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Review Article

Tea Mosquito Bug (*Helopeltis* spp.): A Pest of Economically Important Fruit and Plantation Crops: Its Status and Management Prospects

Sankarganesh, E.[1*], Lavanya Sravani, B.[2], Rajeshwaran, B.[3] and Mounika, M.N.[2]

[1]*Plant Biosecurity Division, National Institute of Plant Health Management (NIPHM), Rajendranagar, Hyderabad, Telangana (500 030), India*

[2]*Dept. of Agricultural Entomology, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Mohanpur, West Bengal (741 252), India*

[3]*Dept. of Agricultural Entomology, Kerala Agricultural University (KAU), Vellayani, Kerala (695 522), India*

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Corresponding Author

Sankarganesh, E.

: e.sankar333@gmail.com

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Abstract

The tea mosquito bug (Hemiptera: Miridae) is the recognized pest of fruits and plantations across the world. In India, three species *viz. Helopeltis antonii*, *H. bradyi* and *H. theivora* are dominant among different species and found attacking a wide range of crops. Several alternate host plants of the tea mosquito bug have been recorded, especially in Africa and Asia. The nymphs and adults of the tea mosquito bug suck the sap from leaves, buds and shoots, which results in heavy crop losses. The pest is posing a serious challenge in domestic and overseas trades. For better management decisions, it is very much important to know about pest status, bionomics, distribution, host range, *etc*. The focus on the management of tea mosquito bug has to emphasize from chemical to traditional, indigenous technical knowledge and integrated pest management using the accessible resources to reduce the resistance development and limit the residual effects. This review highlights the significant works conducted on tea mosquito bug with detailed management strategies. The information on current status, host preference, incidence and early detection of this pest are discussed.

Keywords: *Helopeltis*, Host range, Integrated pest management, Oriental region, Tea mosquito bug

Introduction

From the agricultural viewpoint, mirid bugs are considered an important insect group. Hemipterans occupying the position of fifth-largest insect group in the world and nearly 6,500 species belonging to 92 families have been discovered from India (Jana *et al.*, 2014). It is one of the most important orders of exopterygota insects, comprising all types of bugs (Ghosh, 2008). Insects are the most potent and significant pests of crops and plantations, causing enormous crop losses. In recent years, the pest problems in agriculture have increased manifolds were hemipterans are of great importance as most of them are pests of various commercial crops (Chandra *et al.*, 2012). Out of the described species, more than 160 are found to be effective pests in India. The plant bugs of the genus *Helopeltis* are the serious pests of various cultivated plants in the World (Stonedahl, 1991), and also an important pest of plantation and fruit crops in India. The damaging nature of these insects on tea plantations in India was documented over a century ago (Peal, 1873; Stonedahl, 1991; Wood-Mason, 1884).

Mirids are the most successful heteropteran insects not only in numbers of species and abundance of individuals but also in their range, which extends to all zoogeographic regions (Schuh, 1995). Tea Mosquito Bug (TMB) (*Helopeltis* spp.) has palaeotropical dispersion connecting from Northern Australia and West Africa to New Guinea. Meanwhile, various alternate host plants of the TMB have been recorded, especially in African and Asian continents (Roy *et al.*, 2015). Considering the importance in terms of pest status across

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the globe and expanding host range of TMB needs special attention.

Taxonomy

Miridae comprises of insects with a more or less soft integument but with most variable structural characters. *Helopeltis* spp. is promptly recognized from other members of the group by the elongate cylindrical body and large spine-like process on the scutellum. Eggs are having respiratory horns and the nymphs are brown colour which resembles spiderlings due to their long appendages. The detailed taxonomic studies on *Helopeltis* spp. was done by (Stonedhal, 1991). Many species of oriental *Helopeltis* spp. are very similar in appearance and general structures (Rebijith *et al.*, 2012b). The accurate identification is possible only by examining the genital structures or shape of the lobal sclerite of the male vesicles (Rebijith *et al.*, 2012a). To resolve these researchers have studied the molecular identification and diversity characterization of *Helopeltis* bugs using the mitochondrial DNA sequence (Asokan *et al.*, 2012).

