Indian Journal of Agricultural Sciences **86** (2): 151–62, February 2016/Review Article
https://doi.org/10.56093/ijas.v86i2.55868

Research Review Article

Tea mosquito bug (*Helopeltis* spp.) – A devastating pest of cashew plantations in India: A review

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Received: 1 July 2015; Accepted: 29 December 2015

ABSTRACT

More than 32 countries are growing cashew in the world, wherein India occupies largest area under cashew plantations (20%) and earning foreign exchange of over 5 000 crores per annum through export of cashew kernels and cashew nut shell liquid. Often, there is a serious loss in cashew nut yield due to attack of tea mosquito bug (*Helopeltis* spp., Heteroptera: Miridae) which is a major sucking pest of cashew plantations in India. Under severe out break conditions, yield losses are as high as 40-50%. There are three common species of *Helopeltis,* viz. *H. antonii* Signoret, *H. bradyi* Waterhouse and *H. theivora* Waterhouse found in west coast and *H. antonii* is most predominant in the east coast, though in east coast its occurrence is prevalent from Tamil Nadu to Odisha. Whereas, *H. theivora* is predominant species in north-east region. Besides cashew, a large number of host plants like, tea, guava, cocoa, neem, cinchona etc. are reported. The seasonality study suggested that the population of tea mosquito bug reaches its peak during the flushing, flowering and fruiting season in cashew, i.e. from November to February. As a management strategy, varietal screening suggested that no cashew varieties are resistant to tea mosquito bug infestation but Dhana and Bhaskara varieties are moderately susceptible. Therefore, even today only chemical means of tea mosquito bug management is adopted under commercial cashew plantation. As a biological control strategy, the solitary egg parasitoids, viz. *Telenomus cuspis*, *Chaetostricha* sp. and *Erythmelus helopeltidis* Gahan were specifically promising against *Helopeltis*. The adult parasitoid, *Leiophron* sp. is additional asset for natural control strategies of *Helopeltis* spp. on cashew. Recent researches have incorporated 117 species of spiders and 18 species of reduviids into cashew management strategies. Laboratory mass culture techniques of reduviids have also been standardized using wax moth larvae as prey. Adults of *H. antonii* and *H. theivora* were found to be infested by predatory mite, *Leptus* sp. attached ecdysial line from head and thorax. Moreover, sex pheromone based technology development is the need of the hour to manage this pest. In this paper, efforts have been made to review the literature pertaining to the pest taxonomy, biology, distribution, host plants, nature of damage, seasonality and management strategy of *Helopeltis* spp. focusing on Indian subcontinent, so as to bring out non-chemical based management strategies.

Key words: Biology, Cashew, Host range, Management, Reduviids, Taxonomy, Tea mosquito bug

In India, cashew (*Anacardium occidentale* L.) is grown on 10.27 million ha area with annual production of 7.25 lakh tonnes (2014-15). Sometimes cashew production is drastically affected by Tea Mosquito Bug (TMB) (*Helopeltis* spp.) which is one of the major pests of cashew, cocoa (*Theobroma cocoa* L.), neem (*Azadirachta indica* A. Juss.), cinchona (*Cinchona* spp.), black pepper (*Piper nigrum* L.), guava (*Psidium guajava* L.) and tea (*Camellia sinensis* L.). Both nymphs and adults feed by sucking the plant parts injecting poly-phenoloxydase from their salivary glands (Mandal 2000). Typical feeding damage by *Helopeltis* spp. appears as a discolored necrotic area or a lesion around the point of entry of the labial stylets inside the plant tissue. The infestation of inflorescence results in to "blossom blight" (Devasahayam and Nair 1986). Sometimes, complete scorching of cashew foliage is seen as depicted in Fig 1.

In India, three species of TMB, viz. *Helopeltis antonii* Signoret, *Helopeltis bradyi* Waterhouse and *Helopeltis theivora* Waterhouse were recorded (De Silva 1957, Stonedahl 1991, Sundararaju 1996). Among them, *H. antonii* is the dominant species (Sundararaju and Bakthavatsalam 1994, Sundararaju 1996). Many species of Oriental *Helopeltis* are very similar and several of the broadly distributed taxa are highly variable in overall size, colouration and some structures of external morphology such as scutellar process and it is often necessary to examine structures of male and female genitalia to obtain accurate identifications. The form of the female genital chamber and its associated structures and the shape of the lobal sclerite of the male vesicles are particularly useful

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taxonomic characters (Stonedahl 1991). The buildup of pest commences during October/November is noticed in high numbers during December to March with the population reaching a peak during January when trees are in full bloom with flowering and fruiting, prevails predominantly in the plantation till May and subsequently exists in negligible number during monsoon period (Sundararaju 2005). Each insect can damage 3-4 shoots or panicles leading to heavy loss in yield.

So far, chemical control measures are recommended for management of *H. antonii* on cashew (Sundararaju *et al.* 1993). Since, there is potential restriction in developed countries in import of cashew kernels containing pesticides residues, developing integrated pest management with main emphasis on non-insecticidal control methods, viz. biological control (natural enemy complex) is required. The studies conducted so far have helped in understanding the host range, seasonal abundance, recording of natural enemy complex, efficacy of plant products and insecticides suitable for management of TMB. The development of sex pheromone technology to manage this pest is another area of research. In spite of serious damage by TMB on cashew, very less effort has been made to develop suitable management strategies which are environmentally sound and economically viable. Thus, it was thought to review all the works done on various aspects of TMB and to suggest some future line of action, which will help researcher to formulate some strategic action plan for the management of this serious pest of cashew.

