Akshay Kumar Chakravarthy
Shakunthala Sridhara *Editors*

Economic and Ecological Significance of Arthropods in Diversified Ecosystems

Sustaining Regulatory Mechanisms

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Contents

Arthropod Communities in Cashew: A Perennial Reservoir of Species Assemblages

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P.S. Bhat, K. Vanitha, T.N. Raviprasad, and K.K. Srikumar

Abstract

Over 200 arthropod species are associated with cashew, some of which are common the world over. Depending on the climate, location and age of the plantation, each geographic region has its own distinctive pest complex. Tea mosquito bug and cashew stem and root borer are the two major pests of cashew in most of the cashew-growing tracts of the world. In addition, shoot tip caterpillars, leaf miners, hairy caterpillars, leaf thrips, leaf beetles and inflorescence feeders are capable of causing economic damage during cropping season. Cashew serves as perennial reservoir of arthropod communities, and it is vital to make it balanced to sustain yields and maintain diverse arthropod communities.

Keywords

Cashew • Integrated pest management • Tea mosquito bug • Stem and root borer

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15.1 Introduction

Cashew, *Anacardium occidentale* L. (Anacardiaceae), is an economically important plantation crop native to South eastern Brazil. India was the first country in the world to exploit international trade in cashew kernels in the early part of the twentieth century. Cashew occupies 53.2 lakh ha with a production of 41.5 lakh tonnes. India has the largest area (16.8 %) under cashew followed by Ivory Coast, Brazil, Indonesia, Benin, Tanzania, Nigeria, Guinea-Bissau, Kenya, Vietnam and the Philippines. The highest raw cashew nut production is from Vietnam followed by Nigeria, India, Ivory Coast, Benin, the Philippines, Guinea-Bissau, Tanzania, Indonesia, Brazil and Kenya. There is an ever-increasing demand for cashew kernel both in international and domestic markets. All parts of the plant are fed upon by at least one pest species, resulting in huge yield loss if left unchecked.

Cashew is a commercial nut crop that thrives in hot humid regions and hence is distributed in countries near the equatorial region. The long-lived cashew plantations provide a relatively steady microclimate and food supply for arthropod communities thus serving as perennial reservoir of species assemblage. Cashew plantations nearly resemble a single-species forest, and insect pest species coexist by way of intra-tree distribution or well-defined stratification/ecological niche formation similar to rubber or tea plantations. Weeds are a major component of the cashew plantations and serve as alternative hosts for pests as well as a refuge for their natural enemies and other arthropods (Sundararaju and Bakthavatsalam 1994).

15.2 Arthropod Communities on Cashew

Every part of the cashew tree is economically useful to humans in one or the other way; every part of the tree is damaged by one or other pests. Globally, more than 200 arthropod species are associated with cashew. The production loss is estimated to be about 20–30 % by tea mosquito bug alone and death of 5–10 % of productive trees every year by cashew stem and root borer (CSRB) (Rai 1984). Hence, insect pests pose a severe constraint for cashew production. There are significant contributions in the field of cashew entomology by Ayyar (1942), Abraham (1958), Pillai et al. (1976), Ohler (1979), Stonedahl (1991), Sundararaju (1984, 2000a) and Sundararaju et al. (2006). A meticulous knowledge about the pests is one of the prerequisites in evolving suitable management approach against pests.

15.2.1 Tea Mosquito Bug (TMB): *Helopeltis* spp.

Tea mosquito bug is a low-density pest incurring 36–75 % damage at its mean population level of 0.15–0.36 nymphs and adults per shoot/panicle. Information on distribution, nature and extent of damage, biology, seasonal abundance, natural enemies, alternate host plants and control measures have been reviewed by Devasahayam and Nair (1986) and Stonedahl (1991). The genus *Helopeltis* has a

