ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 6, Issue, 11, pp.9415-9422, November, 2014

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

MANAGEMENT OF MEALYBUGS BY USING BIOAGENTS

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ARTICLE INFO

Article History:
Received 20th August, 2014
Received in revised form
05th September, 2014
Accepted 04th October, 2014
Published online 18th November, 2014

Key words:
Mealybugs,
Coccinellids,
Parasitoids,
Biological control
and IPM.

ABSTRACT

Thirteen important species of mealy bugs occurring in India. It has been proved that some mealy bugs are important plant disease vectors. Management of mealy bugs using chemical pesticides is often difficult, but these pests can be managed well by biological control using predatory coccinellids like. *Cryptolaemus montrouzieri, Scymnus coccivora* and *Brumoides suturalis* have been proved as a effective mealy bug predators. Besides these, others like *Nephus regularis, Brumoides lineatus, Chilomenes sexmaculata, Coccinella septempunctata, Hyperaspis maindroni* are kown to feed o mealybugs. Role of other predatory insects like the chrysopids *Chrysoperla carnea* and *Mallada boninensis*, anthocorids *Anthocoris muraleedharani* and *Blaptostethus pallescens* lycaenid predator, *Spalgis epius* and cecidomyiids, *Diadiplosis koebelei* and *Triommata coccidivora* have also been described. It has been reported that, apart from predators, thirteen species of parasitoids also play important role in suppressing the mealy bug population. The role of entomopathogenic fungi like *Metarrhizium anisopliae*, *Verticillium lecanii, Beauveria bassiana* and *Fusarium pallidoroseum and* entomopathogenic nematodes like *Heterorhabditis indica, Heterorhabditis baujardi*, *Heterorhabditis bacteriophora*, *Heterorhabditis zealandica, Steinernema abbasi* and *Steinernema yirgalemense* in suppressing the mealy bugs population has to studied further for their effective use in IPM programme.

INTRODUCTION

Mealybugs are the insects mostly found in moist, warm climates, in tropical areas of the world including Asia, Africa, Australia and Middle East and these are so named for the powdery secretion covering their bodies. About 5000 species of mealybugs have been recorded from 246 families of plants throughout the world (Muniappan *et al.,* 2006). More than 100 species have been reported to attack a wide variety of plant species including Citrus, Coffee, Cotton, Guava, Grapes, Sugarcane *etc.* in India (Varshney, 1985). In the current decade, a increased trend in the buildup of various mealybug species in crop plants and in the wild species is observed mainly due to certain abiotic changes in climate and environment (Tanwar *et al.,* 2007). During the last few years mealybugs, which were considered to be minor pests in many crops have acquired the status of major pests especially in cotton, vegetables and fruits. The damage caused by mealybugs in different crops ranges from 40-50% in cotton (Dhara Jyothi *et al*., 2008), 60-100% in papaya (Galanihe *et al.,* 2010) 80% in cassava (Rabindra, 2010) and 50-100% and 75% in grapes, jute and mesta respectively (Tanwar *et al.,* 2007).

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Important species of mealybugs in india

Besides these root mealybug, *Paraputo sp.* cause considerable losses in mulberry cultivations in West Bengal (Mukhopadyay *et al.,* 2010).

Nature of damage

Both nymphs and adults suck the sap from leaves causing withering and yellowing of leaves and fruits may drop prematurely. Infested growing points become stunted and swollen which may vary depending upon the susceptibility of each host species. Heavy clustering of mealy bugs can be seen under leaf surface giving the appearance of a thick mat with waxy secretion. Severe infestations resemble patches of cotton all over the plant. They excrete copious amount of honey dew that attracts ants and help in development of black sooty mould which inhibits the plants ability to manufacture food.

