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Invasive Mealybugs and their Management in India: Past, Present & Future

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ABSTRACT: Invasive species are 'non-native species which threaten ecosystem besides habitats and species. Invasive pests include insect pests of agricultural importance. Problems caused by such invasive species in agricultural ecosystems are manifold. Several mealybug pests have got introduced into India, and some of them were known to cause extensive damage to the economically important crops. The important invasive mealybugs include Solenposis mealybug *Phenacoccus solenopsis* Tinsley in 2007, Papaya mealybug *Paracoccus marginatus* Williams & Granara de Willink in 2008, Madeira mealybug *Phenacoccus madeirensis* Green in 2012 and *Jackbeardsleyi mealybug Pseudococcus jackbeardsleyi Gimpel and Miller in 2012.* These alien pests find the new habitat ideal and conducive for breeding and establishment without any restriction through natural regulating factors like natural enemies that keep the species under check in its native range. Classical biological control of the papaya mealybug *P. marginatus* was achieved with the Encyrtid parasitoid *Acerophagus papayae* (Noyes and Schauff), and fortuitous biological of *solenopsis mealybug Phenacoccus solenopsis* with encyrtid parasitoid *Aenasius arizonensis* (Girault) (= *Aenasius bambawalei* Hayat). Local natural enemies namely *Cryptolaemus montrouzieri* Mulsant *Mallada boninensis* (Okamoto) and *Spalgisepeus Westwood* were useful in combating the invasive Jackbeardsly mealybug *Pseudococcus jackbeardsleyi* in India. Four parasitoids namely *Allotropa*sp, *Anagyrusamnestos Ramkumar and Poorani*, *Anagyrus quadrii* (Hayat, Alam & Agarwal) and *Anagyrus loeckii* Noyes & Menezes were found parasitizing the invasive Madeira mealybug, *Ph. madeirensis*. An analysis was made on the serious mealybug pests of common crops in the neighbouring countries, and which are likely to enter India due to frequent travelling and shipments. The Cassava Mealybug, *Phenacoccus manihoti* Matile-Ferrero which has recently invaded India for which *Apoanagyrus lopezi* (De Santis) is available for its effective suppression.

Key words: invasive mealy bugs, classical bio control, natural enemies, India

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Introduction

Invasive species are 'non-native species which threaten ecosystem besides habitats and species. Invasive pests include insect pests of agriculturally importance. Several insect pests have got introduced to India, and some of them were known to cause extensive damage to the economically important crops in India. The present paper deals with important invasive Papaya mealybug *Paracoccus marginatus*, The Madeira mealybug, *Phenacoccus madeirensis*, Jackbeardsley mealybug *Pseudococcus jackbeardsleyi* and the Solenopsis mealybug *Phenacoccus solenopsis* and the attempted bio control initiatives.

1 Papaya mealybug *Paracoccus marginatus* Williams & Granara de Willink (Hemiptera: Pseudococcidae)

Papaya mealy bug (PMB*) Paracoccus marginatus*is native to Mexico and/or Central and North America. In India, it was found for the first time causing serious damage to papaya and many economically important crop plants in Tamil Nadu during 2008 and later in other states in India (Muniappan*et al*., 2008; Mani *et al*,. 2012). Papaya mealybug infestations are typically observed as clusters of cotton-like masses on the above-ground portion of plants. *P. marginatus* damages various parts of the host plant including the leaves, stems, flowers and fruits. Some economically important crops such as papaya, mulberry, cotton, cassava, citrus, sweet potato, peas and beans, okra, eggplant, guava and ornamentals such as hibiscus, Jatropha, Allamanda and Acalypha.