Bionomics

The preference of oviposition, fecundity and life cycle of the pests varied with hosts and the host plant resistance (Devasahayam and Nair, 1986). Female TMB lays elongate sausage-shaped eggs (1.0 to 1.31 mm long) practically in all tender parts of the plant singly or in small groups (Ambika and Abraham, 1979). The incubation period of TMB varies depending on locality, season and host plant, but generally in the range of 6 to 11 days (Stonedahl, 1991). The freshly hatching nymphs resemble spidery in appearance due to their elongate appendages. TMB has the hemimetabolous type of metamorphosis and rather has five nymphal instars that vary in size, colour and development of body parts (Saroj *et al.*, 2016), which depend on climatic factors (temperature and humidity) and rate of quality food (Betrem, 1950; Sundararaju and John, 1992). On cocoa and guava, the nymphs develop more rapidly than on tea (Jeevaratnam and Rajapakse, 1981). The nymphal life span ranges from 9-25 days (Sundararaju, 1996). Adult mean longevity ranges from 7-46 days. The comprehensive information on the biology of *Helopeltis* spp. in different host crops was done by Roy *et al*. (2015).

Geographic Distribution

The TMB, *Helopeltis* spp. are most predominant in the old-world tropic countries (CABI, 1992). The first-ever report of TMB was dated back in 1847 in Java (Rao, 1970) and later the first descriptions of species *H. antonii*, *H. bradyi*, *H. theivora* were given by Signoret in 1858 from Sri Lanka, Waterhouse in 1886 from Malaya and Assam, respectively. Among, 41 recognized species of *Helopeltis*, 26 are confined to Africa and 15 were distributed in the Australasian region (Rebijith *et al.*, 2012b; Stonedahl, 1991; Sundararaju and Sundarababu, 1999). The species which inflict major economic losses to the crops growing in the Oriental and Australian regions are *Helopeltis antonii* Signoret, *H. bradyi* Waterhouse, *H. bakeri* Poppius, *H. cinchonae* Mann, *H. clavifer* Walker, *H. pernicialis* (Stonedahl *et al.*, 1995) and *H. theivora* Waterhouse (Srikumar *et al.*, 2015; Stonedahl, 1991; Stonedahl *et al.*, 1995). The species *H. antonii* is only confined to South and East India, Sri Lanka, Indonesia and the Andaman Islands (Saroj and Swamy, 2017); whereas, *H. bradyi* is restricted to South India, Sri Lanka, Indonesia and Malaysia (Saroj and Swamy, 2017; Sundararaju, 1996) and *H. theivora* predominantly in South East Asia, Sri Lanka and India (Saroj and Swamy, 2017), especially South and North-Eastern parts which attained significant importance (Debnath and Rudrapal, 2011). The species *viz.*, *H. antonii, H. bradyi* and *H. theivora* are predominant and cause serious economic damage to several crops in our country (Saroj *et al.*, 2016; Sundararaju and Bakthavatsalam, 1994) along with *Pachypeltis maesarum* Kirkaldy in a minor proposition (Bhat and Srikumar, 2012). Among these, TMB species *H. theivora* is the most predominant in India, while *H. bradyi* is restricted to Peninsular India (Sivakumar and Yeshwanth, 2019; Sundararaju and Sundarababu, 1999).

Previous studies have identified the importance of this group and the severity of *H. bradyi* infestation is observed in cashew plantations of Puttur, Karnataka region (Srikumar and Bhat, 2013; Srikumar *et al.*, 2015), *H. theivora* in Vandiperiyar and Peerumedu in Kerala regions and recently had spread in an alarming form in tea plantations of Anamala and Valparai hills (Tamil Nadu). In Sikkim, the infestation of TMB, *Helopeltis theivora* (Waterhouse) has been recorded for the first time in red cherry pepper (Kalita *et al.*, 2010). Also, the survey by Srikumar *et al.* (2015) along the coastal regions of 11 major states of India documented *H. antonii* predominates amongst the rest of the species occurring in the cashew ecosystem of India with the new records in the states of Gujarat, Chhattisgarh and Odisha. Besides, the species *H. bradyi* reported for the first time on the high altitude Tura region of Meghalaya (Saroj *et al.*, 2016), which is earlier restricted to southern parts of our country.