Mealybug as a vector of plant diseases

Mealybug causes retardation in photosynthetic activity by honeydew secretion and association of sooty mould growth (Mibey, 1997). Besides this, these also known to spread diseases of crop plants like Tobacco Mosaic Virus (Newton, 1953); swollen shoot of cocoa; and "Tukra" disease of

Table 1. Different mealybugs species in India

Scientific name	Common name	Identifing characters	Hosts
(*Ferrisia virgata*)	Striped mealybug	The body is grey in colour, covered with very long waxy filaments and is provided with long tails. Two dark stripes are present on dorsum and body fluid is light color.	Okra, brinjal, pigeon pea and groundnut.
Pseudococcus longispinus	Longtail mealybug	Anal wax filaments are as long as body and appear as long tails; 2nd to last pair of wax filaments are also long; dorsal median stripe is present on abdomen	Citrus, taro, avocado, guava, eggplant and grapevine.
Planococcus citri	Citrus mealubug	Body is yellow to pink in colour, One dorsal median stripe is present on the back in adults and body fluid is clear. Anal filaments are less than one-eighth the length of the body	Cocoa, bananas, tobacco and coffee and wild trees such as *Ceiba pentandra* and Leucaena.
Phenacoccus solani	Solenopsis mealybug	The body is covered with very short waxy filaments. Long tails and stripes on the body are absent. This species does not produce an egg mass or ovisac.	Cotton, brinjal, okra, tomato, sesame, sunflower and China rose
Saccharicoccus sacchari	Pink sugarcane mealybug	The mealybug, is light pink in colour and occurs underneath of leaf sheaths on sugarcane	occasionally on sorghum, rice and other grasses
*Maconellicoccus hirsutus; s*ynonyms - *Phenacoccus hirsutus*	Pink mealybug	Larger mealybugs are darker in color and covered with significantly more white waxy material. The body is having no long tails or waxy projections around the edge, no stripes and this mealybug produces an egg mass	Chrysanthemum, citrus, coconut, coffee, cotton, corn, croton, cucumber, grape, guava, *Hibiscus sp.*, peanuts, pumpkin, rose, and mulberry.
Phenacoccus solenopsis	Solenopsis mealybug	The body is covered with very short waxy filaments. Long tails and stripes on the body are absent.	Cotton, brinjal, okra, tomato, sesame, sunflower and China rose
Drosicha mangiferae and Ratrococcus iceryoides	Mango mealybug	The females can be identified by their flat shape, covered with white mealy powder.	fruit orchards
Paracoccus marginatus	Papaya mealybug	Presence of oral-rim tubular ducts dorsally restricted to marginal areas of the body, and the absence of pores on the hind tibiae.	Papaya, hibiscus, avocado, citrus, cotton, tomato, eggplant, peppers, beans and peas, sweet potato, mango, cherry, and pomegranate
Brevennia rehi	Rice mealybug	Oval creamy white bugs inside the leaf sheath	*Cyanodon dactylon, Paspalum scrobiculatum, Eleusine indica* and *Digitaria sanguinalis.*
Coccidohystrix insolitus	Eggplant mealybug	Creamish yellow mealybugs with white filaments on the body	Solanaceous vegetables, Malvacea, leguminosae
Planococcus lilacinus	Coffee mealybug	Brownish-red or tan with segmented clumps of pink to purple wax covering the body. A wide but indistinct stripe is noticeable on its back.	lemon, *Citrus limon* pummelo, *Citrus maxima* sour orange, *Citrus aurantium*.

mulberry (Misra,1919) Citrus mealybug (*P. citri*), commonly found associated with black pepper (*Piper nigrum*) plants in India was shown to transmit *Badnavirus* associated with stunted disease.

Management of mealybugs

Mealybugs can be managed by adopting

- Cultural practices,
- Spraying of insecticides and plant products
- Biological control

However, plant protection products are of limited effectiveness against mealy bugs because of their habit of hiding in crevices and the presence of waxy covering of its body. Insecticides often fail to control this pest, because they cannot penetrate the heavy layers of wax that shield the mealy bug's body (Kairo *et al.,* 2000). The egg stage, in particular, is protected by a white, waxy ovisac (Meyerdirk *et al.,* 1998), which most pesticides cannot penetrate (McKenzie, 1967). Late instar nymphs and adult female mealy bugs are also not affected by foliar application of insecticides since they are covered with waxy coating. Some mealy bugs have been able to develop resistance to insecticides (Charles, 1996). Controlling the pest by biological means has been advocated now. Conservation and augmentation of native natural enemies and also introduction of exotic natural enemies, has been accepted as an effective, environmentally non-degrading, technically appropriate, self perpetuating, economically viable and socially acceptable method of pest management. Mealy bugs being sessile insects are quite amenable to biological control (Gautam, 2008).