1.1 Papaya: The potential economic loss due to *P. marginatus* ranges from 60 to 80% in papaya. Domestic quarantine measures are to be strengthened to prevent the movement from one state to other states within the country. In the initial stages of appearance of mealybug, collection and destruction of infested plant parts are to be carried out (Ayyasamy and Regupathy 2010; *Tanwaret al., 2010*). Outstanding control had been achieved with use of parasitoids in several countries (Mani *et al.,* 2012; Shylesha *et al.,* 2011c). In India, a number of local predators particularly *Spalgisepeus* (Westwood) were found feeding on *P. marginatus* but proved ineffective in controlling populations of mealybugs. The three fungal pathogens *Verticillium lecanii* (Zimm.), *Beauria bessiana* (Bals.) and *Metarhizium anisopliae* (Metsch.) were known to cause 40 -50 % mortality of P. marginatus (Banu *et al.,* 2010 Three parasitoids *Acerophagus papayae* (Noyes and Schauff), *Anagyrusloecki* Noyes and *Pseudo leptomastix mexicana* Noyes and Schauff were obtained from the USDA in July 2010. After ascertaining their safety in quarantine, the three parasitoids were distributed by NBAII, Bangalore to different states in India. Prior to parasite release, the crop damage was in the grade 5 on 1-5 scale. There was 15, 45 and 90 % decline in the mealybug population damage at 30, 60, 90 days after release and complete control was achieved within six months. Among them, *A. papayae* gave excellent control in Karnataka, Maharashtra, Tamil Nadu, Kerala, Orissa, Tripura and Rajasthan. It was estimated that this impacted in saving the crop yields in papaya, mulberry and cassava worth about Rs. 2000crores with the exotic *A. papayae* (Shylesha *et al.,* 2011c; Mani *et al.,* 2012).

1.2. Mulberry: *P marginatus has* assumed the status of a major pest resulting in huge losses to farmers in Tamil Nadu, Karnataka, and Kerala. A total of 13 natural local natural enemies were reported attacking *P marginatus* in mulberry ecosytem India. *Spalgisepeus* Westwood is seen devouring all the

stages of the mealybug in several mulberry gardens (Shekhar *et al.,* 2011). However the indigenous predators are not so effective in managing the huge populations of papaya mealybug. The imported parasitoid *A. Papaya* was multiplied and released by farmers through extension units of Department of Sericulture of the southern states of India (Qadri *et al.*, 2011).

Tamil Nadu: About10,000 acres of mulberry was infested with *P. marginatus* and the estimated loss in mulberry crop was Rs.135crores in T.N. According to Qadri *et al., (*2011), more than 33,000 adults of *A. papayae* were released (from Nov'10 to March'11) in the papaya mealybug infested mulberry gardens of 350 farmers in the districts of Erode, Tiruppur and Salem leading to reduction in infestation from 90% to less than 5%, so achieving a suppression of 85-95%.Similiar control was achieved with the parasitoid in Trichy and Coimbatore districts in Tamil Nadu.

Karnataka: A total of 15,000 adults of *A. papayae* were released (from Nov'10 to Jan'11) in infested mulberry gardens of 150 farmers covering about 300 acres in Chamarajanagar district. Further, a total of 20,000 parasitoids were released in Mysore district covering about 400 acres (from Feb'11 to May'11). After the release of the parasitoids, 90-95% suppression in infestation was recorded (Qadri *et al.* 2011). Savings was estimated as few crore rupees in Karnataka.

Kerala: *Paracoccus marginatus* appeared on mulberry in 2009 in Idukki, Wyanad Palakkad, Malappuram, and Thrissur districts of Kerala (Krishnakumar and Rajan, 2009). Mulberry is cultivated in about 300 acres in Kerala. Due to release of *Acerophagus papayae* in 2011, mulberry crop worth of few lakhs was saved. The success of classical biological control using *A. papayae* has emerged as an excellent model reviving the sericulture to normalcy in the entire Tamil Nadu, Karnataka and Kerala.

1.3 Rubber : Mealybug was not a major problem on rubber until the recent introduction of *P. marginatus* in India. Biological control includes spraying entomophathogenic fungus viz., *Verticilium leccanii* (10g/l) in 5 per cent soap solution, encouraging the lepidopteran predator, *Spalgisepeus* and release of release of aphelinid *Acerophagus papaya* Noyes and Schauff. The parasitoid was found highly successful in suppressing *P. marginatus* on rubber. The estimated savings due to biocontrol in rubbering the major growing state of Kerala was Rs. 17.85 lakhs (Mani Chellappan, 2010).