palaeotropical distribution extending from West Africa to New Guinea and Northern Australia. Of the recognised species, 26 are restricted to Africa; 4 to Oriental Region; 4 are endemic to the Philippine Islands; 2 are distributed throughout the Malay Peninsula, Sumatra and Java; and 1 species is endemic to South India, Sri Lanka, Laut Island (southeast coast of Borneo), Sulawesi, New Guinea and Northern Australia. Most of the earlier reports pertaining to *Helopeltis antonii* Signoret may also be of *Helopeltis bradyi* Waterhouse since *H. bradyi* has close resemblance with *H. antonii* (Stonedahl 1991). *H. antonii* existed on varied host plants, viz. neem, cashew, guava, ber, drumstick, Indian gooseberry, cotton, *Ailanthus excelsa* Roxb. and cow pea, whereas in the Western Ghats, *H. antonii* coexisted as a dominant species along with *H. bradyi* and *Helopeltis theivora* Waterhouse on cashew and cocoa. *H. antonii* also coexisted as dominant species on guava along with *H. bradyi*; only *H. theivora* exists on *Chromolaena odorata* (L.) and tea (Sundararaju and Sundarababu 1999a). Venkata (2009) recorded the activity of *Helopeltis* spp. on *Annona* spp., while Srikumar and Bhat (2013a) recorded its activity on Singapore cherry (*Muntingia calabura* L.). Apart from *H. antonii*, *H. theivora*, *H. bradyi* and *Pachypeltis measarum* Kerk were also recorded on cashew causing similar damage in certain areas. Rebijith et al. (2012a, b) used molecular biology tools for the identification of *Helopeltis* spp. and *Pachypeltis measarum*.

Helopeltis antonii

Helopeltis bradyi

Helopeltis theivora

Pachypeltis measarum

The egg and nymphal period last 6–12 and 10–14 days, respectively. The adults can survive for more than a month, and the female bug lays up to 259 eggs during its lifetime (Desai et al. 1977; Abraham and Nair 1981). It generally spreads from neem trees to guava, ber, drumstick and cashew. The eggs are inserted in the tender parts of shoots, petioles and midribs of leaves during flushing and on flower buds, flowering panicles, peduncle, rachis and immature fruits and nuts resulting in severe yield losses.

TMB damage on shoot

TMB damage on developing cashew apple /nut

Cashew plantation damaged by TMB

The typical feeding damage results in the formation of brownish or darker necrotic lesions. Under vulnerable stage, its population increases very rapidly within a month leading to severe loss in yield. Each nymph or adult can cause more than 100 lesions on fruit buds or immature fruits, and feeding lesions coalesce, and the tender shoots and the entire panicles having tender immature apples and nuts dry subsequently resulting in a burnt-up appearance.

The life table analysis carried out in Indonesia (Siswanto et al. 2008a, b) and in India (Sundararaju and Sundarababu 1998; Srikumar and Bhat 2013b) indicated that the survivorship of the *H. antonii* population was a type II with a high hatchability and bulk death occurring during early nymphal stages followed with a relatively lower death rate throughout the older stages (Sundararaju and Sundarababu 1998). Build-up of *H. antonii* population and its damage commenced from October to November onwards synchronising with the emergence of new flushes/panicles after the cessation of monsoon rains. Maximum shoot damage of 49.5 % during November and high panicle damage of 72.1–73.9 % from December to February with a peak pest population during February were recorded by Sundararaju (1984). In young plantations, the pest was noticed continuously with a higher intensity during February and March (Sathiamma 1978). When weather parameters were related to weekly mean TMB population, only minimum temperature had shown consistently negative relationship. Thus the prevalence of low minimum temperature (i.e. below 20.0 °C) continuously for more than 1 week during the months of December and January provides a clue for further surveillance to decide on management option (Sundararaju 2007).

15.2.2 Cashew Stem and Root Borer (CSRB)

Plocaederus ferrugineus L. (Coleoptera: Cerambycidae) is the most important species that infests cashew in most of cashew-growing areas and two other species, viz. *Plocaederus obesus* G. and *Batocera rufomaculata* Deg., were also reported in association with this species (Abraham 1958; Rai 1984). The pest is capable of causing death of 1–10 % of the productive trees annually if left unnoticed (Pillai et al. 1976; Ramadevi and Krishnamurthy 1983; Jena et al. 1985a; Godse et al. 1990; Samiyyan et al. 1991; Mohapatra and Mohapatra 2004; Mohapatra et al. 2007). *P. ferrugineus* was recorded as an emerging serious pest of cashew in Nigeria (Anikwe et al. 2007; Asogwa et al. 2008). Management of this pest is a tough job as the borer remains in a concealed condition in the interface of bark and hardwood which facilitates its escape from the attack of the natural enemies. Curculionid weevil borers *Marshallius multisignatus* (Boheman), *M. anacardi* Lima and *M. bondari* Rosado-Neto were reported from Brazil and French Guiana (Bleicher et al. 2010) and were responsible for death of trees especially dwarf types.