Host Range

Since the late 1800s, numerous species of plants have been reported as hosts for *Helopeltis* spp. including several cash crops such as black pepper (*Piper nigrum*), cashew *(Anacardium occidentale)*, cinchona (*Cinchona* spp.), cocoa (*Theobroma cocoa*) and tea (*Camellia sinensis*) (Srikumar *et al.*, 2015; Stonedhal *et al.*, 1995). Within 20 years of Peal's (1873) prediction, TMB would become a significant pest and started to cause 'enormous' damage which attributes to quality and quantity deterioration (Bamber, 1893) to Indian tea culture and cashew with a crop loss of 30% to 40% (Devasahayam and Nair, 1986). Meanwhile, it is reported as one of the most destructive polyphagous sucking pests of tea in the North-Eastern states of India in the past as well as in recent times (Kalita *et al.*, 2018; Saroj *et al.*, 2016). Comprehensive reviews (Roy *et al.*, 2015; Saroj *et al.*, 2016; Stonedahl, 1991) suggested that the different species of *Helopeltis* pose threat to more than 100 plant species belonging to different families. From the economic perspective, cashew, cinchona, cocoa and tea are being considered as primary hosts (Saroj *et al.*, 2016). Although, the study on TMB revealed that every year the host range of this pest is expanding on a wider range and documented from all over the country including alternate weed hosts (Roy *et al.*, 2015; Srikumar *et al*., 2015). At present, the pest expands its damage to vegetable crops like eggplant, *Solanum melongena* in Southern parts of India (Sivakumar and Yeswanth, 2019) and chilli, *Capsicum annum* in the North-Eastern region (Firake *et al*., 2020; Kalita *et al.*, 2018).

The highly polyphagous behavior of TMB enables them to switch over to several non-crop hosts in the vicinity of major crops when the availability of preferred hosts is scanty, also to avoid the effect of synthetic insecticide on their major host (Das and Mukhopadhyay, 2014). The lists of host and non-host plants of major TMB species are presented in table 1. Apart from conferring temporary shelter during the lean period of major crops, the alternate host giving additional benefits to the TMB by increasing their xenobiotic detoxifying enzymes (Saroj *et al.*, 2016). The General Esterases (GEs), Glutathione S Transferases (GSTs) and the Cytochrome P450 Monooxygenases (CYPs) activity (Prasad and Roy, 2017; Saha *et al.*, 2012) acting against the plant allelochemicals certainly paves the way for the development of cross-resistance against synthetic insecticides (Li *et al.*, 2000) and may pose an additional problem during pest management (Saroj *et al.*, 2016).

Feeding Damage

Initial damage symptom of *Helopeltis* spp. was identified in Indonesia on cocoa in 1841 (Giesberger, 1983) and during 1847 rosette symptom in tea (Shaw, 1928). The nymphs and adults of TMB suck the sap from young buds, tender stems, leaves of the crops through labial stylets. *H. antonii* has a specific sucking character. Initially, the nymphs and adults tap the plant surface, later insert the stylet. Nymphs often cause heavier damage than adults and a single grown nymph or adult can produce 100 spots in a day. The typical feeding damage appears as a discoloured necrotic area or lesion around the point of entry of the labial stylets into the plant tissue (Devasahayam and Nair, 1986). The lesion is elongate or spherical and becomes darker with age as the tissue around the stylet puncture dries up, in response to the enzymatic action (various oxidoreductase enzymes) of TMB salivation (Saroj *et al.*, 2016). The lesions that appeared on the feeding sites is due to the pectinase present in the saliva of *Helopeltis* spp. The adults preferred to feed on tender leaves and damage the foliages of the plants and exhibits corky outgrowth in some fruits. The damage of TMB is also associated with the insertion of eggs into plant tissues during oviposition. In the advanced stage of the attack, complete damage and withering of the leaves will happen and crop losses may reach up to 50% (Sivakumar and Yeswanth, 2019).