1.4 Cassava: Though *P. marginatus* was reported on cassava in more than nine countries, in India particularly Tamil Nadu and Kerala the cassava crop was also found severely damaged. Severe infestation was observed in Namakkal, Salem and Dharmapuri districts of Tamil Nadu state (Sakthivel and Qadri, 2010) besides Coimbatore, Karur, Erode, Tirupur and Trichy districts(Venkatesan *et al.,* 2011).. *A. papayae* releases were made in Tamil Nadu in 2010 (Mani *et al.,* 2012). Heavy population load @ 38.70, 43.85 and 41.21 numbers / 5cm2 was recorded in the districts of Salem, Dharmapuri and Namakkal respectively. No parasitism was observed in a pre-release survey in all the locations. Inoculative release of *A. papayae*@ 200 individuals per location was made in the cassava fields. The parasitism by *A. papaya* went up to 95% within six months of release. There was 94% suppression in the population of the mealybug in all the tapioca fields (Sakthivel, 2013). Similar control of the mealyug was achieved with the release of *A. papaya* in other districts namely Trichy, Erode (Divya, 2012) and Karur (Vijay, 2010). In Perambalur District, *A. papaya* was released in 100 farmer's fields during 2010-

11. A maximum of 100% parasitism was achieved within five months of parasitoid release, and there was also complete suppression of the mealybug (Sankar *et al.,* 2012).

In Erode district, *P. marginatus* was reported to be high (41 50% infestation) in Sithalanthur village. During 2010 -2011, A. *papaya* was released, and the farmers were convinced about the suppression of mealybug (Venkatesan *et al.,* 2011).Savings to the tune of Rs.370 crores was realised due to mealybug control by the parasitoid release (Jonathan *et al.* 2011).

In Kerala, total area for tapioca cultivation is 75000 ha with the production 30 t ha-1. The tuber yield was reduced considerably by the infestation of *P. marginatus*. Due to release of *A. papaya* in 2011, a net savings of 2.5 lakhs ha-1 and 1.8 crores/ year was realized in Kerala. The

ICAR-Central Tuber Crop Research Institute, Trivandrum (ICAR-CTCRI) developed bio formulations "*Shreya*" and "*Nanma*" which are very effective against *P. marginatus*.

1.5 Other crops : *P. marginatus* is also known to infest chillies, tomato and brinjal *A. papaya could be used to control P. marginatus on tomato in India* as it proved to be highly effective against the above mealybug infesting other crops. Two rounds of spraying with *Pseudomonas fluorescens* were given starting from flowering stage at an interval of 10 days using knapsack hydraulic sprayer with a spray fluid volume of 500 L ha-1. *Application of .P. fluorescens* @ (10 g l^{-1}) against *P. marginatus* in brinjal recorded 72%reduction in the mealybug population 10 days after first spray and 80% reduction after the second spray. *P. fluorescens* treatment gave significantly higher yield than *B. bassiana* (Janaki *et al.,*2012).*A. papayae* could also be effectively used for the suppression of *P. marginatus on brinjal.* This is commonly called as papaya mealybug also known to infest groundnut and its degree of infestation recorded was below 15 per cent Tamil Nadu.

2. Madeira mealybug-*Phenacoccus madeirensis* Green (Hemiptera: Pseudococcidae)

Phenacoccus madeirensis is of neotropical origin, and is widespread in tropical South America, but was originally described from Madeira. It is highly polyphagous, feeding on many herbaceous crops, fruit trees, and ornamentals with potential to spread further in Southeast Asia infesting cassava and many other crops including *Citrus* sp. Shylesha *et al.,* (2012) reported *P. madeirensis* first on *Cestrum nocturnam* in 2011, later on cotton, *Hibiscus rosasinensis*, *Lantana camera*, *Clerodendron viscosum*, brinjal, potato, acalypha, crossandra, tapioca and mulberry in many parts of Karnataka and Tamil Nadu. Four parasitoids namely *Allotropa*sp, *Anagyrus sinope*, *Anagyrus quadrii* (Hayat, Alam& Agarwal) and *Anagyrus loeckii* Noyes & Menezes were recorded on *P. madeirensis.* Among them, *A. quadrii*was predominant. *Anagyrus amnestos* was also found to be potential parasitoid of Madeira mealybug. Besides the above parasitoids, *Cacoxenus persipicax* (Knab), *Cryptolaemus montrouzieri* Mulsant, *Scymnus*sp. and some undetermined cecidomyiids were found feeding on the Madeira mealybug (Shylesha*et al.,* 2012). There is very good scope of utilising the above parasitoids for the suppression of the Madeira mealybug. *A. loecki* is a parasitoid of *P. madeirensis* in greenhouse ornamental production in Georgia (Chong, 2005). *A. sinope* sp. nr is a highly host-specific and develops in only *P. madeirensis* (Chong and Oetting, 2007).