Different instars of CSRB grubs

Adults of *P. ferrugineus*

Adults of *P. obesus*

Adults of *B. rufomaculata* are greyish, measuring 50 mm in length, and have yellowish or orange spots on the forewings. *P. obesus* are chestnut-coloured, longicorn beetles, measuring about 40 mm in length and with slight pubescence. Adults of *P. ferrugineus* are dark reddish-brown, medium-sized beetles (25–40 mm in length). Eggs are usually deposited in the crevices of the bark of the main trunk up to one metre in height from ground level and also on the exposed roots. The nascent first instar grubs feed on the tissue near the site of oviposition, and extrusion of fine dusty frass is noticed within few days of hatching. After hatching, the grubs bore into the fresh tissues of the bark and feed on the subsequent subepidermal and sapwood tissues and make tunnels in irregular directions (Bhat et al. 2002). The larval period continues for 6–7 months. The fully grown grub measuring about 100 mm in length enters into heartwood for pupation and makes a circular exit hole of 1.5 cm width for adult emergence. The pupation takes place inside a calcareous cocoon (Pillai et al. 1976; Godse et al. 1990; Bhat and Raviprasad 1996).

Symptoms of damage include extrusion of frass, occurrence of gummosis, premature shedding of leaves, drying of twigs and, finally, death of the tree (Misra and Basu choudhuri 1985). Its infestation is severe in unattended plantation, and infested trees act as source of inoculum (Jena 1990).

Accumulation of frass at the base of cashew tree

Tunnelling by CSRB grub

Even though the occurrence of the pest is noticed throughout year in both East and West Coast, a relatively large population of grubs and severe infestation could be seen in coastal Karnataka and Andhra Pradesh during March–May and May–July, respectively (Abraham 1958; Ramadevi and Krishnamurthy 1983; Jena et al. 1985a, b).

15.2.3 Shoot Tip Caterpillar

Lepidopteran caterpillars are known to infest cashew shoot tips during flushing period and cause considerable damage. Gelechid caterpillar, *Anarsia epotias* Meyr, is pale yellowish-green with black head and bores into the terminal shoots and tunnel inside. A gummy substance oozes out from the infected tips and finally the attacked shoots dry up (Remamony 1965; Subba Rao et al. 2006). Similarly, the tiny, yellowish to greenish-brown larvae of the moth *Hypotima* (=*Chelaria*) *haligramma* M. (Lepidoptera: Gelechidae) also damage shoot tips by folding the fresh leaves and feeding within (Pillai et al. 1976; Mohapatra et al. 1998).

Damage by shoot tip caterpillar

15.2.4 Leaf Miner

The leaf miner, *Acrocercops syngramma* M. (Lepidoptera: Gracillariidae), is one of the serious pests of cashew (Sundararaju 1984; Jena and Satpathy 1989; Jacob and Belvadi 1990). The caterpillars mine and feed below the epidermal layer of the tender leaves causing extensive leaf blisters which later dry up, causing distortion, browning and curling of the leaves. The freshly hatched larvae and younger larvae are pale white in colour, while full-grown caterpillars are reddish-brown and feed by scraping the mesophyll below the epidermis. Abraham (1958) estimated the leaf miner damage to be 26 % in severely infested leaves, while 70–80 %, 60 %, 6–20 % and 18–20 % leaf damage was reported by Basu Choudhuri (1962), Rai (1984), Ayyanna et al. (1985) and Chatterjee (1997), respectively. Besides cashew, jamun and mango serve as additional hosts for this pest (Butani 1979; Sundararaju 1984).

Damage by leaf miner

Leaf miner caterpillars inside the blotch

15.2.5 Hairy Caterpillars

The hairy caterpillars of *Euproctis* spp. (Lepidoptera: Lymantriidae) feed in groups on the inflorescence and tender nuts of cashew. They scrape the green tissues on the inflorescence branches and feed on the shell of the nut in the tender green stage. *Metanastria hyrtaca* Cram. (Lasiocampidae) and *Lymantria obfuscata* Wlk. (Lymantriidae) cause severe sporadic defoliation in cashew (Arjuna Rao et al. 1976; Ramaseshaiah and Bali 1987). Early instar caterpillars are gregarious feeders on tender foliage, and the full-grown caterpillars fed voraciously on mature leaves. They congregate in large numbers on the ground under dry leaves near the base of the tree in crevices of bark or on lower parts of well-shaded branches.