Seasonal Incidence

The *Helopeltis* species are mostly found to occur in the continuous cycle of generations throughout the year (Saroj *et al.*, 2016; Sundararaju and Sundarababu, 1999). *H. theivora* attacks or causes damage to tea plants all around the year, but the incidence is most severe from May to

Table 1: List of host plants of major *Helopeltis* species

Host plant species	References
Helopeltis theivora	
Acalypha indica L.	Das, 1965
Acalypha wilkesiana J.W. Moore	Srikumar *et al*., 2016
Amaranthus sp. L.	Sivakumar and Yeshwanth, 2019
Anacardium occidentale L.	Rao, 1970
Annona squamosa L.	Srikumar *et al*., 2016
Artocarpus heterophyllus Lam.	Rao, 1970
Azadirachta indica A. Juss.	Sundararaju and Sundarababu, 1999
Bidens pilosa L.	Rao, 1970
Camellia sinensis (L.) Kuntze	Mann, 1902
Cannabis sativa	Tocklai, 2010
Chromolaena odorata L.	Srikumar and Bhat, 2013
Cinchona pubescens Vahl	Anstead and Ballard, 1922
Cinnamomum camphora L.	Rao, 1970
Clidemia hirta (L.) D. Don	Srikumar *et al*., 2016
Coffea arabica L.	Rao, 1970
Cordia dichtoma G. Forst.	Tocklai, 2010
Cyclea peltate (Lam.) Hook. f. & Thomson	Srikumar *et al*., 2016
Dioscorea sp.	Srikumar *et al*., 2016
Duranta repens L.	Prasad and Roy, 2017
Erythrina sp.	Rao, 1970
Eurya acuminate DC.	Das, 1984
Ficus benjamina L.	Gogoi *et al*., 2012
Gardenia jasminoides Ellis	Kalita *et al*., 2000
Getonia floribunda Roxb. (Lamk.)	Vanitha *et al*., 2014
Hibiscus sp.	Tocklai, 2010
Ixora coccinea	Gogoi *et al*., 2012
Jasminum scandens Vahl.	Das, 1984
Lantana camera L.	Vanitha *et al*., 2014
Ludwigia peruviana (L.) Hara	Srikumar *et al*., 2016
Macaranga peltata (Roxb.) Mueller	Vanitha *et al*., 2014
Maesa ramentacea Roxburgh.	Das, 1984
Malvavicus penduliflorus DC.	Srikumar *et al*., 2016
Mangifera indica L.	Rao, 1970
Melastoma malabathricum L.	Das, 1984
Melia azadirachta L.	Rao, 1970
Merremia vitifolia (Burm. F.) Hallier F.	Vanitha *et al*., 2014

Table 1: Continue...

Host plant species	References
Mikania micrantha	Saha *et al.*, 2012
Morus sp.	Tocklai, 2010
Mussaenda frondosa L.	Anstead and Ballard, 1922
Neolamarckia cadamba Roxb.	Tocklai, 2010
Ochlandra travancorica Benth.	Anstead and Ballard, 1922
Oxalis acetosella L	Tocklai, 2010
Passiflora sp.	Rao, 1970
Persea bombycina King ex Hook.f.	Tocklai, 2010
Pentas lanceolate (Forssk.) Deflers	Srikumar *et al.*, 2016
Phlogacanthus thrysiflora Nees	Somchoudhury *et al.*, 1993
Piper sp.	Tocklai, 2010
Plectranthus amboinicus (Lour.) Spreng	Srikumar *et al.*, 2016
Psidium guajava L.	Anstead and Ballard, 1922
Sida cordifolia L.	Tocklai, 2010
Similax sp.	Somchoudhury *et al.*, 1993
Solanum melongena L.	Sivakumar and Yeshwanth, 2019
Solanum torvum Sw.	Srikumar *et al.*, 2016
Strychnos nux-vomica L.	Vanitha *et al.*, 2014
Syzygium cumini L.	Tocklai, 2010
Tephrosis sp.	Rao, 1970
Theobroma cacao L.	Rao, 1970
Helopeltis antonii	
Ailanthus excelsa Roxb.	Satapathy, 1993
Anacardium occidentale L.	Puttarudriah, 1952
Annona spp.	Rami, 2009
Azadirachta indica A. Juss.	Sundararaju and Sundarababu, 1999
Bixa orellana L.	Fletcher, 1914
Cinchona pubescens L.	Fletcher, 1914
Emblica officinalis L.	Sundararaju, 1996
Gossypium barbadense L.	Sundararaju, 1996
Gossypium hirsutum L.	Sundararaju, 1996
Gossypium L.	Puttarudriah, 1958