2.1 Host preference : *P. madierensis* survives on 19 different plant species, belonging to 12 botanical families, which include Acanthaceae, Amaranthaceae, Amaryllidaceae, Apocyanaceae,

Araceae, Atseraceae, Convolvulaceae, Euphorbiaceae, Fabaceae, Malvaceae, Marantaceae and Solanaceae. During the surveys conducted seven different ant species belonging to three subfamilies of order Hymenoptera were found attending to the mealybug. The three subfamilies under family Formicidae were Formicinae, Myrmicinae and Dolichoderinae. Ants were found to transfer first and second instar mealybugs from plant to plant and were also found protecting them from natural enemies. Ants were attracted to the honeydew excreted by the mealybugs which in turn helped in spread of crawlers (Lepakshi, 2015).

2.4 Natural enemies : Eleven species of natural enemies were recorded on Madeira mealybug, which included a parasitoid, *Anagyrus amnestos* (Rameshkumar, Noyes and Poorani) (Encyrtidae: Hymenoptera). Eight species of lady bird beetles namely *Cryptolaemus montrouzieri* (Mulsant), *Cheilomenes sexmaculata* (Fabricius), *Scymnus sp., Jauravia sp., Rodalia sp., Chilocorus sp. and Nephusregualris*. Besides one predaceous Lycanaeid butterfly *Spalgisepius* (Westwood) one chrysopid *Chrysoperla zastrowi sillemi* (Esben-Petersen) and a *Cecidomyiid, Diadiplosissp.* (Lepakshi 2015). When *P. madeirensis* was exposed at different numbers to its parasitoid *(A. amnestos*) in II instar nymphs, the parasitization by *A. amnestos* ranged between 52.99- 77.00 per cent. It was significantly highest when number of mealybugs exposed was 20 (77.00 %) and lowest when number of mealybugs exposed was 30 (52.99 %). In III instar nymphs, parasitization by *A. amnestos* ranged between 26.85 to 43.00 per cent. It was significantly highest when the number of mealybugs exposed was 15 (43.33 %) and lowest when the number of mealybugs exposed was 35 (26.85 %). The overall mean per cent parasitization was however significantly higher in II instar mealybugs (65.70 %) as compared to III instar mealybugs (36.15 %). Significant differences were observed between the numbers of parasitoids (*A. amnestos*) that emerged when number of mealybugs exposed to the parasitoid was increased from 5 to 40, this trend was observed in case of both II and III instar nymphs of *P. madeirensis*. In case of II instar mealybugs, significantly highest emergence of *A. amnestos* (20.00) was observed when 25 mealybugs were exposed to the parasitoid, while it was significantly lowest (4.10) when 5 mealybugs were exposed to the parasitoid. When the no. of mealybugs exposed was increased from 30 to 40, no significant increase could be observed with respect to parasitoid number that emerged. In case of III instar mealybugs, significantly highest emergence of *A. amnestos* (25.20) was recorded when 40 mealybugs were exposed to the parasitoid, while the same was significantly lowest (5.90) when five mealybugs were exposed to the parasitoid. Increase in the number of mealybugs exposed to *A. amnestos* from 10 to 30 gave Studies on the bio-ecology of mealybug, *P. madeirensis* with special reference to cotton 39 intermediate levels of parasitoid emergence (i.e., 9.20 to 16.10) which were all on par with each other (Lepakshi, 2015)

3. Jack beardsley mealybug (JMB) *Pseudococcus jackbeardsleyi* Gimpel and Miller (Hemiptera: Pseudococcidae)

*Pseudococcus jackbeardsleyi*is distributed throughout the neotropical region and a few countries in southern Asia (Williams and Watson, 1988). *P. jackbeardsleyi was first found colonized* in the papaya gardens around Sathyamangalam in Erode district of Tamil Nadu (Mani *et al.*, 2013b. *Later it was reported in Karnataka on papaya, custard apple, purplemartin, Streptocarpus sp. jasmine, tapioca, chrysanthemum, Indian spinach* (*Basellaalba) and Cordylenus (*Shylesha, 2013*)*. Jack Beardsley

mealybug (JMB) was attacked by three predator species namely *Cryptolaemus montrouzieri, Mallada boninensis* and *Spalgisepeus*. Larvae of green lacewings, lycaenids and coccinellids were also found actively feeding on JMB in many papaya gardens. All stages of *C. montrouzieri* were found amongst the mealybug colonies indicating natural colonization on JMB. As many as 300 larvae of *C. montrouzieri* were also found per plant (Mani *et al.,* 2013a). A single predatory larva had consumed 3.83 (2-4), 13.75 (12-14), 68.88 (61-73) and 172.50 (164 -179) mealybug nymphs of 10 days old during the development of first second, third and fourth instar, respectively. The predator took 29.30 days on JMB (Mani *et al.,* 2013b).