15.2.6 Leaf Thrips

Occurrence of foliage thrips, viz. *Selenothrips rubrocinctus* Giard, *Rhipiphorothrips cruentatus* Hood and *Retithrips syriacus* (Mayet), has been reported on cashew (Ananthakrishnan 1984; Ayyanna et al. 1985; Jena et al. 1985a, b). The red-banded

thrip, *S. rubrocinctus* is a tropical–subtropical species thought to have originated in northern South America (Chin and Brown 2008) and is found in parts of Asia, Africa, Australia, South America and the West Indies. *S. rubrocinctus* and *R. cruentatus* cause severe damage to young plantations, particularly during summer, and the adults and immature stages of thrips colonise the lower surface of leaves. As a result of its rasping and sucking activity, the leaves become pale brown and slightly crinkled with roughening of the upper surface.

15.2.7 Leaf Beetles and Weevils

During rainy season (June–August), the chrysomelid leaf beetles and weevils defoliate cashew. The chrysomelid beetle *Monolepta longitarsus* Jacoby is an important regular pest in the West Coast regions during the southwest monsoon. These appear in young trees and skeletonize the leaves which gradually dry up. An ash-coloured chrysomelid, *Neculla pollinaria* Baly also attacks the postharvest flushes and also the upcoming tender shoots and buds. *Microserica quadrinotata* Moser (Melolonthinae) was recorded as another defoliator which skeletonizes the leaf by scrapping chlorophyll (Jena et al. 1985b).

Leaf beetles on cashew shoot

15.2.8 Pests of Cashew Apples and Nuts

Thylocoptila paurosema Meyrick and *Hyalospila leuconeurella* R. (Lepidoptera) and *Nephopteryx* sp. (Lepidoptera) attack tender apples and nuts. Damaged nuts get deformed and dry away (Rai 1984; Ayyanna et al. 1985; Dharmaraju et al. 1974, 1976). Besides leaves and shoot, *Orthaga exvinacea* (Hampson) also damages the apple. Similarly, *Hyalospila leuconeurella* Ragnot (Pyralidae) and *Anarsia epotias* Meyr. (Gelechidae) were recorded as apple and nut borers (Basu Choudhuri and Misra 1973). The larvae of *H. leuconeurella* bore through the apple and

remained inside the apple till the fruit droped, and when nuts are attacked they get deformed.

Aphids [*Toxoptera aurantii* (Boyer de Fonscolombe), mealy bugs *Planococcus citri* (Risso) and *Ferrisia virgata* (Cockerell)] suck saps of immature apples and nuts. Flower thrips such as *Rhynchothrips raoensis* G. and *Scirtothrips dorsalis* H., besides flowers, scrap immature apples and nuts resulting in the malformation of nuts and immature fruit drop (Bhat et al. 2002). A pentatomid bug, *Catacanthus incarnatus* Dru Drury) also occurs as cashew apple pest (Bhat and Srikumar 2013a). *Drosophila melanogaster* Meigen is a very serious apple-feeding insect during fruiting stages followed by *Bactrocera* spp. Under coleopteran pests, *Carpophilus* sp. was recorded in India and *Macrodactylus pumilio* Burm. from Brazil feeding on ripe apples (Ohler 1979).

Catacanthus incarnates on cashew apple

15.2.9 Inflorescence Feeders

Cashew shoots bearing fresh flushes and flowers are attacked by two species of leaf- and shoot-webbing caterpillars, *Lamida* (=*Macalla*) *moncusalis* Wlk. (Lepidoptera: Pyralidae) and *Orthaga exvinacea* Hamps. (Lepidoptera: Noctuidae). Symptoms of infestation are presence of webs on terminal portions, with clumped appearance and drying of webbed shoot/inflorescences (George et al. 1984). This pest was sporadic in certain pockets, and maximum infestation of 26 % was noticed in one of the affected areas. During post-monsoon period, the caterpillars feed on the terminal leaves of new shoots and blossoms after webbing them.