Management of mealybugs by using bio agents

Biological control is considered the most effective long-term solution to the mealybug infestation because the parasites and predators are self perpetuating, persist even when the mealybug is at low population densities, and they continue to attack the

mealybugs, keeping populations below economic injury levels. Among the bioagents, use of predators, parasitoids and fungal pathogens were proved effective in managing mealybugs.

Predators

Predators are free living organisms which catch and kill the weaker or small organisms (prey) for food. A number of predators contribute to mealybug control. Few are specialized on mealybugs. Whereas, most of them are generalistic that prey on any small, soft-bodied arthropods. Major predators used in managing mealybugs are

Ladybirds

These ladybirds are predaceous in grub and adult stage and these have been reported to exercise a good deal of natural control on the mealybug (Baba Sahib *et al.,* 2010). Intrestingly, a good number of natural enemies comprising ladybird beetles, viz., *Hyperaspis maindroni* Sicard(earlier reported as *Brumoides lineatus* (Weise), Gautam *et al*., 2007; NCIPM, 2008), *Chilomenes sexmaculata* (Fabricius), *Coccinella septempunctata* Linnaeus, *Nephus regularis* Sicard and *Scymnus coccivora* Ayyar were found as natural regulating agents on *P. solenopsis* in cotton (Pala Ram *et al*., 2007) and on parthenium (Gautam *et al*., 2007). However, Mani (1987) reported *S.coccivora* and *M.hirsutus* in grapevine ecosystem. Whereas Shera *et al. (*2010) reported the potential impact of *C.septempunctata* on cotton mealybug, *P.solenopsis.* Tanwar *et al.* (2007) reported coccinellid beetles such as *Cheilomenes sexmaculata* (Fabricius), *Rodolia fumida* Musant, *Scymnus coccivora* Aiyar and *Nephus regularis* (Sicard) as important predators of mealybugs. All the life stages of four predatory coccinellid species performed well registering more than 80% consumption of first instar nymphs of cotton mealybug, except fourth instar grubs (77.9% consumption); However, adult stage was found more effective predatory stage as maximum and highly significant predation (percent consumption) was registered by this stage (96.7%). Second, third and first instar grubs of all evaluated predatory coccinellid beetles showed 87.6, 86.1 and 81% consumption, respectively.

Cryptolaemus montrouzieri

Commonly called as the redheaded ladybird beetle or the mealybug destroyer, is a black lady beetle. *C. montrouzieri* has been used successfully in Karnataka to reduce large populations of *M. hirsutus*. It is considered a predator of citrus and long-tailed mealybug in greenhouses and interior plantscapes and has already been introduced in a biocontrol program to control pink mealybug. The importance of *C.montrouzieri* was reported on citrus mealy bug *P. citri* on orange trees (Hamid and Michelakis, 1994) and on crossandra (Mani and Krishnamoorthy, 2007). *C. montrouzieri* grub can consume on an average 752.60, 742.80 eggs and 242.00, 222.80 nymphs of *M. hirsutus* and *P. solenopsis* respectively. Adult female consume 4340.20 eggs and 235.20 nymphs of *P. solenopsis* and 4355.00 eggs and 241.20 nymphs of *M. hirsutus* respectively. While male beetle can devoure 3586.00 eggs and 149.60 nymphs of *M. hirsutus* and 3519.20 eggs and 148.00 nymphs of *P. solenopsis* respectively (Gosalwad *et al.,* 2010). Dose of release of Australian lady beetle/grub *Cryptolaemus montrouzeri* (also known as mealy bug destroyer) @ 10,000 per ha. Both adults and larvae kill mealybugs. Single grub can feed 900-1500 eggs or 300 nymphs or 30 adults in its lifetime. Biological control in grapes includes one to three releases of *C. montrouzieri* at 10 per tree or @ 5,000 beetles/ha, two times in a season especially during August– September and December–January. It is better to release a mixed population of grubs and adults rather than only adults (Tanwar *et al.,* 2007).

Recently this predator is found to preying upon the papaya mealybug *Paracoccus marginatus.* The predation rate is nearly similar to that on *M.hirsutus* (Mishra, 2011). An individual of *C.montrouzieri* can consume about 355 mealybugs eggs or 498 nymphs of *Rastrococcus iceryoides* during its total larval period. Field release of *C.montrouzieri* @50/plant can provide significant reduction of the mealybug infested mango fruits (Mani *et al.,* 1995).