The impact of natural enemies on the population of JMB on papaya revealed that C. *montrouzieri* was found in large numbers followed by *S. epeus* and *M. boninensis*. A mean of 16.6 mealybugs /plant was observed in mid May 2012. Following the appearance of the mealybugs, the natural enemies have also started appearing on JMB. The mealybug population steadily increased to 179.00 in the mid-August, and thereafter steadily declined to 1.72 in the first week of December. The natural enemies were observed throughout the study period. The population of *C. montrouzieri* reached peak of 65.62/plant in August. During the same period, the mean of 10.00 *S. epeus* and 4.10 *M. bonensis*/plant were recorded. All these three predators particularly *C. montrouzieri* played a major role in the suppression of JMB on papaya. The reduction of the mealybugs was attributed mainly to the action of by all the three predators, particularly *C. montrouzieri* (Mani *et al.,* 2013a). No classical biological control attempt has been made for JMB and apparently it is kept under control by the local natural enemies in the invaded countries (Muniappan*et al.,* 2011). Hence there is no need for any panic for the new invasive *P. jackbeardsleyi* in India (Mani *et al.,* 2013a).

***4. Solenopsis mealybug- Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae)**

Phenacoccus solenopsis was probably introduced accidentally from North America into India in 2007.

4.1 Damage : It was found to cause severe economic damage in all nine major cotton growing states of India resulting in loss worth of US $16-20 million while reducing yields up to 50% in the affected fields in 2007 (Nagrare*et al,.*2009). *P. solenopsis* is the major mealybug species attacking sunflower particularly grown near cotton in India. Mealybugs cause typical symptoms of curling of leaves, stunted growth, deformation and death of plants, within 30 days of germination. At this stage, it could cause 100% crop loss. If incidence is at the reproductive stage of the crop, it affects flower buds and flowers leading to deformation of head without seed set. In some cases partial seed setting is also noticed with about 50% yield loss (Chandrashekar, 2011). It is found severe on sunflower in different parts of Karnataka, Andhra Pradesh, Maharasthra and Tamil Nadu. *P.s solenopsis* causes devastating damage on *Hibiscus* spp. (Mani, 2008). *P. solenopsis is also* known to infest groundnut, jute and tobacco. In Gujarat, *P. solenopsis* has been reported to be parasitized in okra, brinjal, tomato, sunflower, besides on *tomato* in North, Central and South zones in India (Mohindru *et al.,* 2009).

4.2 **Management of solenopsis mealybug**

Biological control

Six species of coccinellids i.e. *Scymnus coccivora* Ayyar, *Nephus regularis* Sicard, *Brumoides*