Damage due to leaf and blossom webber

Flower thrips such as *Rhynchothrips raoensis* Giard, *Haplothrips ganglbauer* (Schmutz), *Thrips hawaiiensis* (Morgan), *H. ceylonicus* Schmutz, *Frankliniella schultzei* (Trybom) and *Scirtothrips dorsalis* Hood cause premature shedding of flowers, scabs on floral branches, apples and nuts (Thirumalaraju et al. 1990; Bhat et al. 2002). The occurrence of damage, extent of damage and seasonal incidence were reported for *R. roanensis* (Abraham 1958; Ayyanna et al. 1985; Patnaik et al. 1986; Thirumalaraju et al. 1990), *S. dorsalis*, *H. ganglbauer*, *T. hawaiiensis* (Ayyanna et al. 1985), *H. ceylonicus* and *F. schultzei* (Patnaik et al. 1987).

15.3 Factors Influencing Arthropod Population in Cashew

Insect population always fluctuates according to the dynamic condition of its environment. Climatic factors such as rainfall and humidity have been known to greatly influence the population change of *Helopeltis* spp. (Pillai et al. 1979; Muhamad and Chung 1993; Karmawat et al. 1999). Knowledge of the seasonal abundance and trends in the population build-up of pest have become important for effective control schedules. Population fluctuation study conducted in Indonesia provides good information that rainfall increased the number of shoots and inflorescence which indirectly influenced the number of *H. antonii* population (Siswanto et al. 2008a).

Other factors include natural enemies (Giesberger 1983; Karmawat et al. 1999; Peng et al. 1999a, b), temperature (Pillai et al. 1979) and food supply (Pillai et al. 1979). Less population of tea mosquito bug in the older plantation during monsoon period was due to existence of resistant phenological (matured flush) stage of cashew (Sundararaju and Sundararbabu 1999a). Population growth of TMB was estimated by obtaining the difference between average TMB population recorded

during particular week and that recorded during the preceding week. Minimum temperature between 15 and 20 °C was reported optimum for triggering the population build-up of *H. antonii* (Rao et al. 2002; Sundararaju 2005).

15.4 Tactics for Integrated Pest Management

Habitat Management It is quite obligatory to keep proper surveillance at vulnerable habitats (young cashew plantations or neem groves). Neem trees existing on the border or fence side of cashew fields act as reservoir for tea mosquito bug throughout the year (Sundararaju and Sundarababu 1999b). Therefore, it is quite obligatory to eliminate the growth of neem in the vicinity of these fields, and thereby the spread of tea mosquito bug from neem to all horticultural crops can be curtailed. Severely infested trees and dead trees should be uprooted before and after monsoon season as a main phytosanitary measure to manage cashew stem and root borer.

Monitoring The population build-up of tea mosquito bug can be monitored by using single virgin (unmated) adult TMB female as bait insect. It is possible to detect the male population at 20 m distance in few minutes during day time by this pheromone-based technology (Sundararaju and Sundarababu 1999b).

Soil Fertility In general, the optimal physical, chemical and biological properties of soils determine the capability of a crop to resist or tolerate insect pests. These properties can be manipulated through soil fertility management by way of application of organic amendments/manures. Balanced N, P and K levels induce tolerance to many of the pests and besides indirectly induce resistance upon any pest attack.

Weed Management/Phytosanitation The weeds serve as host plants to important pests of cashew. For example, *Helopeltis theivora* is capable of completing its life cycle and multiplies in a very common weed, *Chromolaena odorata*, which is present in cashew plantations (Srikumar and Bhat 2013c). Fourteen weed species belonging to ten different families were found as alternate hosts of TMB during flushing period of cashew (September–October). Hence, weed management is very important during vulnerable period (Vanitha et al. 2014). Phytosanitation activities involving removal of infested dead trees to achieve reduction of pest population in a given location are very essential for the management of cashew stem and root borer (Misra and Basu Choudhuri 1985; Raviprasad and Bhat 1998; Raviprasad et al. 2009).

Host Plant Resistance Histopathological investigations made in the tea mosquito bug-infested tender cashew shoot revealed that cashew is inherently (genetically) provided with very active phenol–phenolase system (Sundararaju and Sundarababu 1999b). Any feeding injury will result in rapid hypersensitive reactions leading to necroses, blighting and drying of affected parts especially tender shoot, panicle and fruits. The matured shoots of cashew irrespective of varieties exhibited highest ovi-

position and feeding deterrence. Every year, this type of resistant phenological stage brings down the population build-up during non-flushing period (June–September) on older plantation. Mid-season/late-season flowering cashew varieties are able to escape from the severity of the pest infestation. One such variety, Goa 11/6, showed consistent performance with yield of 2 t/ha under unsprayed situations, under moderate level of pest incidence which was later released as 'Bhaskara' (Sundararaju et al. 2006). Even though incidence of shoot tip caterpillars and apple and nut borers was observed in all the recommended varieties of cashew, sometimes the fruit set was partially affected in the varieties which were having early mixed phase of flowering with male and hermaphrodite flowers, whereas in varieties which were having early male phase, the damage was severe resulting in poor fruit set.

