1. INTRODUCTION

Tea, *Camellia sinensis* (L.) O. Kuntze* is a native of China and the Chinese are said to have discovered its use nearly 5000 years ago. The word tea had its origin from 't'e (pronounced "tay") in "Amoy" dialect while in Cantonese it was called 'ch'a (pronounced "chah"). This name was known in Japan, India, Persia and Russia. The Dutch introduced the Amoy word to Europe through Java and the English word "tea" is a deviation from Dutch. Tea is unknown in the Bible and appears to be unrecorded in English literature until the latter half of the 17th century, although it is appeared to have been known in England during the first Elizabethan era. The tea plant is predominantly grown in Asia followed by Africa and to a very small extent in Europe, South America, Australia and New Zealand (Fig. 1). India ranks first in production and second in area as compared to China. Tea is cultivated in India in more than 4,28,000 ha and the principal tea growing states are Assam, West Bengal, Tamil Nadu and Kerala (Figs. 2 & 3). The commercially cultivated tea plants are derived from the short leaved China plants, *Camellia sinensis*, the Assam plants, *Camellia assamica* (Masters) and the Cambod plants, *C. assamica lasiocalyx* (Planchon ex Watt) Wight and the numerous hybrids among them. Tea plants prefer a warm humid climate, well-distributed rainfall and long sunshine hours. Shoots, comprising two or three tender leaves and a bud are harvested and processed in factories to manufacture different types of tea.

Every part of the tea plant is subjected to the attack of pests (Fig. 4). It is estimated that 1034 species of arthropods and 82 species of nematodes

* The names of authors of species are cited only at the first instance
Fig. 2. Tea growing areas in India
Fig 3. Tea growing areas in southern India
Fig 4. Spatial distribution of pests in a tea bush
infest tea. Mites, thrips, bugs, caterpillars, beetles and termites are the most important among the arthropods. Two species of eriophyid mites, \textit{Acaphylla theae} (Watt) (pink mite), \textit{Calacarus carinatus} (Green) (purple mite) are serious pests of tea throughout India. \textit{Oligonychus coffeae} (Nietner) (red spider mite), \textit{Brevipalpus australis} (Tucker) (scarlet mite), \textit{Polyphagotarsonemus latus} (Banks) (yellow mite) are the other mites which attack tea. Many species of thrips are found on the flowers and foliage of tea plants. The most common tea thrips found in southern India is \textit{Scirtothrips bispinosus} (Bagnall), while \textit{S. dorsalis} (Bagnall) is common in the north east India.

Several species of plant sap sucking bugs attack on tea plants. Among them, the tea mosquito bug, \textit{Helopeltis theivora} Waterhouse is an important one causing considerable economic loss. Lygus bug (\textit{Lygus sp.}), tea aphid (\textit{Toxoptera aurantii} Boyer de Fonscolombe), scale insects, mealy bugs and jassids are the other hemipterans that attack tea plants. The flushworm, \textit{Cydia leucostoma} (Meyrick), tea tortrix, \textit{Homona coffearia} Nietner, leaf roller, \textit{Caloptilia theivora} (Walsingham), loopers \textit{Buzura suppressaria} (Guenee), cutworm, \textit{Spodoptera litura} (Fabricus), jelly grub, \textit{Belippa lalaena} Moore and different nettle grubs are some of the important caterpillar pests of tea. The scolytid beetle, \textit{Euwallacea fornicatus} (Eichhoff), commonly called the shot hole borer is a serious pest of tea in the mid and low elevation areas in southern India. The beetle constructs galleries in stems leading to branch breakage. Adults and grubs feed on the fungus, \textit{Fusarium bugnicourtii}, growing in the galleries.

It is estimated that the annual crop loss due to pests ranges between 15\% and 20\%. In addition to the direct losses, damage caused to tea leaves by pests could adversely affect the quality of made tea. In most cases the
end product is of a low grade or of an inferior quality fetching comparatively lower prices.

The tea mosquito bug (TMB), *Helopeltis theivora* Waterhouse (Hemiptera: Heteroptera: Miridae), subject matter of this thesis, is known from the early days of tea cultivation (Peal, 1873; Wood-mason, 1884) (Plate 1). This insect was considered the most serious pest of tea in Kerala, especially in the gardens of Vandiperiyar, Peermade and Mundakayam (Idukki Dist). During the early forties, DDT dusting was a routine practice in Central and South Travancore to combat the problem of this pest. In 1954, the menace was rather low and its damage could hardly be regarded as causing loss of crop. After four decades it has reappeared during 1994 in an alarming way in these areas as well as in Assam.