suturalis Fabricius, *Hippodamia variegate* Goeze, *Cheilomenes sexmaculata* Fabricius and *Coccinella septempunctata* L. were associated with *P. solenopsis in* and around Hisar, Haryana (Kedar*et al.,* 2011). In Tamil Nadu, the lycaenid predator *Spalgisepeus* was found associated with cotton mealybugs (Suganthi*et al.,* 2009). The Australian ladybird beetle *Cryptolaemus montrouzieri* was found to feed on colonies of *P. solenopsis*. *C. montrouzieri* having a remarkable predatory potential, can be used for suppressing population of mealybug *P. solenopsis* (Nagrare*et al.*, 2009). *Cryptolaemus montrouzieri* can also be used to control *P. solenopsis* on tobacco (Rao, 2009). *Cryptolaemus montrouzieri* gave excellent control of *P. solenopsis* on Hibiscus within four months of release in 2007 at Pune (Mani, 2008).The fungal pathogen *Lecanicillium* (*Verticillium*) *lecanii* was found to be pathogenic to *P. solenopsis* in Tamil Nadu (Banu *et al.,* 2009). Entomopathogenic nematode *Steinernema thermophilum* was known to cause 83% mortality of mealybugs within 72 h after inoculation at 50 IJ/ml and 100% within 48 h at 500 IJs/ml. (Kumar *et al.,* 2011). At MPKV, Rahuri, the treatment with *Metarhizium anisoplae* @ 2000 gm/ha was observed to be most effective by recording minimum of 87.46 mealy bugs/ 5 cm shoot tip length/plant as compared to 322.06 mealy bugs/5 cm shoot tip in untreated control. The higher seed cotton yield of 1521 kg/ha was obtained in a treatment with *M. anisopliae* @ 2000 gm/ha. As compared to 913 kg/ha in the untreated control (Kharbade *et al.,* 2009). *Aenasius arizonensis*is a potential encyrtid parasitoid which can be exploited in managing *P. solenopsis*. The encyrtid parasitoid *A. arizonensis* was recorded on *P. solenopsis* infesting cotton and other crops in India (Hayat, 2009). The parasitoid *A.* was able to keep *P. solenopsis* under check in Haryana ((Ram Pala *et al.,* 2009), Punjab (Dhawan *et al.,* 2011), Gujarat (Jhala *et al.,* 2009), Tamil Nadu (Amuthaet *al.,* 2009), Karnataka (Hanchinal *et al.,* 2009) and Andhra Pradesh (Saroja, 2009). Parasitism on *P. solenopsis* went up to 90% at many locations (Tanwar*et al.,* 2011). *A. arizonensis* was found parasitizing the *P. solenopsis* on hibiscus in Bangalore North. *A. arizonensis*is a potential biocontrol agent causing parasitism up to *30% of P. solenopsis on tomato in India* (Mohindru *et al.,*2009).The hymenopterous parasitoid, *A. arizonensis* was able to parasitise *P. solenopsis* up to 70-80% on okra (Sharma, 2007). In Gujarat, *A. arizonensis* was found on *P. solenopsis* up to 30 % parasitism on tobacco (Bhatt, 2010), and this is the most successful example of fortuitous biological control of *P. solani* in India (Ram Pala and Saini, 2010).

5. Cassava mealybug *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae)

Phenacoccus manihoti, the Neotropical species (South America) was accidentally introduced into Africa in the early 1970s, and it has become naturalized throughout sub-Saharan Africa (Matile-Ferrero, 1978). Damage includes destruction of terminal shoots and expanded leaves by sucking of sap (and possibly by the injection of a salivary toxin) leading to short internodes, small leaves and sometimes die-back. The economic damage is partly from the loss of fresh leaves (which are edible) and partly from loss in root yield. The yield loss went up to 50% (Schulthess *et al.,* 1991). In the absence of its natural enemies and other control measures, this damage can reduce yields by more than 80 per cent (Nwanze, 1982). *Phenacoccus manihoti* remains a threat to the cassava areas of southern Asia. *P. manihoti* was first detected in Thailand in 2008 (Winotai *et al.,* 2010). There was a drop of about 25% in tuber yield in 2010 and economic losses resulting from mealybug damage were expected to be 2.8 billion Baht. With

the appearance of the mealybug, the Department of Agriculture estimated losses of 40-50 per cent, adding up to more than US$150-200 million in crop damage in the first year alone. Further it was also detected at Vienam, Lao PDR, Cambodia, Myanmar, and threatens to engulf the cassava growing areas of southern China, Indonesia and Philippines (Muniappan et al., 2009. *P. manihoti remains a threat to the cassava areas of southern Asia. P. manihoti* was not known to occur in Asia until 2008, when it was first detected in Thailand. Since that year, it has spread aggressively throughout Thailand's cassava-growing region (Winotai *et al.,* 2010), also invading its neighbouring countries and Indonesia (Muniappan *et al.,* 2009), and raising significant concern over its potential arrival to more countries (Wu and Wang 2011). The introduction of the parasitoid *Apoanagyrus (=Epidinocarsis) lopezi* (De Santis) into Africa in 1980 reduced high infestations by 90%, becoming a highly successful case of classical biological control. *A. lopezi*is an efficient biological control agent across several ecological zones of the African cassava (Hammond and Neuenschwander, 1990.).The wasp has been effective in bringing the mealybug under control and reduces yield loss by 2.5 tons per hectare. The successful control of the cassava mealybug problems has raised cassava yields and turned cassava into a cash crop that is now spreading throughout Africa.