Babasaheb *et al.* (2010) studied the predatory response of different developmental stages of *C. montrouzieri* with respect to the developmental stages of *P. solenopsis*. They also observed increased in feeding potential with age of the grubs and also stated that consumption rate of fourth instar *C. montrouzieri* (18.00±0.45 adult prey consumed per day) where as third instar *C. montrouzieri* consumed (13.20±0.37 adult prey per day). Release of *C. montrouzieri* @ 30 larvae/plant provided a mean of 97.74%, 90.17% and 82.37% reduction in the population of *P. citri*, *F. virgata* and *N. viridis,* respectively in a period of 60 days after release on pummel (Mani and Krishnamoorthy, 2008).

Scymnus coccivora

Scymnus coccivora Ayyar is an important coccinellid predator of the grapevine mealybug, *Maconellicoccus hirsutus* (Green) in South India. Besides these it is found feeding on the mealybug *F. virgata* infesting custard apple and *Planococcus lilacinus* infesting *Ficus sp.* and *Rastrococcus iceryoides* (Green). The grubs are active pradators on all the stages of mealybug. During the development each grub preyed upon a total of 307.7 eggs, 62.20 nymphs and 6.55 adults (Mani and Thontadarya, 1987).

Brumoides suturalis

The three-striped beetle, *Brumoides sutuaralis* belonging to the Subfamily Coccinellinae, order Coleoptera is important and most voracious predator of mature and immature stages of mealy bug on different field and vegetable crops (Lohar, 2001). Feeding potential of lady bird beetle, *Brumoides suturalis* Fabricius (Coleoptera:Coccinellidae) on cotton mealybug *Phenococcus solenopsis* in laboratory and field and reported *Brumus suturalis* as a voracious feeder of *Phenococcus solenopsis* (Khuhro *et al.,* 2012). 3rd and 4th instars were found more voracious as compare to 1st and 2nd instars (Khuhro *et al.,* 2008).

Chrysopids

Chrysopids play a major role in regulating the mealybug population in nature (Mani and Krishnamoorthy, 1990). The

larvae of all species, as well as the adults of certain species are predaceous and could be important biocontrol agents of several soft bodied arthropods. This predator is widely distributed in India, Europe, USSR, North America, South America, Tanzania, Sudan, Egypt, Kenya and Nigeria. The predator has a significant potential for commercialization and use against a variety of pests in combination with other insect pest management tactics (cultural, mechanical, host plant resistance, chemical and microbial insecticides).

For the first time feeding potential of *Chrysoperla carnea* was studied on the eggs, nymphs and adult females on *Planococcus citri* under laboratory conditions. The grubs were found active predators on mealybugs, and the predatory grub preyed on all the stages of the mealybug. The chrysopid grub consumed a total of 3783.73 eggs or 728.52 nymphs, or 96.39 adult females of *P. citri* (Malleshaiah *et al*., 2000). However Geetalaksmi *et al*. (2000) reported the predatory potential of *C. carnea* as 24.6 nymphs of *P.citri* per day. Another green lace wing *Mallada boninensis* (Okamoto) is known to feed on many mealybug species (Mani and Krishnamoorthy 1989). During the entire period of development, a single larva preyed a mean of 344.7 nymphs of *F. virgata* or 490.25 nymphs of *P. lilacinus* or 562 nymphs of *P. citri*. Similar feeding behaviour of *M. boninenis* on yet another mealybug *Maconellicoccus hirsutus* (Green) was observed by Mani and Krishnamoorthy (1989) who reported that a single larva consumed 237.9 mealybug nymphs. Of the mealybug species, *P. citri* was found to be relatively more preferred and preyed more by *M. boninensis* (Mani and Krishnamoorthy, (1990).

Anthocorids

Anthocorid predators have been reported to be potential predators of sucking pests like thrips, aphids and mealybugs. *Blaptostethus pallescens* was recorded as a potential mortality factor of cassava mealybug *Phenacoccus manihoti* in Africa. In India *A. muraleedharani* showed a clear preference for *P. solenopsis* (Chandish *et al*., 2012). It was also recorded from Tamil Nadu and Bangalore (Jalali and Singh, 2002). *Anthocoris muraleedharani* Yamada was recorded as a predator of the striped mealybug, *Ferrisia virgata* on purple orchid tree, *Bauhinia purpurea* (Yamada *et al.,* 2010). Simultaneously, Tohamy *et al*. (2008) reported *Orius albidipennis* Reut. as one of the predators of pink sugarcane mealybug *Saccharicoccus sacchari*. One adult could feed on a total of 34.8 crawlers and 22.83adults of *P.solenopsis* during its life time with a feeding rate of 1.73crawlers/day and 1.93adults/day. Where as Simultaneously *A. muraleedharani* could feed on a total of 65.5 crawlers of cotton mealybug, with a feeding of 4.6 crawler/day and 140.67 adults life time with a feeding rate of 7.73adults/day (Chandish *et al*., 2012).

