and third valvula distinctly separated and articulated with third valvifer. These character combinations might also serve to differentiate Aphelinidae from other families of Chalcidoidea.

Adult aphelinids may feed on honeydew exuded by their hosts or on secretions issuing from the wound caused during oviposition. The eggs of aphelinids are often stalked. A number of endoparasitic species have an apneustic caudate primary larva. Those that are endoparasitoids (e.g. *Coccophagus*) have larvae with neither spiracles nor a functioning tracheal system. Some species pupate inside the living host within a pupation chamber, which becomes filled with air. There is some evidence that the air inside this chamber is derived from the hosts' tracheal system as in the Encyrtidae. Parasitoids emerge by cutting a hole through the integument of the host mummy; but if the mealybug has a delicate covering, they push their way out from beneath it. The adults of some such species lack functional mandibles. Overwintering is normally as a mature larva or pupa. The Aphelinidae are very unusual in that the males and females may have different ontogenies. The females of such species always develop as primary endoparasitoids of mealybugs.

#### *Coccophagus gurneyi*

It is quite polyphagous and is native of Australia. It is a solitary internal parasitoid of all the nymphal instars of *Ps. fragilis, Ps. comstocki* and *Ps. longispinus. Coccophagus gurneyi* Compere has a complex developmental biology. The female-producing eggs are laid free in the body fluids of the mealybug, where they hatch in about 4 days at 27 °C. The larva develops in 10 days followed by a 2-day prepupal stage and an 11-day pupal stage. The total duration goes up to 44 days. The male-producing egg of the parasitoid is deposited in the developing larva of the female parasitoid. It gave a good control of *Ps. fragilis* in South Africa and Chile.

### 13.2.1.4 Other Families

There are species belonging to the families Braconidae, Eucoilidae, Signiphoridae, Eulopidae and Pteromalidae that are known to attack the mealybugs but are of minor importance (Table 13.2).

**Table 13.2** List of some important encyrtid parasitoids of mealybugs

| Parasitoid | Mealybug |
|---|---|
| **Hymenoptera, Encyrtidae** | *Maconellicoccus hirsutus* |
| *Anagyrus kamali* Moursi | |
| *Apoanagyrus (Epidinocarsis) lopezi* (De Santis) | *Phenacoccus manihoti* |
| *Anagyrus ananatis* Gahan | *Dysmicoccus brevipes* |
| *Hambletonia pseudococcina* Compere | *D. brevipes* |
| *Anagyrus aegyptiacus* Moursi | *Nipaecoccus viridis* |
| *Anagyrus dactylopii* (Howard) | *M. hirsutus and N. viridis* |
| *Anagyrus pseudococci* (Gir.) | *Planococcus citri* |
| *Anagyrus fusciventris* (Girault) | *Pseudococcus longispinus* |
| *Anagyrus loecki* Noyes and Menezes | *Paracoccus marginatus* and *Phenacoccus madeirensis* |
| *Anagyrus punctulatus* Agarwal | *Saccharicoccus sacchari* |
| *Anagraphus* sp. | *P. citri* |
| *Pseudectroma* sp. | *Pseudococcus viburni* |
| *Acerophagus maculipennis* (Mercet) | *Pseudococcus viburni* |
| (*Pseudaphycus maculipennis*) | |
| *Acerophagus notativentris* (Girault) | *Ps. longispinus* |
| *Arhopoideus peregrinus* (Compere) | *Ps. longispinus* |
| *Anarhopus sydneyensis* Timberlake | *Ps. longispinus* |
| *Leptomastidea abnormis* (Girault) | *Pl. citri* |
| *Leptomastix dactylopii* Howard | *Pl. citri* |
| *Leptomastix epona* (Walker) | *Pseudococcus affinis* and *Spilococcus cactearum* |
| *Pseudleptomastrix mexicana* Noyes and Schauff | *Pa. marginatus* |
| *Praleurocerus viridis* (Agarwal) | *Rastrococcus iceryoides* |
| *Pseudaphycus phenacocci* Yasnosh | *Phenacoccus mespili* |
| *Pseudaphycus utilis* Timberlake | *Nipaecoccus nipae* |
| *Pseudaphycus malinus* Gah. | *Ps. comstocki* |
| *Pseudaphycus angelicus* (Howard) | *Pseudococcus maritimus* |
| *Acerophagus notativentris* (Girault) | *Pseudococcus maritimus* |
| *Apoanagyrus (Epidinocarsis) lopezii* De Santis | *Phenacoccus manihoti* |
| *Gyranusoidea tebygi* Noyes | *Rastrococcus invadens* |
| *Gyranusoidea indica* Shafee, Alam and Agarwal | *M. hirsutus* |
| *Praleurocerus viridis* (Agarwal) | *Rastrococcus icerioides* |
| *Acerophagus papayae* Noyes and Schauff) | *Paracoccus marginatus* |
| *Aenasius bambawalei* Hayat | *Penacoccus solenopsis* |
| *Aenasius advena* Comp. | *F. virgata* |
| *Aenasius abengouroui* (Risbec) | *Planococcus njalensis* |
| *Cheilonerus* sp. | *M. hirsutus* |
| *Alamella flava* (Agarwal) | *M. hirsutus* |
| *Tetracnemoidea indica* Ayyar | *Planococcus lilacinus* |
| *Acroaspidia myrmicoides* (Comp and Zinna) | *F. virgata* |
| *Blepyrus insularis* (Camp.) | *F. virgata* |
| *Bothriocraera bicolor* (Comp and Zinna) | *F. virgata* |
| *Chrysoplatycerus splendens* How. | *F. virgata* |
| *Neodiscodes martini* Comp. | *F. virgata* |
| *Neodusmetia sangwani* (Subba Rao) | *Antonina graminis* |