Incidence in India:

In India, infestation by this pest was first observed on around 2000 square meter experimental plot of cassava in Thrissur, Kerala (Joshi *et al.,* 2020). The mealybug was found to be surviving and breeding on three weeds *viz*., *Alternanthera sessilis*, *Synedrella nodiflora* and *Blumealacera* which may support the carryover of the pest during absence of cassava crop. Three predators *viz*., *Cardiastethus* sp. (Hemiptera: Anthocoridae), *Spalgisepeus* (Lepidoptera: Lycaenidae) and *Scymnuscoccivora* (Coleoptera: Coccinellidae) were found to be predating upon the mealybug (Joshi *et al.,* 2020).DNA Barcoding of invasive cassava mealybug during August 2020 and molecular identification using cytochrome oxidase I gene (CO-1) showed that the sequences were matching 100 % as *P.manihoti* with GenBank Acc. Nos. KY611349; KY611348; KY611347; KY611346 (deposited from China) and were confirmed as *P. manihoti* and Genbank Acc No: MT895817 was obtained for the first time in India. Severe infestation on cassava varieties Mulluvadi and Thailand white was found during 2020 in Edapaddi, Pethanaickenpalayam blocks of Salem District and Sendamangalam and Namagiripettai blocks of Namakkal District of Tamil Nadu. In the observed colonies, *Hyperaspis maindroni* was found actively predating on *P. manihoti* (Sreedevi *et al.*, 2020), whereas many species of *Homalotylus have earlier been reported from P. manihoti* (Noyes, 2020). Based on our observation, *H. turkmenicus* was the common parasitoid attacking *H. maindroni* in the colonies of *P. manihoti*from multiple locations in Tamil Nadu. When dissected, up to seven wasps were observed per mummified *H. maindroni* larva. The different associations found in the food webs of CMB are: *Aprostocetus* sp. (Eulophidae), *Homalotylus turkmenicus* Myartseva (Encyrtidae), *Metastenus concinnus* Walker (Pteromalidae) and *Chartocerus* sp. (Signiphoridae) parasitizing immature stages of *Hyperaspis maindroni* Sicard (Coleoptera: Coccinellidae); *Tetrastichus* sp. (Eulophidae) and *Brachycyrtus* sp. (Ichneumonidae) parasitic on *Mallada desjardinsi* (Navas) (Neuroptera: Chrysopidae) actively predating on CMB; *Antrocephalus japonicus* (Masi) (Chalcididae) parasitizing pupae of *Autobasilicula* (Swinhoe) (Erebidae); *Apanteles*

sp. (Braconidae), *Brachymeria nephantidis* Gahan (Chalcididae), *Bucekiadifferens* (Boucek) (Chalcididae), *Elasmusanticles* Walker (Elasmidae), *Eurytomasp.* (Eurytomidae), *Hockerianikolskayae* Husain and Agarwal (Chalcididae) and *Hockeria* sp., *Phanerotomasp.* (Braconidae) .The Lepidoptera species complex present in the CMB niche are: *Autobasilicula* (Swinhoe) (Erebidae), *Anatrachyntis sp.* (Walsingham) (Cosmopterigidae), *Conogethessp.* (Crambidae), *Lobesiasp.* (Tortricidae), Nola sp. (Nolidae), *Psuedohypatopasp.* (Blastobasidae), *Spalgisepius* (Westwood) (Lycaenidae), *Stathmopodasp.* (Oecophoridae) and indet Pyralidae out of which *S. epius* is found actively predating on CMB. The Neuroptera predators associated with CMB are: *Mallada desjardinsi* (Navas), *Pseudomallada astur* (Banks) and *Apertochrysa sp.* and among them *M. desjardinsi* is observed as the most predominant predator of CMB. The other miscellaneous species associated are: *Cheilomenes sexmaculata* Fabricius (Coccinellidae) and *Carpophilus mutilates* Erichson (Nitidulidae). *Acerophagus papayae* Noyes & Schauff (Encyrtidae) was heavily parasitizing *Paracoccus marginatus* Williams and Granara de Willink in the CMB niche. With no indigenous parasitoid currently for targeting this invasive pest, it was assessed that the long-term and indirect ecosystem risks will be significant until *Anagyruslopezi (*De Santis) (Encyrtidae) importation and further establishment is successful. Efforts are being made to tackle this pest with the exotic parasitoid *Apoanagyrus lopezi.* Import permits have been procured and waiting for the introduction of the parasitoid to India.