Different species of TMB cause damage to tea in different countries. Though commonly called "tea mosquito" these are true bugs belonging to the family Miridae and have nothing to do with mosquitoes. In the early years of tea cultivation, planters mistook this pest for a mosquito and hence this name. Adults and nymphs suck the sap from buds, young leaves, petioles and tender stems. At the time of feeding, enzymes are injected into the plant tissues, which facilitate efficient feeding by the insects. Within an hour after feeding, a circular ring forms around the point of injury. Gradually, these spots dry up and holes appear in the later stages. Severely infested leaves become deformed, curl up and remain small. In addition to the damage by feeding, these bugs inflict injury on the tender stems by ovipositing also. *Helopeltis* damage is of two kinds: (1) a direct loss of crop by damaging pluckable shoots (2) acute debilitation of the bushes leading to die-back and delayed and meagre flushing thereafter, which account for poor yields following a severe attack.
Plate 1. Tea mosquito bug *Helopeltis theivora* on a tea leaf
Even though, general information on the life history and chemical control of *H. theivora* is available, our understanding of the bioecology, pest-host plant interactions and natural enemies of this pest in southern India is rather inadequate.
REVIEW OF LITERATURE
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Tea is a perennial monocultural crop, which provides a stable microclimate as well as continuous supply of food for a large number of arthropods. Each geographical area has its own distinctive pest fauna on tea but many species have been recorded from more than one country. Our knowledge of tea pests mainly relates to the contributions of Green (1890), Cotes (1895), Watt and Mann (1903), Hainsworth (1952), Eden (1958) and Cranham (1966a). Apart from these, regional accounts of tea pests are also available (Andrews, 1920; Rau, 1955; Das, 1965; Cranham, 1966b; Rao, 1976; Dharmadi, 1979; Rattan, 1988; Muraleedharan, 1991). Several species of hemipterans attack tea plants throughout the world and Helopeltis species belonging to Miridae are serious pests in almost all countries (Stonedahl, 1991; Stonedahl et al., 1995; Rattan, 1991).

The genus Helopeltis includes 41 species with a paleotropical distribution, extending from west Africa to New Guinea and northern Australia. The most important species of Helopeltis causing economic damage to crops in the Oriental, Australasian and African regions are H. antonii Signoret, H. bakeri Poppius, H. bradyi Waterhouse, H. cinchonae Mann, H. clavifer (Walker), H. theivora Waterhouse, H. schoutedeni Reut. (Rattan, 1991; Stonedahl, 1991; Stonedahl et al., 1995). Different species of Helopeltis infest several economically important crops such as tea, cashew, guava, neem, cocoa, black pepper, cinchona, apple and grapes as well as a number of weed species. More than one hundred species of host plants have been reported for Helopeltis species.
In India, the presence of *H. theivora* on tea was documented more than a century ago (Peal, 1873; Wood-mason, 1884). In south India, its outbreak was reported around 1920 (Shaw, 1928).

Tea shoots were damaged by *H. antonii* in Sri Lanka (Mann, 1907; Ballard, 1921), *H. bradyi* in Indonesia and Malaysia (Leefmans, 1916; Lever, 1949), *H. bergrothi* in Malawi-Africa (Leach and Smee, 1933), *H. cinchonae* in Malaysia (Lever, 1949), *H. clavifer* in New Guinea (Smith, 1978), *H. fasciaticollis* in China (Xie, 1993), *H. sumatranus* in Sumatra (Miller, 1941), *H. schoutedeni* in Malawi (Rattan, 1988) and *H. theivora* in India and Indonesia (Mann, 1902; Leefmans, 1916; Ballard, 1921).

*Helopeltis theivora* primarily feeds on leaves and new flushes and to a lesser extent on tender stem of tea plants. *H. schoutedeni* in Malawi was capable of causing a phenomenal loss in crop, up to 55% and short-term loss can be considerably higher (Rattan, 1984). A highly significant negative correlation was found between loss in crop and the percentage of damaged shoots in the harvest (Rattan, 1984). Due to its infestation, an average of 25% of the total crop was lost. The loss due to the attack of *Helopeltis theivora* in south India varied from 11 - 100% during the high cropping season (Rao and Murthy, 1976).

Das (1965) had given an account of the life history of this pest in northeast India. The duration of life cycle varied during different seasons of the year depending on climatic conditions. The life cycle was completed in about a fortnight during June and July but during cold weather the developmental period extended for 5-8 weeks (Das, 1984).
Preference for oviposition sites depended on the host plant. On cocoa, *H. theivora* preferred the pods, but would occasionally oviposit on young shoots (Miller, 1941; Tan, 1974). On tea, young shoots were preferred and rarely petioles and midribs of leaves (Mann, 1902; Das, 1984). *H. antonii* laid eggs primarily on the young cashew shoots, inflorescence stalks and sometimes on the petioles and ventral midrib of leaves (Devasahayam and Nair, 1986). It was reported that the preferred oviposition site was close to feeding lesions, which helped to minimise the injury by further feeding (Muhamad and Way, 1995). The number of eggs laid daily by the female varied. Normally, only two to three eggs were laid; rarely it could be 8-12 (Sweeney, 1967). Smee (1928), however, reported a female laying as high as 28 eggs in one day. The eggs normally hatched out early in the morning. *H. antonii* on cashew completed its life cycle within 16-17 days comprising an incubation period of 6-7 days and nymphal period of 10 days (Pillai *et al*., 1976). Sudhakar (1975) observed that the life cycle of this species on guava was completed within 22-35 days covering an incubation period of 9.2 days and a nymphal period of 19.5 days.