Host plant species	References
Lactuca runcinata DC	Sundararaju, 1996
Lawsonia alba Lam.	Sundararaju, 1984
Leea sp.	Vanitha *et al.*, 2014
Malus domestica Borkh.	Puttarudriah and Appanna, 1955
Mangifera indica L.	Devasahayam and Nair, 1986
Melia azedarach	Fletcher, 1914
Moringa oleifera Lam.	Pillai *et al.*, 1979
Muntingia calabura L.	Sundararaju *et al.*, 2002
Persea americana Mill.	Puttarudriah, 1952
Piper nigrum L.	Devasahayam and Nair, 1986
Psidium guajava L.	Ayyar, 1940
Swietenia mahagoni (L.) Jacq.	Fletcher, 1914
Syzygium jambos (L.) Alston	Devasahayam and Nair, 1986
Terminalia paniculata Roth	Vanitha *et al.*, 2014
Theobroma cacao	Abraham and Remamony, 1979
Thespesia populnea L.	Sundararaju and Baktavatsalam, 1994
Vigna unguiculata (L.) Walp.	Sundararaju, 1996
Vitis vinifera L.	Puttarudriah and Appanna, 1955
Zizyphus mauritiana Lam.	Sundararaju, 1996
Helopeltis bradyi	
Acacia mangium Willd.	Hamid, 1987
Anacardium occidentale L.	Sundararaju, 1996
Camellia sinensis (L.) Kuntze	Miller, 1941
Capsicum sp.	Lever, 1949
Cephaelis angustifolia Ridl.	Miller, 1941
Chromolaena odorata L.	Vanitha *et al.*, 2014
Cinchona pubescens Vahl	Miller, 1941
Citrus sp.	Lever, 1949
Coffea arabica L.	Hamid, 1987
Dioscorea sp.	Miller, 1941
Eucalyptus saligna Sm.	Lever, 1949
Oxalis sp.	Miller, 1941
Palaquium gutta Hook.	Lever, 1949
Theobroma cacao L.	De Silva, 1957

September in India (Chakraborty and Chakraborty, 2005; Saroj *et al.*, 2016). The past studies are indicating that TMB species populations fluctuate in response to more localized and less regular climatic events (Betrem, 1950; Pillai *et al.*, 1976; Saroj *et al.*, 2016). The damage caused by *H. bradyi* on tea in the Cameron Highlands of Malaysia was most severe during periods of dull, calm and misty weather (Lever, 1949; Srikumar *et al.*, 2015). The late evening hours and the congenial climate may favor the attack on other hosts apart from the regular hosts (Firake *et al.*, 2020).

Management Options

In India, the management of TMB is mostly based on chemical insecticides. Because of the overuse of synthetic insecticides, there were reports of resistance and residue problems. It was a well-known Kasaragod incident in Kerala, where endosulfan was extensively used for the management of TMB, which leads to long-term health problems of the residents in those regions. Because of which, during 2011, endosulfan chemical has been banned for use in India. The management programmes should be appropriate and effective in managing the pest species, at the same time it should not cause any detrimental effects to the non-target organisms and environment. At present, the focus on the management of TMB has been emphasized from chemical to traditional, Indigenous Technical Knowledge (ITK) and Integrated Pest Management (IPM) (Saroj *et al.*, 2016).

A pest management strategy is a total approach to eliminate or reduce the pest problem. There are four types of strategies of pest management based on pest characteristics and economics of management (Gray *et al.*, 2009), *viz*. (i) do nothing, (ii) reduce pest numbers, (iii) reduce host susceptibility to pest injury, and (iv) combine reduced pest populations with reduced host susceptibility. Reliance on a single management tactic is prone to the risk of failure. Integration of various eco-friendly management techniques such as cultural, mechanical, physical, host plant resistance, biological control with the judicious chemical application may aid in managing the pest effectively (Roy *et al.*, 2015). With the multifaceted approach, if one tactic fails, then the other one operates to modulate the losses (Gray *et al.*, 2009). Monitoring, early detection and timely action are the main steps for achieving success in the management of TMB.