6. *Phenacoccus herreni* Cox & Williams (Hemiptera: Pseudococcidae)

*Phenacoccus herreni*is native of South America. It is known to attack the young shoots and causing rosetting, stunting and shoot and stem malformations resulting yield loss in cassava in South America (Bellotti, 1983). It is a future threat to cassava industry in India. The mealybugs are spread largely by wind and the movement of infested plant material. Mealybugdensities were highest in the dry season. Mealybug densities had declined sharply with the onset of rains. Three encyrtid parasitoids *Apoanagyrus diversicornis* (Howard), *Aenasius vexans* Kerrich and *Acerophagus coccois* Smith, are used to control the cassava mealybug *P. herreni* in South America. For efficient field application, it is suggested to release *A. vexans* and *A. coccois* late in the morning during the period of increasing activity (Driesche *et al.,* 1990). A multi-species *A. vexans* and *A. coccois* approach to biological control of *P herreni* may yield best results. If the mealy bug gets introduced into Asian Countries, the above parasitoids can be imported to suppress *P. herreni* in India.

7. Recent Quarantine interceptions of mealybugs of different crops

7.1 Citrus mealybug *Pseudococcus caleceolariae*

P. calceolariae is an endemic pest throughout most of Australia, and is perhaps the most serious pest of citrus in South Australia. These mealybugs are generally recognized as being difficult to control. Abutilon (Indian mallow), *Arachis hypogaea* (groundnut), Brassica, Chenopodium, *Citrus medica* (citron), *Daucus carota* (carrot), Dodonaea viscose, Eugenia are some of the hosts recorded for this species in other countries, it feeds on the phloem of plants, populations seldom reach sufficiently high levels to debilitate the plant, and the symptoms of attack are usually restricted to visual sighting of mealybugs or sooty mould. *P. calceolariae* has recently been shown to be a vector of the closterovirus

associated with grapevine leafroll disease,

7.2 Ginger mealybug: *Formicococcus polysperes* Williams (Hemiptera: Pseudococcidae)

This mealybug is also intercepted frequently in quarantine material. The mealybug *Formicococcus polysperes* Williams (Hemiptera: Pseudococcidae) is here reported for the first time attacking rhizomes ofginger-*Zingiber officinale* Roscoe (Zingiberaceae) in Meghalaya State of India. Plants infested by the sap-sucking nymphs and adults of this mealybug turned yellow within 1 to 2 weeks and then started drying from the tip downwards. Infested rhizomes shrivelled and eventually dried out. Fields and a nearby storage facility experienced up to 48% crop loss due to the infestation. In this paper we describe the plant damage and the morphological characteristics of *F. polysperes* from Meghalaya (Firke*et al.*, 2015)

7.3.The Sapota mealybug, *Exallomochlus philippinensis* Williams (Hemiptera :Psuedococcidae)

Exallomochlus philippinensis was intercepted from the samples of Rambutan (*Nephelium leppaceum*) is a major mealybug attacking Sapota and other crops of horticultural importance. The same was destroyed and the consignment was sent back avoiding possible losses to the tune of Rupees 3-4 crores.

Conclusions

Invasive mealybug pests of India, papaya mealybug *Paracoccus marginatus,* Madeira mealybug, *Phenacoccus madeirensis*, cassava mealybugs *Phenacoccus manihoti* and *Phenacoccus herreni*. The encyrtid parasitoid- *Acerophagus papaya* imported from Puerto Rico has given excellent control of *P. marginatus* infesting tapioca in peninsular India. *Phenacoccus manihoti*, the Neotropical species (South America), has spread fast in many Asian countries Thailand, Vietnam, Lao PDR, Cambodia and Myanmar. It is an immediate threat to cassava industry in India. *Phenacoccus herreni* is known to cause yield losses in cassava in its native South America, is a future threat to cassava in India. Three encyrtid parasitoids *Apoanagyrus diversicornis*, *Aenasiuvexans* and *Acerophagus coccois* are used to control the cassava mealybug *P. herreni*in South America. If the mealybug *P. herreni*gets introduced into India, the encyrtid parasitoids *Apoanagyrus diversicornis*, *Aenasiuvexans* and *Acerophagus coccois* can be imported to suppress *P herreni.* It is concluded that chemicals give temporary relief from the invasive mealybugs, and exotic and sometimes the local natural enemies give permanent control of the mealybugs particularly invasive mealybugs.

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