(continued)

**Table 13.2** (continued)

| Parasitoid | Mealybug |
|---|---|
| *Tananomastix abnormis* Gir. | *F. virgata* |
| *Zarhopalus inquisitor* How. | *F. virgata* |
| *Neodusmetia sangwani* (Subba Ra) | *Antonina graminis* |
| *Rhopus nigroclavatus* (Ashmead) | *Brevennia rehi* |
| *Leptomastix nigrocincta* Risbec | *Coccidohystrix insoilta* |
| *Leptomastix nigrocoxalis* Compere | *Coccidohystrix insoilta* |
| *Leptomastix epona* (Walker). | *Spilococcus cactearum* |
| *Leptomastidea abnormis* (Girault) | *Pl. citri* |
| *Leptomastix dactylopii* How | *Pl. citri* |
| *Pseudleptomastrix mexicana* Noyes and Schauff | *Pa. marginatus* |
| *Alamella flava* Agarwal | *Pl. citri* |
| *Coccidoxenoides perminutus* (Timberlake) | *Pl. citri* |
| **Platygasteridae** | *Pl. citri* |
| *Allotropa citri* Mues. | |
| *Alltropa japonica* sp. nr | *M. hirsutus* |
| *Allotropa burrelli* Mues. | *Pseudococcus comstocki* |
| Allotropa *utilis* Mues. | *Phenacoccus aceris* |
| *Allotropa convexifrons* Mues. | *Pseudococcus comstocki* |
| *Allotropa mecrida* (Walker) | *M. hirsutus, P. citri* |
| *Leptacis* sp. | *Pseudococcus* sp. |
| **Braconidae** | |
| *Phanerotoma dentata* (Panzer) | *M. hirsutus* |
| *Trioxys angelica* Hal | *F. virgata* |
| **Eucoilidae** | *M. hirsutus* |
| *Leptopilina* sp. | |
| **Signiphoridae** | *M. hirsutus* |
| *Chartocerus walkeri* sp. nr. | |
| *Chartocerus* spp. | *C. insolita* |
| **Aphelinidae** | *M. hirsutus* |
| *Aphelinus* sp. | |
| *Erioporus aphelinoides* (Comp.) | *M. hirsutus* |
| *Coccophagus caridei* (Brethes) | *Planococcus citri* |
| *Coccophagus sexvittatus* Hayat | *Rastrococcus invadens* |
| *Coccophagus sexvittatus* Hayat | *Rastrococcus iceryoides* |
| *Coccophagus gurneyi* Comp. | *Ps. calceolariae* |
| *Coccophagus pseudococci* Compere | *C. insolita* |
| **Eulopidae** | *F. virgata* |
| *Syntomosphyrum zygaenarum* Ferriere | |
| *Aprostocetus ajmerensis* (Khan and Shafee) | *C. insolita* |
| **Pteromalidae** | *F. virgata* |
| *Anysis alcocki* Ashm. | |
| *Catolaccus crassiceps* (Masi) | *C. insolita* |

## 13.3 Entomopathogens

The wax cover and the secretion process are involved in mealybug defence against natural enemies particularly the pathogens. Among the microbes, only the entomopathogenic fungi are recorded as causing natural infection against the mealybugs and these records are sparse and confused. The pathogens of the mealybugs appear to be restricted as yet to the Zygomycotina and Deutromycotina and the former to the class Zygomycetes. The class contains two orders, namely Mucorales and Entomophthorales. Table 13.3 records a number of pathogens from the mealybugs. Pathogenicity of many of the pathogens have not been seen on mealybugs. Some of the records might have resulted from saprophytic growth on the dead mealybugs. A total of 13 pathogens were reported in different countries (Moore 1988).