Monitoring and Early Detection

Soon the habitat and bio-ecology of these bugs are understood, hassle-free monitoring could be done. A temperature within 20-27 °C and high humidity play a major role in the higher population buildup. Damage caused by *H. theivora* populations in the sub-Himalayan North Bengal tea plantations is found to have an association with seasonal life cycles (Roy *et al.*, 2015). Low damaging small populations were observed from January to May, medium populations with moderate damage from June to August and peak populations with serious damage from September to November months. During cloudy days, TMB is usually found on the topmost branches in the bushes. However, the pest moves down the stems or falls on the ground quickly when disturbed (Roy *et al.*, 2015).

Bio-ecology studies on TMB indicated that the pest oviposits in the new flush growth and also prefers moisture and humid conditions, which are mostly available in the shaded areas of the estates. Monitoring during the new flush for the presence of insect damage at the shaded sites based on seasons in the estates helps in the early detection of the pest. Considering the pest's population cycles, the planters should continuously monitor the pest even after the application of pesticides in the peak population seasons.

Cultural Tactics

To eradicate inserted eggs and early instar nymphs of TMB species, there is a necessity of a regular plucking schedule. This practice is very much useful for reducing the egg load and early nymphal instar populations from the frequent infestation sites. In case of severe infestation, hard plucking, black plucking and level off skiff operations were found to be effective as they deny the food source available to the bug (Roy *et al.*, 2010a; Roy *et al.*, 2015) and minimizes the infestation level for next-generation (Roy and Mukhopadhyay, 2011). Pruning is another best alternative solution for managing TMB, which helps in reducing the population level, further buildup and spread. Besides, pruning also offers an advantage in opening up the tree canopy for more aeration and light penetration that creates unfavorable conditions for the population buildup. The studies showed that the tea plantations with 60% shade were found to have the least pest attack and better crop yield (Roy *et al.*, 2015).

Maintaining the plantation crops free from alternate hosts *viz*., Jackfruit (*Artocarpus heterophyllus*), Melastoma (*Melastoma* sp.), Dayflower (*Commelina* spp.), Sesbania (*Sesbania cannabina*), Fragrant thoroughwort (*Eupatorium odoratum*), Mulberry (*Morus alba*), Wood-sorrel (*Oxalis acetosello*), Kadam (*Anthocephalus cadamba*), Oak (*Quercus* spp.), Jamun (*Eugenia jambolana*), Boal (*Ehretia acuminata*), Mikania (*Mikania micrantha*), Golden shower (*Acacia moniliformis)* and Arani (*Premna latifolia*) restricts population buildup. The non-economic plants or weeds with damage symptoms of TMB may serve as a population build of the particular species which has to remove from the premises of the main crop. Apart from this, the potassium salts in the soil act as a repellent for this insect (Ballard, 1921). The study on the relationship between TMB and soil type revealed that high potash in the soil considerably affected the insect population (Roy *et al.*, 2015). It was also found that fields that recorded a low ratio of available potash to available phosphorus were vulnerable to being attacked by TMB (Andrews, 1923; Roy *et al.*, 2015). Besides, the validation of the 'Push and Pull' strategy is one of the novel options in TMB control (Srikumar *et al.*, 2016).

Mechanical Control

During the initial population buildup, handpicking and destroying the adults is the best solution to prevent further population buildup. Early morning (6:30-8:30) or late evening (16:00-18:00) hours appear to be the best time for monitoring and handpicking of adult bugs (Roy *et al.*, 2015). The experiment on trapping TMB in a dark room with five colours of LED *viz*., red, yellow, white, blue and UV light in a wind tunnel was performed in China to know about the efficacy. The LED light in the following order: UV > Blue > Red > Yellow > White was efficient in trapping capability. But the synchronization of the dark environment with active periods of the TMB is a challenging task, and sometimes sole field trapping may not function well (Chiu, 2012). However, it may have advantages in some areas during the winter months as the light fades earlier, creating the congenital condition for this practice.

Physical Control

The ultrasound is one of the physical options which induce considerable stresses leading to initial hyper feeding followed by reduced feeding, oviposition and longevity. The early mortality of larval instars of TMB was observed when exposed to an ultrasound of 20 kHz frequency for 15, 30 and 45 min day^{-1} (Borthakur *et al.*, 2011). The ultrasound-based control may serve as a potential weapon against this pest in the IPM programme. A phenomenal work has been made in pheromonal research with the use of pheromone bait for control of TMB which attracted 100 to 500 males day^{-1}. The mass trapping reduces the insect population and reduced infestation as well (Radhakrishnan and Srikumar, 2015). This technique is environmentally safe, cost-effective and highly efficient in trapping the adult males of TMB.