Taxonomy

The group of bugs commonly referred as mirids belongs to order Heteroptera (Suborder: Hemiptera). Miridae contains a number of species important both from phytophagy and the maintenance of natural balance (Akingbohungbe, 1983). The latest classification is by Carvalho (1957-60) who recognized six subfamilies, viz. Bryocorinae, Phylinae, Orthotylinae, Mirinae, Cylapinae and Deraecorinae. Schuh (1986) proposed a phylogenetic scheme for the subfamilies of Miridae and also presented an analysis relationship for the subfamily Bryocorinae. According to Carvalho (1957-60), in the largest subfamily Mirinae, more than 250 Mirine genera were described by 1955. Sub family Bryocorinae consists of two tribes, viz. Monaloniini and Odoniellini. Signoret (1858) erected the genus *Helopeltis* under the tribe Monaloniini to receive an insect found on the tea by Antonie Dohrn in Sri Lanka and described as *H. antonii*. Subsequently for *Helopeltis* spp., lot of research work has been conducted and compiled in three prominent reviews (Devasahayam and Nair 1986, Stonedahl 1991, Sundararaju and Sundarababu 1999). *Helopeltis* is distinguished from other groups of Bryocorinae by the elongate, cylindrical body form, the structure of the pretarsus, the reduced numbers of meso and metafemoral trichobothria with strongly tuberculate bothria and indistinct trichomae, the metathoracic scent efferent system lacking developed ostiole and evaporative area on metaepisternum (Stonedahl 1991) and the eggs with respiratory horns (Schuh 1976). *Helopeltis* is readily distinguished from other members of the tribe by the large, spine like process on the scutellum and by characteristics of the male and female genitalia, particularly the structure of the genital chamber of the female (Bhat and Srikumar 2013).

Biology

The eggs are white, ovoelongate (slightly narrower apically) and laterally compressed apically, 1.0 to 1.31 mm long (Miller 1941, Tan 1974, Satapathy 1993, Ambika and Abraham 1979). Two unequal extra-chorionic processes (a long ventral one and shorter dorsal one) arise from the anterior end of the eggs; those usually are 0.29-0.67 mm in length. The eggs are embedded in plant tissue singly or in small groups usually with the operculum and extra-chorionic processes exposed. On finding the puncture, the ovipositor was thrust through it and the egg was laid (Thontadarya and Basavanna 1962). Initially, after deposit of egg in the plant tissue, the shape of egg is almost cylindrical. After two days, expansion of eggs to a tune of 0.04 to 0.08 mm both longitudinally and laterally, particularly at the distal region is seen. The colour of the operculum is hyaline for the first two days and it later turns light brown in colour. Similarly, the eggs are whitish for first two days and subsequently turn to orange colour with a distinct dark orange band at the distal region (Sundararaju 1996, Sundararaju and Sundarababu 1999). Hinton (1962) described respiratory function of extra-chorionic process.

The majority of species appear to have preferred oviposition sites depending on the host plant. On cocoa, *H. theivora* prefers the pods but occasionally oviposit on young shoots (Miller 1941, Tan 1974), while on tea this species prefers new shoots and rarely the petioles and midribs of leaves (Das 1984, Mann 1902). *H. antonii* lays its eggs primarily on the young shoots, inflorescence stalks and tender nuts of cashew, but sometimes accept the petioles and ventral midribs of leaves (Ambika and Abraham 1979). On guava, *H. antonii* lays eggs primarily on ventral midribs of leaves, flower buds and pea size guava fruit either singly or in groups (Sundararaju and Sundarababu 1999). Lever (1949) reported that both *H. bradyi* and *H. cinchonae* select young tea shoots for oviposition. Incubation periods vary depending on locality, season and host plant, but generally in the range of 6 to 11 days (Stonedahl 1991). Much longer period (20-27 days) were noted for winter populations of *H. theivora* in north east India (Das 1984) and for *H. bradyi* (13-16 days) and *H. cinchonae* (17-22 days) on winter tea in the Cameron Highlands, West Malaysia (Lever 1949). Incubation period of *H. antonii* on neem (8-9 days), guava (9-10 days) and cashew (7-8) was reported by Sundararaju (1996). However, in all species for proper hatching of eggs, the plant parts containing eggs should be always in alive and turgid condition (Devasahayam and Nair 1986, Sundararaju and Sundarababu 1999).

Helopeltis spp. has five nymphal instars that vary in size, colour and development of body parts. Descriptions and illustrations of the nymphal instars are provided by Ambika and Abraham (1979) and Satapathy (1993) for *H. antonii* and Miller (1941) for *H. theivora*. The rate of nymphal development is affected by climatic factors and/ or rearing conditions such as temperature and relative humidity (Betrem 1950, Sundararaju and John 1992), as well as quality of food source (Awang *et al.* 1988). Nymphs develop more rapidly on cocoa and guava (22-23 days) than on tea (Jeevaratnam and Rajapakse 1981). Most reported nymphal lifespans (I-V) are in the range of 9 to 19 days (Ambika and Abraham 1979, Devasahayam 1985, Miller 1941, Tan 1974, Sundararaju 1996) and 22 to 25 days (Jeevaratnam and Rajapakse 1981). Nymphal developmental periods of 15.3 ± 0.82 days was recorded for *H. antonii* on neem; 20.24 ± 1.79 days on guava and 12.60 ± 0.50 days on cashew (Sundararaju 1996).

Longevity and fecundity vary depending on rearing conditions. Tan (1974) recorded a mean adult longevity of 30 days for *H. theivora* raised on cocoa pods in West Malaysia. The same species was reported by Awang *et al*. (1988) to have a mean longevity of 20 days when reared on cocoa pods, but only 6 days when raided on the shoots. According to Songyot and Punpen (1997), longevity of female and male *H. theivora* on cashew was 36.8 and 33.6 days, respectively. The longevity of *H. antonii* varied from 7 to 46 days (Stonedahl 1991, Sundararaju 1996, Srikumar and Bhat 2011). Fecundity of *H. antonii* on cashew was 10 to 41 eggs (Pillai, *et al*. 1984) and 28 to 35 eggs (Ambika and Abraham 1979). Fecundity of *H. antonii* on cashew and guava varies from 10 to 220 and 48 to 185, whereas, of *H. theivora* on tea and cocoa is 172 and 63, respectively, and of *H. bradyi* is 235 eggs/ female (Sundararaju 1996, Srikumar and Bhat 2011). Fecundity of *H. theivora* on cocoa is in the range of 50 to 63 eggs (Wheeler 2001, Schaefer and Panizzi 2010).