Pheromones and Kairomones The use of attractants in pest management systems can be a precise, specific and ecologically sound pest management approach. Kairomonal effect of cashew bark and frass extracts towards cashew stem and root borer adults have been confirmed. The components accountable for their kairomonal activity were studied. Similarly, in the case of tea mosquito bug, presence of sex pheromone activity is confirmed for *H. antonii*. A confined virgin female TMB can attract more than 30 male insects in a single day under field condition. The whole body extract of virgin females of *H. antonii* was analysed through GC-MS, and 17 components were identified including pinene, 9-hexadecenoic acid and 9-octadecenoic acid, but none of them could be implicated as sex pheromone (Sundararaju and Sundarababu 1999b). The volatiles collected from virgin female and field-collected female were analysed, and methyl butyrate, a compound exhibiting pheromone activity in other insects of family Miridae, was one of the compounds detected in the analyses (Bhat and Raviprasad 2008).

Biological Control Natural enemy (NE) diversity in the cashew ecosystem has a significant role in biological control of various cashew pests.

(A) Parasitoids A parasitoid *Erythmelus helopeltidis* Gahan (Mymaridae: Hymenoptera) was recorded to parasitise the eggs of *H. antonii* (Devasahayam and Nair 1986; Devasahayam 1989). Subsequently, two hymenopteran egg parasitoids, namely, *Telenomus* sp. (*laricis* group) (Scelionidae) and *Chaetostricha* sp. (Trichogrammatidae) were reported (Sundararaju 1993a). *E. helopeltidis* Gahan (Hymenoptera: Mymaridae), *Telenomus* sp. (*laricis* group) (Scelionidae), *Chaetostricha* sp. (Trichogrammatidae) and *Gonatocerus* sp. nr. *bialbifuniculatus* Subba Rao were the egg parasitoids reported on this pest from West Coast regions, while *Ufens* sp. was an egg parasitoid reported from the East Coast (Vridhachalam). *E. helopeltidis* Gahan (Hymenoptera: Mymaridae) was recorded as an egg parasitoid from *Pachypeltis maesarum* (Heteroptera: Miridae) (Bhat and Srikumar 2012). The build-up of TMB was naturally regulated through these egg parasitoids (Devasahayam 1989; Sundararaju 1993a, 1996). Two eulophid larval parasitoids, viz. *Sympiesis* sp. and *Cirrospilus* sp. (Hymenoptera: Eulophidae), were recorded

on leaf miners. *Panerotoma* sp. (Braconidae) and *Trathala* sp. (Ichneumonidae) were recorded as hymenopteran larval parasitoids of *T. paurosema*.

(B) Predators An array of ants, spiders, mantids, reduviids, coccinellids and a few wasps were identified as the main natural enemies of various cashew pests during different parts of the season. Many pests were preyed upon by a large assortment of natural predators such as spiders and mites, lacewings, predatory thrips and predatory bugs (Sundararaju 1993b; Chin and Brown 2008).

(C) Spiders Spiders are potential biological control agents in agroecosystems including cashew (Riechert and Bishop 1990). Several species of spiders, *Hyllus* sp., *Oxyopes sehireta*, *Phidippus patch* and *Matidia* sp. *Sycanus collaris* (Fab.), *Sphedanolestes signatus* Dist. and *Endochus inornatus* Stal., *Irantha armipes* Stal. and *Occamus typicus* Dist. have been recorded as predators (Sundararaju 1993b). The mean spider population varied from 0.22 to 0.31 per panicle, and the spider population had influence on arthropod complex during fruiting season (Sundararaju 2004). Bhat et al. (2013a, 2013b) reported spiders as indigenous natural enemies of tea mosquito bug (TMB), and the study revealed occurrence of 117 species of spiders belonging to 18 families, viz. Araneidae, Clubionidae, Corinnidae, Gnaphosidae, Hersiliidae, Linyphiidae, Lycosidae, Miturgidae, Nephilidae, Oxyopidae, Pholcidae, Pisauridae, Salticidae, Sparassidae, Tetragnathidae, Theridiiae, Thomisidae and Uloboridae. Salticids were predominant (30 %) followed by Araneidae (22 %). Field observation revealed that *Telamonia dimidiata* and *Oxyopes shweta* as the major predators of *Helopeltis* spp. The spiders, viz. *Argiope pulchella*, *Cyclosa fissicauda*, *Eriovixia laglazei*, *Neoscona mukerjei*, *Nephila pilipes*, *Oxyopes sunandae*, *Bavia kairali*, *Carrhotus viduus*, *Epocilla aurantiaca*, *Hyllus semicupreus*, *Achaearanea mundula*, *Camaricus formosus* and *Thomisus lobosus*, were also superior with respect to their predatory activity. This rich diversity of spiders is indicative of overall insect biodiversity of cashew plantation since spiders are considered to be useful indicators of species richness and health of terrestrial ecosystem.