Lycaenid predator

S.epius was recorded as a potential predator of different species of mealybugs and scales. The adults of *S.epius* congregate the plants infested with the hemipteroid insects. The lycaenid predator was commonly associated with the natural control of *Phenococcus iceryoides, P. glomeratus, Pseudococcus lilacinus, P. citri* infesting cotton, *Pithocolobium saman*, Chinese rose and dolichos lablab and Sesbania. Pushpaveni *et al*. (1973) recorded natural control of *Macnellicoccus hirsutus* on Mesta while Mani and Krishnamoorthy (1998) recorded *S. epius* as a natural enemy of mango green shield scale. Recently papaya mealy bug incidence was noticed on mulberry crop in western parts of Tamil Nadu. During the whole larval period the predatory larvae can consume about (48.15 ± 4.08) ovisacs and (210.99 ± 10.77) nymphs and adults of *P. marginatus* (Thangamalar, 2010).

Cecidomyiid predators

Cecidomyiid flies (*i.e*., predaceous midges) are another common mealybug predatory group (Abbas, 1999). In most regions, little is known about their impact on mealybug population densities. However, Charles (1985) reported that *Diadiplosis koebelei* (Koebele) reduced *P. longispinus* in New Zealand vineyards by about 30%. Midges associated with mealybugs include *Dicrodiplosis californica* Felt in California (Geiger and Daane, 2001), *D. koebelei* in New Zealand. *Triommata coccidivora* Felt has been reported in India as mealybug predator (Mani *et al*., 1987). The adult fly, which is not predatory, deposits its eggs in or near the mealybug ovisac and the maggots feed primarily on mealybug eggs and small crawlers.

Predatory mites

Most of the predatory mites belong to Phytoseiidae, Stigmaeidae, Bdellidae, etc. *Hypoaspis* is a small mite that feeds on crawlers of mealybugs. Tandon *et al.* (1976) recorded two predatory mites *viz., Leptus sp.* and *Bocharia sp.* (Erythraeidae: Acarina) on mango mealy bug, *Drosicha mangiferae* Green (Margarodidae: Hemiptera).

Entomo-pathogenic nematodes

Predatory nematodes have also proven their effectiveness in managing sucking pests. Mohan *et al.* (2004) reported the successful management of mango mealy bug, *Drosicha mangiferae* by *Photorhabdus luminescens*, a symbiotic bacteria from entomopathogenic nematode, *Heterorhabditis indica.* The infectivity of three Egyptian Heterorhabditid nematode species *Heterorhabditis bacteriophora* (Poinar), Heterorhabditis indica (Poinar) and *Heterorhabditis baujardi* (Poinar) (Rhabditida: Heterorhabdilidae) and one imported Steinernematid species, *Steinernema abbasi* (Elawad) (Rhabditida: Steinernematidea) were evaluated against preadult of the citrus mealybug *Planococcus citri* (Risso) (Hemiptera: Pseudococcidae) and adult of Egyptian mealybug *Icerya aegyptiaca* (Douglas) (Hemiptera: Monophlebidae) under laboratory conditions(Rahman *et al.,* 2012). Various laboratory bioassays were conducted to determine the potential of entomopathogenic nematodes to control *P. citri.* Adult female *P. citri* were screened for susceptibility to six indigenous nematode species. *Planococcus citri* was found to be most susceptible to *Steinernema yirgalemense* and *Heterorhabditis zealandica*, causing 97% and 91% mortality, respectively (Sonnica, 2012).

Entomopathogeic fungi

These are the fungi which causes diseases in insects. More than 500 species of insects have been observed to be infected with fungi.