Colour morphs

Colour variations in *H. antonii* and *H. bradyi* were reported by Sathiamma (1981) and Sundararaju (1996). Three pronotal color variants occurred in the adults of the *H. antonii* and *H. bradyi*: dark red (DR), black (B) and brownish black (BB). In *H. antonii*, dark red variants were significantly higher than black and black were significantly higher than brownish black. In contrast, male *H. bradyi* population dominated with higher occurrence of black colour variant. *H. theivora* population in the Sub-Himalayan dooars tea plantation exhibited 9 pronotal colour variants with males having 3 colour variants, while female with 6 colour variants (Roy *et al*. 2009).

Molecular diversity

Mitochondrial Cytochrome Oxidase I (mtCOI) shows reliable inter-specific variation as compared to other markers (Savolainen *et al*. 2005). The mtCOI gene analysis of 32 individuals of *Helopeltis* spp. from different host plants and geographical location in India revealed that very less intraspecific variation for *H. antonii* (0.00-0.51%), *H. theivora* (0.00-0.48%), and *H. bradyi* (0.00-0.73%), whereas the interspecific variation between *H. antonii* and *H. bradyi, H. antonii* and *H. theivora,* and *H. theivora* and *H. bradyi* were 8.2, 13.14, and 13.94 per cent, respectively. The neighbour-joining tree for the 32 individuals of *Helopeltis* species revealed that, there are three major clades, in which the Clade I clearly associated with the *H. antonii* population, whereas the Clade II represents the closely related species *H. bradyi* and the Clade III consists of *H. theivora* collected on various hosts from different geographical locations in India. On the other hand the mtCOI analysis did not reveal any host-associated genetic differentiation in *Helopeltis* spp. (Asokan *et al*. 2012, Rebijith *et al*. 2012). The genetic polymorphism detected using RAPD-PCR among colour variants show that *H. theivora* population consists of discontinuous phenotypes among individuals within a freely interbreeding population. Latip *et al*. (2010) developed microsatellite markers for *H. theivora*.

Distribution and host range

Palaeotropical distribution of *Helopeltis* has been reported, extending from West Africa to New Guinea and northern Australia. Comprehensive reviews (Schmitz 1968, 1988, Stonedahl 1991, Stonedahl *et al*. 1995, Sundararaju and Sundarababu 1999) suggested occurrence of 41 recognized species of which 26 are restricted to Africa and 15 prevalent in Asia and Pacific region. Stonedahl (1991) recognized two subgenera: *Afropeltis* subgen. Nov. (type species *Eucerocoris westwoodi* White) including all the African species of the genus and *Helopeltis sensu stricto*, containing the Oriental and Australasian species which included one non-existing species *H. podagricus* (Costa). Earlier the records of *H. antonii* occurring in Indonesia are the mistaken identity (Roepke 1916, Sudarmadji and Gunawan 1994) and its correct identity is *H. bradyi* (Stonedahl 1991, Sundararaju and Sundarababu 1999). *H. antonii* is only confined to south and east India, Andaman Islands and Sri Lanka whereas, *H. bradyi* is confined to south India, Sri Lanka and Indonesia and Malaysia (Stonedahl 1991, Sundararaju 1996) and *H. theivora* in south India, north east India, Sri Lanka and southeast Asia. Three species of *Helopeltis,* viz. *H. antonii, H. bradyi* and *H. theivora* were recorded in India, where *H. antonii* is the dominant species (Sundararaju and Bakthavatsalam 1994). Recent surveys in west coast and east coast of India confirmed three species, viz. *H. antonii*, *H. bradyi* and *H. theivora* spread over different host plants (Srikumar *et al*. 2013a) and *H. antonii* was observed as the predominant species from 14 locations whereas; *H. bradyi* from five locations. *H. antonii* was also reported recently from Gujarat, Chhattisgarh and Odisha cashew growing regions. *H. bradyi* was reported from high altitude Tura region, Meghalaya and *H. theivora* was predominant species on cashew in the north east region.

Fig 1 TMB infested cashew plantation

Since the late 1800s over 100 species of plants have been reported as hosts for *Helopeltis* spp. (Stonedahl 1991). Devasahayam and Nair (1986) and Sundararaju and Sundarababu (1999) complied various plant species representing different families of *H. antonii.* The host range of *Helopeltis* spp. as follows:

Helopeltis antonii: Cocoa, cinchona, Persian neem and annatto (Fletcher 1914), Mahogany (Fletcher 1914, Rao 1915); cashew and guava (Ayyar 1940, Puttarudriah 1952); avocado (Puttarudriah 1952), apple and grapevine (Puttarudriah and Appanna 1955); cotton (Puttarudriah 1958) cocoa (Abraham and Remamony 1979); camphire (*Lawsonia alba* Lam.) (Sundararaju 1984); drumstick (*Moringa oleifera* Lam.) (Pillai *et al*. 1979); rose apple, mango, all spice and black pepper (Devasahayam and Nair 1986); poria tree (*Thespesia populnea* L.) (Sundararaju and Baktavatsalam 1994); *Ailanthus excels* Roxb. (Satapathy 1993, Sundararaju, 1996); ber (*Zizyphus mauritiana* Lam.), Indian gooseberry (*Emblica officinalis* L.), cotton (*Gossypium barbadense* L. and *G. hirsutum* L.), cowpea and a Compositae weed plant (*Lactuca runcinata* DC.) (Sundararaju 1996); neem