Telamonia dimidiate

Oxyopes shweta

Oxyopes sunandae

Agriope pulchella

Telamonia dimidiate feeding on TMB

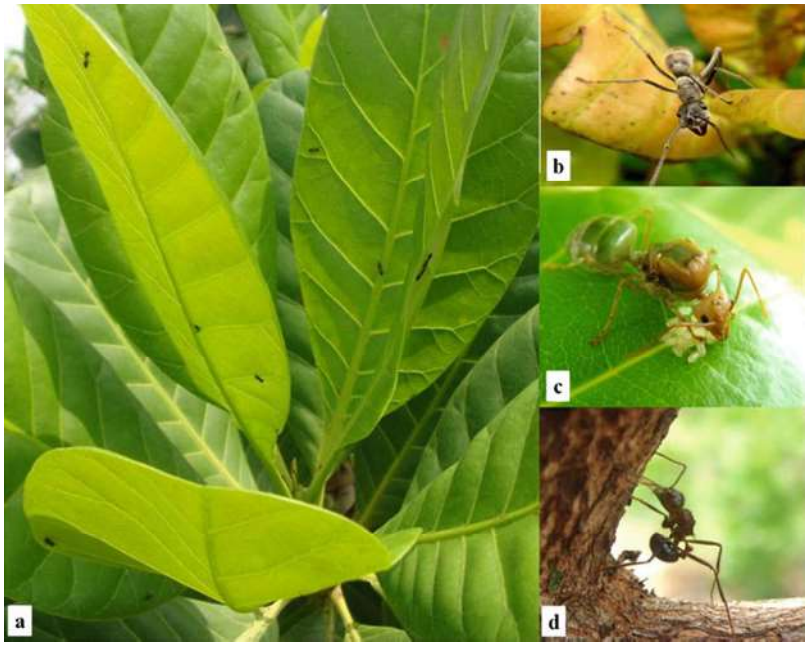
Oxyopes shweta feeding on TMB

(D) Ants The green ant, *Oecophylla smaragdina* (Fabricius), is an effective predator, and it can significantly reduce the numbers of over 30 important insect pest species of many tropical crops (Way and Khoo 1992). The green ant can significantly reduce the damage levels of the main cashew insect pests, such as the tea mosquito bug, *Helopeltis pernicialis* (Stonedahl, Malipatil and Houston); the mango tip borer, *Penicillaria jocosatrix* (Guenee); the fruit-spotting bug, *Amblypelta lutescens* (Distant); the leaf roller, *Anigraea ochrobasis* (Hampson); and the green vegetable bug, *Nezara viridula* (Fabricius) (Peng et al. 1995, 1997a, b, c, 1998). In the cashew ecosystem of the west coast of India, inter colony rivalry and death of queen due to infection by broad-spectrum mycopathogen (*Beauveria bassiana*) were commonly observed in the case of *O. smaragdina*, and these might be possible reason for low establishment (Sundararaju 2004).

The role of *Dolichoderus thoracicus* to control *Helopeltis* spp. has been extensively studied and well understood (Way and Khoo 1991, 1992; Khoo 1992; Khoo and Ho 1992). The predatory ant, *O. smaragdina*, was also found in high numbers

for each observation, and no *H. antonii* was found on cashew plants occupied by this ant. In Northern Australia, *O. smaragdina* has been used to control *H. pernicialis* on cashews (Peng et al. 1995, 1997a, b, 1999a, b). Other predators frequently found in quite high numbers were arachnids and to a lesser extent mantids and coccinellids (Siswanto 2008a). Among the five species of ants, viz. *Camponotus* sp., *Anoplolepis longipes*, *Crematogaster* spp., *Paratrechina longicornis* and *O. smaragdina* observed under cashew trees, only *Oecophylla* could control TMB effectively, while other ants were found to feed on extrafloral nectaries and as scavengers (Sundararaju 2000a). *Crematogaster wroughtonii* Forel (Formicidae) has been recorded as a predator of nymphs of TMB (Ambika and Abraham 1979).