Table 2. Parasitoids identified on different mealybugs in India

Mealybug species	Parasitoid	Family	Reference
Phenacoccus solenopsis	*Aenasius bambawalei*	Encyrtidae	Vennila *et al.* (2010) Manickavasagam (2010)
Ferisia virgata	*Aenasius advena*	Encyrtidae	Manickavasagam (2010); Mani (1992)
Paracoccus marginatus	*Acerophagus papaya A.loeki* *Pseudileptasmatrix Mexicana Acerophagus papaya*	Encyrtidae	Muniappan (2006); Amarasekare (2009) Rabindra and Shylesha (2011)
Planococcus citri	*Leptosmatix dactylopii*	Encyrtidae	Mani and Krishnamoorthy (1990)
Maconellicoccus hirsutus	*Anagyrus kamali*	Encyrtidae	Tanwar *et al.* (2007); Kairo *et al.* (2000)
Maconellicoccus hirsutus	*Chartocerus kerichi* *Pachyneuron leucopicida*	Signiphoridae Pteromalidae	NBAII (2010)
Phenacoccus manihoti	*Anagyrus lopezi*	Encyrtidae	Rabindra (2010)
P.solenopsis	*Aenasius sp. Promuscidea unfaceati*	Encyrtidae	NCIPM (2008)

Table 3. Role parasitoids in reducing mealybug population

Parasitoid	Sp. of mealybug	Reference
Anagyrus locki Psuedoleptamastrir Mexicana Acerophagus papaya	*P. magninatus* Reduced to 99% @46,200 in field	Meyerdirk *et al.* (2004)
Aenaicus bambawalei	*P. solenopsis* Reduced to 57.2% in field and 60.6 % in field.	Kumar *et al.* (2009)
Aenaicus bambawalei	*P solenpsis* 20-70% 37.6-72.3%	Tanwar *et al.* (2008) Ram *et al.* (2009)
P. magninata	*A. papaya* @ 1,500 adult 85-92%	NBAII (2010)
M.hersutus	*A.kamali* 66-98%	Kairo *et al.* (2000)
Aenaicus spp	*P. solenopsis* 20-10%	NCIPM (2008)
Blepyres insulais	*Ferisia virgata* 6.7-70.6%	Attia (1997)

Mealybugs are also subjected to infection by such fungi and they can be exploited for their biological control. For instance, foliar spray of *Verticillium lecanii* or *Beauveria bassiana* (2×10^8 cfu/ml) @ 5 g/ml per litre of water is effective during high humid months in reducing the population of mealybugs (Tanwar *et al*., 2007). Similarly, Monga *et al*. (2010) observed 80-95% mortality of *P. solenopsis* due to the attack of *Fusarium pallidoroseum* in Haryana. When *M. anisopliae*, *L. lecanii* and *B. bassiana* were tested against *P. marginatus* adults, *L. lecanii* recorded the highest mortality of 80% at 7 days after treatment. *M. anisopliae* and *B. bassiana* recorded 75 and 70% mortality, respectively, at 9 DAT. A maximum of 100% mortality of nymphs were recorded at 9 DAT by all three fungi. In general, insect mortality increases with an increase in the exposure period. (Banu *et al.,* 2010) Fungal biological control agents have also been demonstrated to be effective in controlling populations of *M. hirsutus*. A study by Ujjan and Shahzad (2007) showed that three different strains of the pathogenic fungus *Metarhizium anisopliae* var. *acridum* infected adults of *M. hirsutus* within two days. Adult mortality was 90 % within 8 days and crawler mortality was 100% of achieved by the 4th day.

Parasitoids of mealybugs

Most successful biological control programs rely primarily on encyrtid parasitoids that are mealybug specialists, some attacking only a few specific mealybug species (Noyes and Hayat 1994). These parasitoids are typically internal koinobionts, but can be either solitary or gregarious and preferentially attack varying host stages. Parasitoids have been credited with some level of control for vineyard mealybugs throughout the world. For example, *Anagyrus pseudococci* (Girault), as a parasitoid of *Pl. citri* and *Pl. fi cus* (Table 2), is one of the most well-studied (Daane *et al.,* 2004) and parasitoids like *Anagyrus dactylopii* found parasitizing mealy bug up to 70%. The parasitoid (Table 3), *Aenasius bambawalei* has an excellent searching ability attacking mealybugs on different host plants of mealybug and parasitization ranges from 37.6-72.3% (Ram *et al.,* 2009) and 20-70% (Tanwar *et al.,* 2007) *P.solenopsis* on cotton and other host plants in Hisar

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