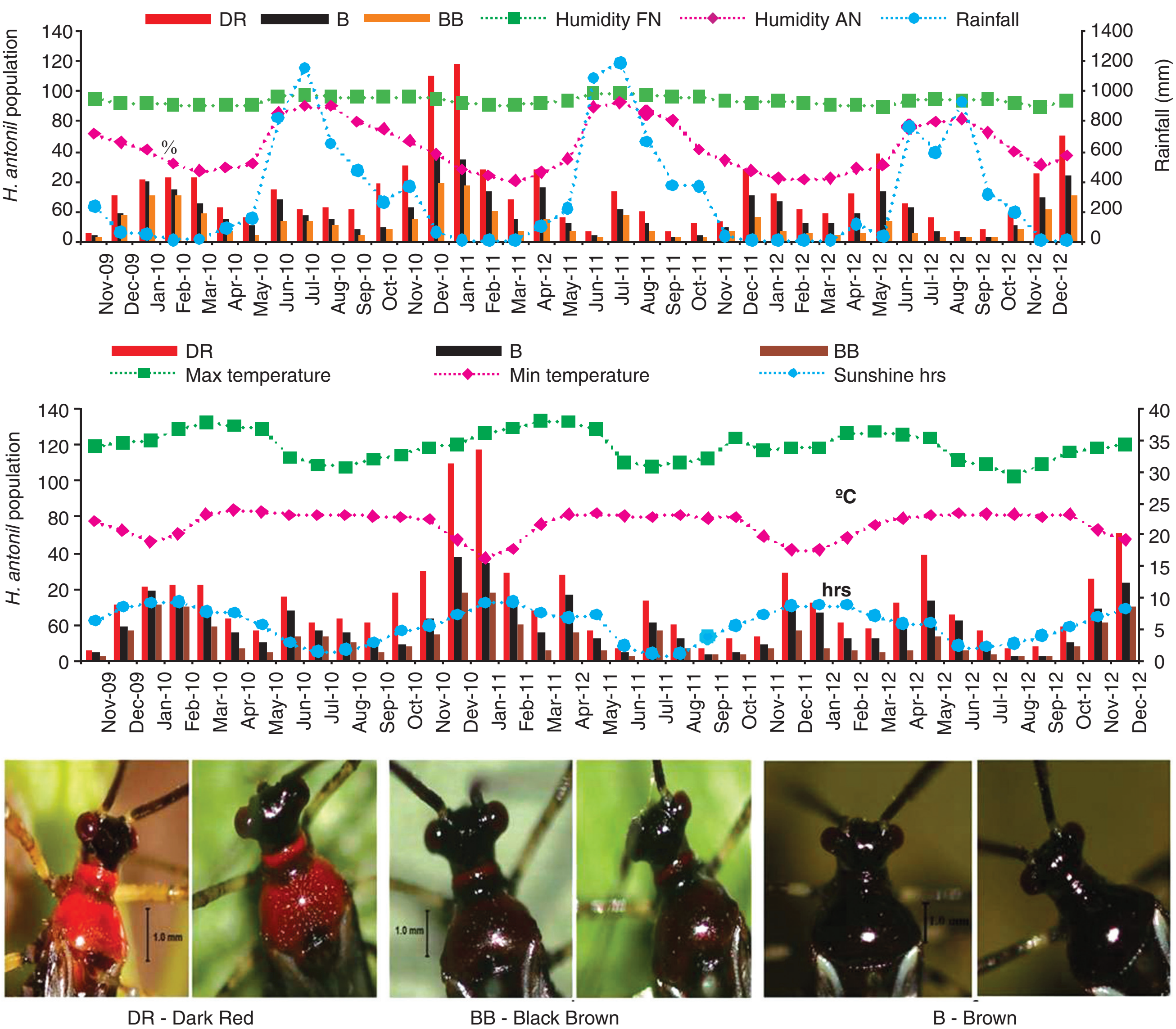

Fig 2 Influence of climatic parameters on TMB population

(Onkarappa and Kumar 1997, Sundararaju and Sundarababu 1999); Singapore cherry (*Muntingia calabura* L.) (Sundararaju *et al*. 2002, Srikumar and Bhat 2013a); *Annona* spp. (Venkata Rami 2009).

Helopeltis bradyi: Tea, cinchona, *Dioscorea* sp., *Oxalis* sp. and *Cephaelis angustifolia* Ridl. (Miller 1941); cocoa, cashew, cinchona, tea, *Capsicum* sp. and *Citrus* sp. in Java, gutta percha (*Palaquium gutta* Hook.) in West Malaysia, coffee (*Coffea arabica* L.) in Sri Lanka and *Eucalyptus saligna* Sm. in Sumatra (Lever 1949), cocoa (De Silva 1957); coffee in Sri Lanka, *E. saligna* and *Acacia mangium* Willd. in Sarawak (Hamid 1987); cashew (Sundararaju 1996).

Helopeltis theivora: Tea (Mann 1902, 1907), *Solanum* spp., *Mussaenda frondosa* L., *Ochlandra travancorica* Benth., guava and cinchona (Anstead and Ballard 1922); cinchona, cocoa, *Cinnamomum camphora* L., *Erythrina* sp., *Melia azadirachta* L., *Tephrosis* sp., guava, *Maesa* sp., *Polygonum* sp., jack, *Jasminum* sp., ornamental *Camellia* sp., red gum, coffee, *Bidens pilosa* L., morning glory, sweet potato, mango, cashew and *Passiflora* sp. (Rao 1970); wild rhododendron (*Melastoma malabathricum* L.), *Maesa ramentacea* Roxburgh., *Eurya acuminate* DC., *Jasminum scandens* Vahl. and *Mikania micrantha* (Das 1984); *Similax* sp. and *Phlogacanthus* sp.(Somchoudhury *et al*. 1993); *Chromolaena odorata* L.(NRCC 1993, Srikumar and Bhat 2013b); golden dew drops (*Duranta repens* L.), tita phool (*Phlogacanthus thrysiflora* Nees), jungli pan (*Piper* sp.,) pepal tree (*Ficus* sp.), bor sonborial (*Sida cordifolia* L.), sorn tree (*Persea bombycina* King ex Hook.f.), bhang leaf (*Cannabis sativa*), ixora, missi (*Melastoma malabathricum* L.), Mikania (*M. micrantha*), *Acalypha* sp., Malati (*Jasminum scandens* Vahl.), Bortengeshi (*Oxalis acetosella* L.), *Eurya acuminata* DC., *Morus* sp., kadam (*Neolamarckia cadamba* Roxb.), jamun (*Syzygium cumini* L.), boal (*Cordia dichtoma* G. Forst.) and China rose (*Hibiscus* sp.) (Tocklai 2010).