Forty-nine species of ants (Fam: Formicidae) belonging to five subfamilies were recorded having multiple roles like predators, pollinators, scavengers, extrafloral nectarine feeders, etc. Ants belonging to Myrmicinae subfamily were dominant (22 species) followed by Formicinae (13 species). Among the ant species, *Oecophylla smaragdina* (Fabricius) and *Anoplolepis gracilipes* Smith were most abundant, while *Camponotus compressus* and *C. sericeus* were found throughout the year. The activities of most ant species are predominant during flowering and fruiting period (November–April) and pre-monsoon period (May), while during heavy rain, i.e. southwest monsoon, activities of *Myrmicaria brunnea*, *C. sericeus*, *Prenolepis naoroji* and *C. angusticollis* were only seen. In a single tree, foraging activities of maximum of seven species were found at a time especially during flowering and initial fruiting season (Vanitha et al. 2015).



Ants foraging on (**a**) cashew shoot. (**b**) *Diacamma* sp. (**c**) Queen ant of *Oecophylla smaragdina* and its eggs. (**d**) *Myrmicaria brunnea*

(E) Reduviids (Hemiptera: Reduviidae: Harpactorinae) Reduviids are recorded as potential natural enemies of *Helopeltis* spp. (Stonedahl 1991; Sundararajau 1996). Five species of reduviids, viz. *Sycanus collaris* Fab., *Sphedanolestes signatus* Dist., *Endochus inornatus* Stal, *Irantha armipes* Stal and *Occamus typicus* Dist., were reported as predators of *Helopeltis antonii* Sign. on cashew in India (Sundararaju 1984). All these predate on tea mosquito nymphs. A total of 16 species of reduviids belonging to the subfamily Harpactorinae, viz. *Alcmena* sp., *Biasticus* sp., *Cydnocoris gilvus* Burmeister, *Endochus albomaculatus* Stal, *Endochus* sp., *Epidaus bicolor* Distant, *Evagoras plagiatus* Burmeister, *Irantha armipes* Stal, *Lanca* sp., *Panthous bimaculatus* Distant, *Rhynocoris fuscipes* Fabricius, *Rihirbus trochantericus* Stal var. *sanguineous*, *Rihirbus trochantericus* Stal var. *luteous*, *Sphedanolestes signatus* Distant and *Sycanus galbanus* Distant were recorded from cashew ecosystem. The damage to cashew trees by tea mosquito bug can be reduced by the introduction of assassin bugs (Sundararaju 1984; Bhat et al. 2013c).

Cydnocoris gilvus

Panthous bimaculatus Distant

Epidaus bicolor

15.5 Pollinators

In Brazil, honeybee (*A. mellifera* L.) and solitary bee are the efficient pollinators of cashew (Freitas 1997). The fruit set is mainly influenced by activity of the pollinators (Reddy 1993). Devasahayam (1986) had reported that halictid bee [*Pseudaspis oxybelloides* (Smith)], another species of bee [*Pithitis smaragdula* (Fabr.)], honeybee (*Apis cerana indica* Fabr.) and wasp (*Odynerus* sp., Fam: Eumenidae) are pollinators of cashew and the pollen grains were detected on their legs and bodies (Sundararaju 2000b). These pollinators remove nectar or sticky pollen grains of cashew by resting directly or hovering on newly opened cashew flowers. Application of insecticides during flowering had not affected the fruit set.

Honeybee visiting cashew flowers

15.6 Future Challenges

The perennial nature of cashew is ideal for assemblage of a vast number of arthropods throughout the year. The gap in the area of bioecology of certain pests and biological control of key pests needs to be filled up. It is essential to have concerted efforts to popularise plant protection measures in cashew. Basically, cashew farmers have to be trained about the nature of the initial damage symptoms for correct identification of the pests. Need-based and timely application of pesticides is effective which needs to be based on surveillance of pests of endemic nature, since the indiscriminate sprays may result in elimination of natural enemies, mainly arthropods harbouring in cashew.

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