*Neozygites fumosa* Speare was found to be a very important natural agent in regulating the mealybug *Phenacoccus manihoti* Matile-Ferrer in Congo (Le Ru 1986). Development of epizootics appeared to be influenced by a relative humidity of 90 % or more, minimum daily temperatures greater than 20 °C and the mealybug density. Adult mealybugs are more susceptible than the

**Table 13.3** List of entomopathogens and entomopathogenic nematodes recorded on mealybugs

| Pathogens/nematodes | Mealybugs |
|---|---|
| **Entomopathogens** | |
| *Fusarium pallidoroseum* (Cooke) Sacc | *Phenacoccus solenopsis* |
| *Fusarium equiseti* (Corda) Sacc | *Coccidohystrix insolita* |
| *Verticillium lecanii* (Zimm.) | *Paracoccus marginatus* |
| *Lecanicillium* (*Verticillium*) *lecanii* (Zimm.) | *Phenacoccus solenopsis,* M. hirsutus |
| *Metarhizium anisopliae* (Metsch.) Sorokin | Root mealybugs (*Planococcus* sp., *Planococcus citri*, *P. lilacinus*, *Dysmicoccus brevipes* and *Ferrisia virgata* |
| *Metarhizium anisopliae* | *Maconellicoccus hirsutus* |
| *Metarhizium* sp. | *Dysmicoccus boninsis* |
| *Pseudomonas fluorescens* Migula | *Paracoccus marginatus* |
| *Beaveria bassiana* (Bais-Criv) Vuill | *Paracoccus marginatus* |
| *Neozygites fumosa* (Speare) | *P. citri, Phenacoccus* sp., *Phenacoccus manihoti* |
| *Cladosporium* sp. | *Phenacoccus herreni* Cox and William |
| *Entomophthora fumosa* Speare | *Planococcus citri* |
| *Entomophthora fresenii* (Nowak.) | *P. citri, F. virgata, Nipaecoccus nipae* |
| *Aspergillus parasiticus* Speare | *Saccharicoccus sacchari, Dysmicoccus boninsis, Planococcoides njalensis* (Laing) |
| *Aspergillus flavus* Link | *Pseudococcus calceolariae* (Maskell) *Dysmicoccus boninsis* (Kuwana) *Saccharicoccus sacchari* (Cockerell) |
| *Cephalosporium* sp. | *Planococcoides njalensis* (Laing) |
| *Cladosporium oxysporum* Berk and M.A. Curtis | *Planococcus citri* (Risso) |
| *Conidiobolus pseudococci* (Speare) | *Pseudococcus calceolariae* |
| *Hirsutella sphaerospora* H.C. Evans and Samson | *Rastrococcus invadens* |
| **Entomopathogenic nematodes** | |
| *Steinernema thermophilum* Ganguly and Singh | *Phenacoccus solenopsis* |
| *Steinernema meghalayensis* sp. n. | *Phenacoccus solenopsis* |
| *Steinernema riobrave* Cabanillas, Poinar and Raulston | *Phenacoccus solenopsis* |
| *Steinernema harryi*. sp. n. | *Phenacoccus solenopsis* |
| *Heterorhabditis zealandica* Poinar | *Pseudococcus viburni* |