Population dynamics

Helopeltis spp. exhibit a more or less continuous cycle of generations throughout the year. In peninsular India, the buildup of populations of *H. antonii* on cashew in October/November is synchronized with the emergence of new foliage following the cessation of the monsoon rains. Peak abundance is reached in January/February when cashew trees are in full bloom, the insects remaining active on the plants until the onset of the monsoon rains in June (Devasahayam 1985, Sundararaju 1984). There is also evidence indicating that *Helopeltis* populations fluctuate in response to more localized and less regular climatic events, tending not to do well under conditions of heavy rain, high winds, or low relative humidity (Miller 1941, Betrem 1950, Pillai *et al.* 1984). During the monsoon period, June to September when the succulent parts are not generally available on grown up trees the population of the pest was completely absent (NRCC 1993, Sundararaju 2005). However, the pest is known to damage younger trees throughout the year as they produce flushes almost continuously (Sathiamma 1977, Devasahayam and Nair 1986, Sundararaju and Sundarababu 1999). *H. antonii* population build up was negatively correlated with minimum temperature, relative humidity, rainfall and positively with sunshine (Pillai *et al*. 1984). Meanwhile, negative relationship between rainfall and incidence of *H. antonii* was also reported by Senguttuvan and Bhaskaran (1993). The significant relationship of population was also stressed especially with minimum temperature, rainfall and sunshine hours (Sundararaju 2005). The population distribution of various types of *H. antonii* in relation to climatic parameters at Experimental farm of ICAR-Directorate of Cashew Research, Puttur (Karnataka) during 2009-2012 is depicted in Fig. 2. Distribution analysis of *H. antonii* population on cashew plantations in Indonesia showed aggregated distribution particularly during flushing-flowering seasons of cashew (Siswanto *et al*. 2008).

Economic damage

In Indonesia (Java), the first record of symptoms that could almost certainly be attributed to attack of *Helopeltis* was on cocoa in 1841 (Giesberger 1983) and on tea as 'Roest' disease in 1847 (Shaw 1928). Typical feeding damage by *Helopeltis* spp. appears as a discoloured necrotic area or lesion around the point of entry of the labial stylets into the plant tissue. The lesion can be elongate or spherical and becomes darker with age as the tissue around the stylet puncture dies, presumably in response to the enzymatic action of the insect's salivary secretions. Miles (1987) reported pectinase in the salivary glands of *H. clavifer* and noted that the insect feeds by evacuating the contents of individual plant cells, leaving the cell walls intact and uncollapsed. Nymphs and adults of *H. antonii* initially tapped the plant surface with labial tip followed by immediate insertion of stylet with a minimum depth of 0.3 mm. Water soaked lesion appeared within a minute after insertion of stylet indicating rapid diffusion of salivary secretion. Subsequently, the melanization and necrosis of feeding lesions appeared (Sundararaju 1996). In the salivary gland of *H. antonii*, hydrolytic enzymes (protease and lipase), oxido-reductase enzymes (catecol oxidase, catalase and peroxidase) and free amino acids were detected. The salivary enzymes were implicated for the phytotoxaemia on various host plants as well detoxification of defensive chemicals especially in the neem (Sundararaju 1996, Sundararaju and Sundarababu 1999).

H. antonii is the most serious pest of cashew, with crop losses sometimes reaching 30 to 40 per cent (Devasahayam and Nair 1986). The co-existence of *H. theivora* and *H. bradyi* with *H. antonii* was found in the west coast of India (Sundararaju and Sundarababu 1999) and in few other parts of India (Ambika and Abraham 1984). Losses in nut yield of 25 to 50 per cent have been reported from Karnataka, Goa, Kerala and West Bengal (CCRS 1966, Desai *et al*. 1977, Abraham and Nair 1981, Chatterjee 1989, Sundararaju and Sundarababu 1999). The nature of damage caused by *H. antonii* has been described by various workers (Abraham 1958, Pillai and Abraham 1975, Ambika and Abraham 1979, Pillai *et al*. 1979, Devasahayam and Nair 1986, Satapathy 1993, Sundararaju 1996). The nymphs and adults feed on the leaves, new shoots, panicles, and on the developing nuts. In severe infestations the young shoots and panicles dry up, giving the infested trees a scorched appearance. The lesions on shoots and panicles coalesce and ultimately result in shoot blight and blossom blight. Successive attacks on new growth can result in stunting or death of the tree. Damage to immature nuts causes them to shrivel, while older nuts develop a blistered or scabby appearance. Infestations during the early stages of fruit set often result in an immature fruit drop. In field trials, Sathiamma (1977) found that panicles (48.5%) and fruits (32%) sustained higher levels of attack than young shoots (14%). Nymphs caged on young shoots made an average of 114 feeding lesions per day (range 78-235), while females made an average of 97 (16-238) and males 25 (11-59). A single nymph can cause blighting of emerging tender shoots and panicles within 3 to 4 days of feeding. In 24 hour feeding, the mean number of feeding lesions produced by a single nymph/adult on tender shoot and leaves of cashew seedlings varied from 87.4 ± 41.4 to 139.4 ± 60.5. In the damaged cashew shoot, hypersensitive reactions consisting of melanization, shrinking of cell walls and necrosis of feeding lesion occurred in a sequence within a week's time (Sundararaju 1996, Sundararaju and Sundarababu 1999).