Indigenous Traditional Knowledge

Generally, the Indigenous Traditional Knowledge **(**ITK) is based on the cultural values of the community (Ramaiah and Raju, 2004) which are safer as well as compatible with IPM practices. For example, in India, the small tea growers of Assam have developed their ITKs for the management of pests especially TMB (*Helopeltis theivora*) from the locally available plant or animal ingredients (Bhuyan *et al.*, 2017). Also, farmers in China witnessed sunflower seed oil when mixed with soapberry solution suppressed oviposition by TMB which was later developed as ITK thereafter (Lin, 2016).

Biorational Pesticides

Neem provides multifaceted biological activity, providing successful management for many pests. Moreover, neem-based pesticides offer a viable alternative to chemical pesticides, in terms of raw material availability, low production cost and eco-friendly nature (Dutta *et al.*, 2013; Saroj *et al.*, 2016). The different concentrations of azadirachtin had different levels of pest control, making azadirachtin concentration an important determining factor for its bioactivity against pests (Roy *et al.*, 2010a; Saroj *et al.*, 2016). Aqueous extract of neem seed kernel of 5% concentration tested against F_1 population of *Helopeltis* spp. in the laboratory showed superior antifeedent activity, hatching percent, oviposition period and nymphal duration (Dutta *et al*., 2013; Saroj *et al.*, 2016).

The chloroform extracts of *Clerodendron inerme* and *Polygonum orientale* have recorded the highest antifeedant and repellency activity against the first instar of TMB (Deka *et al.*, 2019). Toxicity studies on four concentrations of aqueous extract of *Clerodendrum viscosum* Ventenat (Verbenaceae) under field conditions showed 73-86% significance in TMB management, which was comparable to that of synthetic and neem pesticides. Moreover, the tea samples were taint free, which is an important aspect considered for tea quality in export (Roy *et al.*, 2010b). The neem-based biopesticides, *i.e.*, foliar application of azadirachtin 10,000 ppm @ 1 ml L^{-1} or NSKE 5% was effective in managing TMB infesting *Ailanthus excelsa* (Manimaran *et al.*, 2019). The recent study on the novel strain of *Beauveria bassiana* (BPA/B7) having spore density of 1.68×10^{6} spores ml^{-1} (from Tinsukia soils of Assam) showed LC_{50} of 21.87 ml L^{-1} within 96 hrs against TMB (Ekka *et al*., 2019).

Selective pest management is a key source under consideration in recent times and chitin metabolism is assumed as an excellent target (Shternshis, 2005). Chitin is the major component of the insect exoskeleton and inner linings of the fore and hindgut. Chitinase based biopesticides affect insect digestion, inhibit growth and development leading to the death of the insect. Moreover, chitinase based biopesticides act as both contact and systemic poison on insects (Broadway *et al.*, 1998) with action on the hydrolysis of chitin. It is considered an opening avenue for new strategies in pest management (Suganthi *et al.*, 2016) which is applicable for controlling this devasting insect pest.

Biocontrol Agents

In most instances, the natural enemies playing an important role in pest control. The *Helopeltis* spp. were attacked by several natural enemies *viz.* numerous parasitoids, praying mantids (Vanitha *et al*., 2016); neuropterans like *Mallada* (Borah *et al.*, 2012); reduvids like *Rihirbus trochantericus* (Bhat *et al.*, 2013); spiders and syrphids (Muraleedharan *et al.*, 2001). Also, the green tree ant, *Oecophylla smaragdina* had high potential as a biocontrol agent against TMB (Sreekumar *et al.*, 2011). An extensive study in the sub-Himalayan tea ecosystems of West Bengal on the predator population showed that rich diversity of predators (Das *et al.*, 2010) especially spider population (43%) was found to be high. The spider *Oxyopes* spp. was recorded as a natural enemy of TMB from different agro-ecosystems (Das *et al*., 2010; Devasahayam and Nair, 1986; Sivakumar and Yashwanth, 2019). These predators may aid in the natural control of this pest and may consider as one of the important components in the IPM strategy.