immature mealybugs. Besides *Neozygites fumosa*, the fungi that have been confirmed as pathogenic to mealybugs are *Hirsutella sphaerospora*, *Verticillium lecanii, Aspergillus parasiticus* and possibly *Cladosporium oxysporum. Entomophthora fumosa* caused up to 58.1 % mortality of the third-instar nymphs and adult *Planococcus citri* (Risso) in a period of high rainfall and humidity in the wet season in January (Murray 1978). The fungal pathogen *Metarhizium anisopliae* (Metsch.) Sorokin was found to cause 79.6 % reduction in the mealybug population, 30 days after the treatment under laboratory conditions (Devasahayam and Koya 2000). *Beauveria bassiana* (Bals.) Vuill and *Metarhizium anisopliae* (Metschn.) Sorokín, *Lecanicillium lecanii* (Zimm.) Zare and W. Gams and *Isaria fumosoroseus* (Wize) were found pathogenic to *Maconellicoccus hirsutus* Green at 15 and 20 °C. The fungus *Beauveria bassiana* (Bals.-Criv.) Vuill. was found to cause high mortality in short time periods in adult females of the mealybug *Dysmicoccus texensis* (Tinsley) (Andalo et al. 2004). *Fusarium pallidoroseum* caused 80–95 % mortality of *Ph. solenopsis* (Monga et al. 2010). The fungal pathogen *Lecanicillium* (*Verticillium*) *lecanii* was found to be pathogenic to *Ph. solenopsis* in Tamil Nadu (Banu et al. 2010). Cadavers of *Ph. solenopsis* infected with *Fusarium pallidoroseum* (Cooke) Sacc were collected from Haryana and Punjab during 2007–2010. In the laboratory, *F. pallidoroseum* caused 80–95 % mortality of *P. solenopsis* (Monga et al. 2010). The fungal pathogen *Lecanicillium* (*Verticillium*) *lecanii* was found to be pathogenic to *Ph. solenopsis* in Tamil Nadu (Banu et al. 2010).

*In vitro* application of *Verticillium lecanii*, *Beauveria bassiana*, *B. brongniartii* and *Metarhizium anisopliae* at single dose ($1 \times 10^7$ conidiospores/mL) against *P. citri* inflicted a mortality of 91.1, 75.5, 66.6 and 45.3 %, respectively. *Verticillium lecanii* at five doses (ranging from $1 \times 10^5$ to $1 \times 10^9$ conidiospores/mL) caused a mortality of 45, 65, 80, 90 and 95 %, respectively (Saranya 2008). *Pseudomonas fluorescens* Migula, a common Gram-negative, rod-shaped bacterium, as foliar application, was found to cause 72 % reduction in the mealybug population (*Pa. marginatus)*.

*Root mealybugs*: Drenching of 3 % Neem seed kernel extract (NSKE) and *Verticillium lecanii* Econil 7 g/L) was effective against the root mealybugs (Smitha and Mathew 2010).

## 13.4 Entomopathogenic Nematodes

Entomopathogenic nematodes (EPNs) have potential for biological pest control and have been successfully used in several countries in soil and cryptic pest control. It is hypothesized that the rarity of infestation by nematodes is related to the wax shield. Stuart et al. (1997) found a varied susceptibility of *Dysmicoccus vaccinii* Miller and Polavarapu to several nematode species; they showed that the removal of the waxy coating from the mealybug did not influence their susceptibility to *Heterorhabditis bacteriophora* Poinar. *Heterorhabditis bacteriophora* has been successfully shown to kill mealybugs. *Planococcus citri* was found to be the most susceptible to *Steinernema yirgalemense* and *Heterorhabditis zealandica*, causing 97 % and 91 % mortality, respectively.

In Western Cape Province, South Africa, an isolate of *Heterorhabditis zealandica*, has resulted in mortality of *Pseudococcus viburni* (Signoret) up to 80 % after 48 h. All stages of *P. viburni* beyond crawlers appeared to be susceptible to the nematode infection. Hence, the control in the field should take place when the intermediates and adults are most abundant (Stokwe and Malan 2010). In India, *Steinernema thermophilum* caused 83 % mortality of the mealybug (*Ph. Solenopsis*) within 72 h after inoculation at 50 IJ/mL and 100 % within 48 h at 500 IJs/mL. *Steinernema riobrave* and *S. harryi* n. sp. produced intermediate mortality of about 66 % within 60 h at 500 IJs/mL. Emergence was observed only in 16.6 % of the mealybug cadavers infected with *S. thermophilum* and *S. harryi* sp. nr. Entomopathogenic nematode *Steinernema glaseri* was also known to cause mealybug mortality under laboratory conditions.

The nematode *Steinernema carpocapsae* (Weiser) was found to cause high mortality in short time periods in adult females of the mealybug *Dysmicoccus texensis* (Tinsley) (Andalo et al. 2004). The aqueous suspension of EPN (JPM3) was more efficient with 70 % control efficiency on the root mealybug *Dy. texensis* (Alves et al. 2009). *Heterorhabditis bacteriophora* Poinar strain HC1 was known to cause 100 % mortality in the inoculated coffee mealybug complex (Rodriguez et al. 1998). *Dysmicoccus texensis* is an example for the coffee root mealybug. Greenhouse results demonstrate that the aqueous suspension (JPM3) was more efficient with 70 % control efficiency.

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