MANAGEMENT STRATEGIES

Varietal resistance

The identification of promising cashew types having tolerance to TMB infestation would be one of the most desirable and eco-friendly non-chemical strategies to manage the pest and augment the productivity. Beevi and Mahapatro (2007) stated that in spite of a wide array of cashew germplasm available in India, the use of host plant resistance to manage this problem pest has not been exploited well. Though, studies indicated that wide variation exists in the cashew tree populations with regard to the susceptibility to TMB infestation. In earlier field screening studies with the seedling progenies, cashew accessions, viz. VTH 153, Kunthur 24, Goa 11/6, VTH 153/1, VTH 9/78 and 51 different cashew types in Karnataka, accession No. 665 in Kerala and BLA-39-4 in West Bengal were reported as least susceptible to *H. antonii* (Ghosh and Chatterjee 1987, NRCC 1988, Uthaiah *et al*. 1994, Hiremath 1991, Sundararaju and John 1993). Least susceptible types to *H. antonii* contain higher phenols (Annapoorna and Nagaraja 1988) which cannot be implicated towards resistance, since *H. antonii* has potential salivary detoxification mechanism. Besides, the existence of other antibiosis mechanism is also remote, since Kunthur 24 and Goa 11/6 accessions had not shown any inhibitory effect on the growth of *H. antonii* (NRCC 1994).

The screening of cashew types at Ullal Centre (coastal Karnataka) revealed that 51 types are promising against (Hiremath 1991). Beevi *et al*. (2001) attempted in categorizing the cashew accessions based on damage score in to four groups: less susceptible (0-0.250), moderately susceptible (0.251-0.500), susceptible (0.501-0.750) and highly susceptible (0.751-1.000). Screening of 68 cashew accessions revealed that all the accessions were susceptible to TMB infestation with none resistant/tolerant to the target-insect pest. Accessions Amrutha, Damodar and Raghav were found to be least susceptible (LS), while Priyanka and Anagha were highly susceptible (HS). Damage analysis indicated that, none of the accessions exhibited damage below 10 per cent (very low) (Beevi and Mahapatro 2007). Dhana variety showed significantly least damage score (0.36 ± 0.05) for three year screening studies. The varieties, viz. Bhaskara, VRI 3, Vengurle 7, Ullal 3, Ullal 4, Vengurle 3, NRCC Sel-1, Madakkathara 2, NRC 493, VTH 174, Kanaka, Ullal 1 and Ullal 2 were statistically on par with damage score ranging from 0.48 ± 0.07 to 0.58 ± 0.09. While, NRCC Sel-2, Vengurle 4 and Priyanka, showed significantly higher damage score ranging from 0.73 ± 0.09 to 0.92 ± 0.13. Dhana and Bhaskara varieties consistently showed lower damage score value and were grouped under Moderately Susceptible (MS) category.

Natural enemies

(i) *Egg parasitoids: Telenomus* (Hymenoptera: Platygastridae) are particularly promising egg parasitoids of *Helopeltis* spp. (Chang 1982). In Ghana 10 to 73 per cent of *H. bergrothi* eggs were parasitized by *Telenomus* sp. (CIBC 1983). *Telenomus* sp. has been reported in India on *H. cinchonae* Mann (Simmonds 1970), on *H. theobromae* Miller from Malaysia (Ibrahim 1989) and on *H. antonii* Signoret from India (Sundararaju 1993). Four species of egg parasitoids, viz. *Telenomus* sp., *Ufens* sp., *Chaetostricha* sp. (Trichogrammatidae), *Erythmelus helopeltidis* Gahan and *Gonatocerus* sp. (Mymaridae) has been reported attacking *Helopeltis* spp. (Sundararaju 1996, Sundararaju and Sundarababu 2000). All these species are solitary parasitoids. In Malaysia *E. helopeltidis* has been reported to parasitize up to 36 per cent of the fertile eggs of *H. cinchona* on tea (Lever 1949) and 11 to 47 per cent of the eggs of *H. theivora* on cocoa (Ibrahim 1989). *E. helopeltidis* has been reported as egg parasitoid of *H. antonii* (Devasahayam 1989); *H. theivora* on tea (Sudhakaran and Muraleedharan 2006) in India. The highest parasitism up to 70.8 per cent by *Telenomus* sp. in certain months was recorded by Sundararaju (1996). Parasitism by *Telenomus* sp. is negligible in the eggs of *H. antonii* laid on neem in east coast (Tamil Nadu) whereas it is a dominant species in cashew ecosystem of west coast of India. *Ufens* sp., thelytokous type is the dominant species in the neem ecosystem of Tamil Nadu. The study on relative intensity of parasitism indicated that *Telenomus* sp. might have evolved in the eggs of *H. bradyi* (Sundararaju 1996). Recently, the recorded *Telenomus* species parasitizing eggs of *H. antonii* was identified and described as a new species:

Telenomus cuspis Rajmohana and Srikumar (Rajmohana *et al.* 2013)

(ii) Nymphal adult parasitoids: Parasitoids of genus *Leiophron* (Hymenoptera: Braconidae) were reported as promising biological control agents of *Helopeltis*. Parasitism levels of 6 to 66 per cent have been reported for *L. sahlbergellae* Wilkinson on *Sahlbergella singularis* Haglund (Heteroptera: Miridae) in West Africa (CIBC 1983). The existence of hyperparasitoids limited their potentiality in biological control especially due to *Stictopisthus javensis* Ferriere (Hymenoptera: Ichneumonidae) on *H. bradyi* (Giesberger 1983) and *Stictopisthus* sp. on *H. bergrothi* (Kirkpatrick 1947). In India, nymphal parasitoid and nematode, *Agamermis paracaudata* Steiner (Mirmithida: Mirmithidae) have been reported from *H. theivora* on tea (Durgadas and Sambhunath 1956). Sundararaju (2002) reported that *Leiophron* like nymphal adult parasite attack on *H. antonii*. From a total population of 2452 *H. antonii* adults collected 32 were parasitized with *Leiophron* sp. The size of the mature parasitoid (just before pupation) larvae was 3.66 ± 0.11mm in length and 1.31 ± 0.03 mm in breadth, respectively. However in depth studies are required to understand its role in regulation of *H. antonii* population.

(iii) Predators: Predators also appear to play an important role in the natural control of *Helopeltis* spp. The main predators of *Helopeltis* includes spiders, reduviids, mantids and ants.