The eggs of the tea mosquito bug are deep and concealed. A variety of hymenopteran parasitoids often attack these eggs (Sundararaju and Sundarababu, 2000) which include *Telenomus floridanus*, *T. nigrocoxalis*, *T. phymatae* and *T. podisi*; and the species *T. laricis* is specialist egg parasitoid of mirid bugs (Johnson, 1984; Saroj *et al.*, 2016). Similarly, the species *T. cuspis* is the potential egg parasitoid of TMB which had a solitary behavior and 28% parasitism capability during June and July (Rajmohana *et al.*, 2013; Saroj *et al.*, 2016). Apart from the genus *Telenomus*, *Chaetostricha* sp. (Trichogrammatidae) was reported as an egg parasitoid of TMB (Bhat and Srikumar, 2013; Saroj *et al.*, 2016). Insect pathogens like *Aspergillus* sp., *Beauveria bassiana* can also effectively use against *Helopeltis* spp. (Visalakshy and Mani, 2011). There is a huge diversity of natural enemies for TMB in different crop ecosystems. Therefore, conservation and preservation of the natural enemies in the orchards and plantations are the prerequisites that ultimately help in minimizing the chemical load.

Host Plant Resistance

Varieties which show pest resistance play a major role in IPM strategy as they reduce the efforts of pest management.

Especially the cashew varieties displayed wide variations in response to TMB infestation. The varieties which can withstand TMB infestation are grouped as less susceptible varieties (Ambika *et al.*, 1979). The biochemical changes among different cashew varieties have significant variation with the infestation. The defensive compound such as tannin, phenols and the defensive enzymes like polyphenol oxidase and phenylalanine lyase was found associated with less susceptible cashew varieties (Nimisha *et al.*, 2019).

Chemical Approach

The use of chemicals is the final solution when the pest population reaches a drastic rate. Initially, DDT proved to be the most effective pesticide for pest reduction from large populations to small local populations as sprays and dusts in 1948 (Rau, 1949). Later, the ban of DDT, three major classes of pesticides *i.e.* organophosphates, synthetic pyrethroids and neonicotinoids have been registered as foliar sprays against TMB (Anonymous, 2017). Bifenthrin 8.0% SC @ 40 a.i. ha^{-1}, Clothianidin 50% WDG @ 60 a.i. ha^{-1}, thiacloprid 21.70% SC @ 90 a.i. ha^{-1}, Thiamethoxam 25% WG @ 25 a.i. ha^{-1}, Thiamethoxam 12.6% + Lambda-cyhalothrin 9.5% ZC @ 33 a.i. ha^{-1} are the recently approved chemicals by CIB&RC for effective pest management of TMB population. When the TMB population exceeds 10% to the terminal shoot, as a last resort, foliar application of thiacloprid 240 SC @ 1.5 ml L^{-1} or Prophenophos 50 EC @ 2 ml L^{-1} is highly effective for the management of TMB, especially in *Ailanthus excelsa* (Manimaran *et al.*, 2019). However, the time of spraying should coincide with the surfacing of the insect for better control.

Following recommended doses and avoiding sub and supra-lethal doses during the spraying would help in preventing susceptibility change in pest populations. The sublethal doses of chemicals were found to be a kind of behavioural resistance, *i.e.*, oviposition preference in insecticide stress induced adults was changed. They laid eggs in the nonpluckable portion of tea shoots to protect the eggs from insecticide exposure (Roy *et al.*, 2008). The sex-based variation study of insecticide tolerance and susceptibility of TMB found that female has a higher chance of survivability when the recommended dose of pesticide is applied which in turn leads to higher insecticide tolerant population (Roy and Prasad, 2018). Moreover, 1.5-82.9 folds reduced susceptibility in the TMB test population when they compared the LC_{50} values of effective field dosages with recommended dosages of commonly used insecticides (Roy *et al.*, 2008). Therefore, the quality, dosage and application should be kept in mind for effective pest control and judicious application of pesticides to prevent environmental risks.

Conclusion

It is always important to focus on reliable management practices against the pest by adopting valid IPM strategies to combat the risk. Integration of multiple pest suppression techniques and improved research in non-chemical methods with use of tolerant varieties, sex pheromones, conservation of natural enemies, biotechnological approaches have better scope in managing TMB population and have high probability for sustaining the long-term crop protection.

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