Spiders: In cashew agro-ecosystem, spiders are the most abundant predators of arthropod-pest complex. Basu (1962) had documented large number of spiders belonging to seven families occurring predominately in Kerala. Spider population corresponds to the seasonal occurrence of pests on the cashew crop (Devasahayam and Nair 1986). Four spider species, viz. *Hyllus* sp., *Oxyopes schireta*, *Phidippus* sp. and *Matidia* sp. has been observed predating on *H. antonii* (Sundararaju 1984, Devasahayam and Nair 1986). Most of the studied spiders preferred adults than nymphs, while *O. sunandae* Tikader, *Telamonia elagans* Thorell and *Hyllus diacanthes* preferred nymphs (Beevi and Mahapatro 2008). Recent diversity studies of spiders on cashew ecosystem by Bhat *et al.* (2013) has reported 117 species of spiders belonging to 18 families. The spiders, viz. *Telamonia dimidiata* and *Oxyopes shweta* were the major predators of *Helopeltis* spp., whereas *Argiope pulchella*, *Cyclosa fissicauda*, *Eriovixia laglazei*, *Neoscona mukerjeri*, *Nephila pilipes*, *Oxyopes sunandae*, *Bavia kairali*, *Carrhotus viduus*, *Epocilla aurantiaca*, *Hyllus semicupreus*, *Achaearanea mundula*, *Camariacus formosus and Thomisus lobosus* were also recorded as superior predators of *Helopeltis* spp.

Reduviids: Five species of reduviid predators, viz. *Euagorus plagiatus* Burm., *Rhinocoris margnellus* Thub., *Sycanus Leucomesus* Wlk., *Isyndus heros* F. and *Cosmolestes picticeps* Stal. were introduced into tea plantations in the Cameron Highlands of Malaysia from the lowlands to prey on *H. bradyi* and *H. cinchona*. Three other species, *Endochus cameronicus*, *Isyndus* sp. and *Euagorus* sp. which were already known to attack *Helopeltis* in highlands were also bred and released. However, the effect of these predators on the pest was not known (Rao *et al*. 1971). Naik and Sundararaju (1982) recorded *Endochus inornatus* Stal as a predator of *H. antonii*. *E. inornatus* was also reported predating as many as 20 individuals of *H. antonii* per day (Devasahayam and Nair 1986). Sundararaju (1984) and Vennison and Ambrose (1990) reported five species of reduviid bugs, viz. *Sycanus collaris* Fab., *Sphedanolestes signatus* Dist., *E. inornatus*, *Irantha armipes* Stal and *Occamus typicus* Dist., as predators of *H. antonii* on cashew in India. In addition to the above species recently *Alcmena* sp., *Biasticus* sp., *Cydnocoris gilvus* Burmeister, *Endochus albomaculatus* Stal, *Endochus* sp., *Epidaus bicolor* Distant , *Epidaus* sp., *Euagoras plagiatus* Burmeister, *Lanca* sp., *Panthous bimaculatus* Distant, *Rhynocoris fuscipes* Fabricius, *Rihirbus trochantericus* Stal var. sanguineous, *Rihirbus trochantericus* Stal var.luteous, *Scadra* sp. and *Sycanus galbanus* Distant. were recorded as predators of *Helopeltis* spp. Mass culture technique for *R. Trochantericus* were standardized using wax moth (*Galleria mellonella* L.) larvae, as prey and its predatory potentiality was proved in laboratory conditions (Bhat *et al*. 2013).

Ants: Some work has been done on the role of ants in controlling or deterring *Helopeltis* spp. on cocoa and measures had been taken to encourage certain species of ants in cocoa growing areas (Entwistle 1972). However, Collingwood (1977) discussed this in detail and concluded that the activities of ants normally have only a marginal effect on mirid population. But the later studies have shown encouraging results by increasing the activities of *Dolichoderus thoracicus* Smith and *Oecophylla smaragdina* F., the infestation of *Helopeltis* spp. could be reduced (Way and Khoo 1992, Peng *et al*. 1995). Ambika and Abraham (1979) reported *Crematogaster wroughtoni* Forel as the predator of first and second instar larvae of *H. antonii* at Madakkathara (Kerala). *The O. smaragdina* significantly reduced the numbers *H. pernicialis* Stonedahl on cashew trees in tropical northern Australia (Peng *et al*. 1995, 1997). Beevi and Mahapatro (2008) reported 3 species of ant genera, viz. *Tetraponera*, *Crematogaster* and *Oecophylla* were noticed as predators of *Helopeltis* spp. In a field experiment, Sreekumar *et al*. (2011) reported TMB population was significantly lower in plants colonized by red ants.

Other predators: *Chrysoperla carnea* Stephens (Neuroptera: Crysopidae) as predator of *H. theivora* has been reported by Das *et al*. (2010). Green lacewing (*Mallada* sp.) consumed 10 to 11 nymphs/hr and the time taken to consume a single nymph varied from 3 to10 minutes. Praying mantids were also recorded feeding on *H. theivora* (Mamun and Ahmed 2011). Adults of *H. antonii* and *H. theivora* were found to be infested by predatory mite, *Leptus* sp. attached by mouth parts to the ecdysial lines on the bugs head and thorax.

(iv) *Insect-pathogens:* Two fungal pathogens, viz.

Aspergillus flavus Johann and *A. tamarii* (Eurotiales: Trichocomaceae) can cause infection to *H. antonii* (Sathiamma and Saraswathy 1990, Karthikeyan 1992, Satapathy 1993). An entomopathogen, *Beauveria bassiana* Bals. (Hypocreales: Clavicipitaceae) was isolated from *H. antonii* infesting guava (Visalakshy and Mani 2011).

Pheromones

As a prelude, studies on existence of sex pheromones have been established in females of *H. clavifer* (Smith 1977) *H. theivora* (Somchoudhury *et al*. 1993) and *H. antonii* (Sundararaju *et al*. 1994). Gas chromatography-mass spectrometry (GC-MS) analysis of female thoracic extracts and dynamic head space samples of virgin females showed the presence of five compounds: (*Z*)-3 hexenyl acetate, (*Z*)-3 hexenyl butanoate, (*E*)-2 hexenyl pentanoate, 2,4 dimethyl pentanal, and (*E*)-2-hexenol. Male insects were attracted to blends of (*Z*)-3 hexenyl acetate and (*E*)-2-hexenol in the wind tunnel with a 1:5 ratio eliciting the greatest response. EAG recordings of male antenna confirmed the ability of this blend to evoke antennal responses in male insects. This female sex pheromone blend may be useful for TMB control and management in future (Sachin *et al*. 2008).

Use of botanicals

Plant products especially neem formulations evaluated against *H. antonii* indicated low mortality and also with low feeding deterrence (Satapathy 1993, NRCC 1994, Bhat *et al*. 1994, Angaiah 1995). However, kernel extracts of Pongamia, Calophyllum and Pongamia oil extracts gave increased mortality of *H. antonii* than any other plant extract (NRCC 1993, Satapathy 1993). The aqueous extract of *Clerodendrum viscosum* L. (Lamiaceae) effectively and significantly reduced the mite population as well as the infestation of *H. theivora* in tea by 68 to 95 and 73 to 86 per cent, respectively, and their bioefficacy is comparable to synthetic and neem pesticides (Roy *et al*. 2010).

Chemical control

For management of *Helopeltis* spp., use of chemicals is the only successful and widely accepted technique. The insecticide to combat against *Helopeltis* spp. started by Damodaran and Nair (1969) where they reported that two sprayings of DDT at 15 days interval proved the best control of *H. antonii* on cashew. Later, lindane was widely used to control *H. antonii* on cashew in India (Pillai, 1987). Lindane was replaced with endosulfan to control *H. antonii* on cashew (Devasahayam and Nair, 1986) and *H. theivora* on tea (Das 1984, Smith *et al.* 1985). Endosulfan (0.05%) was found to be effective when sprayed thrice during emergence of flushes, panicles and after fruit set (Sundararaju and Sundarababu 1999) but now it is not in use. Other efficacious chemicals like carbaryl, monocrotophos, phosalone, phosphamidon, quinalphos, dimethoate and dichlorvos had been recommended for control of *H. antonii* on cashew (Sundararaju 1984, Devasahayam and Nair 1986, Samiayyam *et al*. 1989, Sundararaju and Bakthavatsalam 1994). Effectiveness of synthetic pyrethroids, viz. decamethrin (0.002%), permethrin (0.01%), cypermethrin (0.0075%) against *H. antonii* was also reported (NRCC, 1988; Godse *et al*. 1993)

The method and timing of insecticide applications have been shown to be important factors in the control of *Helopeltis* spp. infestations on tropical crops. On cashew, it is recommended that insecticide treatments coincide with the emergence of new shoots, panicle emergence and again at fruit set (Babu *et al.* 1983, Pillai 1987). Early morning and late afternoon applications have been shown to be most effective, as these are the times when *Helopeltis* spp. are most active. Insecticides such as lindane, carbaryl and phosalone are very effective when applied as dusts or powders particularly in dry weather conditions (Smith 1984) and a few such as the synthetic pyrethroids are best applied through fogging (Tuck 1987). Superiority of carbaryl dust formulations in bringing down TMB infestation was reported by Bakthavatsalam *et al.* (1993).

Although, cashew is an insect pollinated crop, spraying of insecticides during flowering season did not influence the fruit set (Sundararaju *et al*. 1993). Under severe outbreaks of *H. antonii* on cashew, carbaryl (0.1%) or monocrotophos (0.05 %) can be used (Sundararaju 1996). All the insecticides tested shown no ovicidal action but l-cyhalothrin followed by carbaryl and monocrotophos exhibited highest residual action for seven days against late instar nymphs and adults of TMB (Raviprasad *et al*. 2005). The sequential sprays of monocrotophos, λ-cyhalothrin and carbaryl registered the least per cent TMB damage and higher nut yield (Naik and Chakravarthy 2013). In general, λ-cyhalothrin has been recommended as alternative and effective insecticide against *H. antonii* (Mahapatro 2008).

Future thrusts

In Indian subcontinent, three species of TMB, viz. *H. antonii*, *H. bradyi* and *H. theivora* cause serious economic damage to cashew and other crops such as cocoa, guava, neem and tea. It is quite possible to develop IPM strategy against *Helopeltis* spp. by reviewing the present scenario on host plant resistance, natural enemies, behavioural approaches and insecticidal control. Using tolerant varieties play a key role in integrated pest management programs where moderately tolerant varieties may increase the effectiveness of biological and chemical control methods.

Biocontrol programs, focused on natural enemies of *Helopeltis* spp. have also been a step forward in recent time. The new species of egg parasitoid *Telenomus cusps* from *H. antonii* provides higher scope for its augmentation techniques as they are highly specialized parasitoids, specific to *Helopeltis* spp. Besides, field observation revealed that spider species like *Oxyopes sweta* and *Telamonia dimidiata* are very good predators of *Helopeltis* spp. Another important step is mass rearing of reduviids *Cydnocoris gilvus* which showed higher predatory potential against *Helopeltis*. The success of *Oecophylla smaragdina* against *Helopeltis* is another area of research. The research for utilization of *Beauveria bassiana* strain for the management of *Helopeltis* spp. on different crops has been in swift. Since the presence of sex pheromone communication was well demonstrated in all species of *Helopeltis*, further investigations have to be intensified to identify the bioactive components of sex pheromone and for further synthesis. The synthetic sex pheromone can be used as a lure and kill method.

Even though investigations on newer molecules of insecticides are under progress, the potential risk of pesticidal residues in cashew kernels is a major predicament. Improving the non-insecticidal methods like use of tolerant varieties, biocontrol agents, biotechnological approaches and synthetic sex pheromone (as lure and kill method) will have better scope to manage this pest and reduce the dependency on insecticidal control of *Helopeltis* spp.

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