Multiple mating occurred at irregular intervals. At times, a female mated 6 - 8 times during her adult life (Jeevaratnam and Rajapakse, 1981). Unfertilised females of *H. antonii* infesting cashew laid usual number of eggs, which were sterile. Laboratory rearing revealed that sex ratio was approximately 1:1. However in the field there was preponderance of females (Ambika *et al*., 1979).

Temperature and light influenced the life cycle of the pest considerably. It was found that for *H. antonii* the most suitable temperature for fertilization and oviposition was 25 °C while for embryonic development it was 28 °C (Ambika *et al*., 1979). The nymphs of *H. antonii* developed best at
temperatures between 25°C and 30°C with a mean developmental period of 22 days. There was no development of *H. antonii* at temperatures above 37°C and below 14°C (Jeevaratnam and Rajapakse, 1981). Light has been proved to be an important phase setter. During sunny hours adults rest on underside of the cashew leaves and nuts possibly to avoid the direct sunlight. Sampling in the morning (07.00 h), in the afternoon (11.30 h) and in the evening (16.00 h) showed that significantly more number of insects were present in the morning than in any other time of the day (Jeevaratnam and Rajapakse, 1981).

*Helopeltis* spp., in general, have overlapping generations. In the tea growing regions of north-east India, population density of *H. theivora* reached the peak from June to September and gradually declined from November, as the weather cooled down. Few adults were found on the tea plants during winter months but their numbers increased again in March as nymphs emerging from over wintering eggs (Mann, 1902; Das, 1984). Ahmed *et al.*, (1992) developed a population model for *H. theivora* in Bangladesh tea based on the data on seasonal abundance. The model simulated the population dynamics of the pest throughout the season and output of the model indicated that the population density of eggs, nymphs and adults was low during the early part of season, increased rapidly to a peak in September, declined slightly in October and quickly in November to become very low from December to March. This seasonal pattern appeared to be influenced by high fecundity and short developmental period during June to October.

Detailed information on the seasonal prevalence of *H. theivora* in south India is not available but it is generally considered a wet weather pest appearing in large numbers during south west and north east monsoons, the insect being intolerant to very dry condition (Shaw, 1928; Rau, 1940; Rao,
Smee (1928) found a significant correlation between outbreaks of *H. bergrothi* on tea in Malawi and the number of rainy days particularly in November and February.

In peninsular India, the build up of populations of *H. antonii* on cashew in October/November synchronized with the emergence of new foliage following the cessation of northeast monsoon. It reached a peak in January/February when cashew trees were in full bloom, the insects remain active on the plants until the onset of the monsoon rains in June (Pillai et al., 1984; Sundararaju, 1984; Devasahayam, 1985; Rajapakse and Jeevaratnam, 1983; Satapathy, 1993). Senguttuvan and Bhaskaran (1993) reported a negative relationship between rainfall and the incidence of *H. antonii*.

Most of the species of *Helopeltis* were found to thrive best in dull, overcast weather with frequent mist. de Jong (1935) suggested that some changes in the tea plants during wet season favoured reproduction. However, high winds with low humidity were limiting factors in the development of *Helopeltis* in eastern Sumatra where the insects developed under fairly dense shade.

Chinery and hybrid tea jats were found invariably more susceptible to *H. theivora* than 'Assam' varieties (Anstead and Ballard, 1922; Rau, 1940). However, in Assam, all tea clones were found infested and among them TV-1 was the most susceptible (Das, 1984). The clones TV-11, TV-17, TV-21, TV-25 and TV-26 had been reported tolerant (Somchoudhury *et al.*, 1993). To a certain extent this holds good since the dark-leaved Manipuri jat of tea hardly suffers severely from the attack of *H. theivora*. 
Ecological life tables are one of the tools useful in the study of insect population dynamics, and the general format for the preparation of the same was discussed by Harcourt (1969). The components of life table studies are developmental period, reproductive period, fertility and survival. The intrinsic rate of natural increase was the main focus of the study because it had been used as a bioclimatic index for rating the populations (Messenger, 1964). Several articles are available on the life tables of hemipteran pests (Kalita et al., 1996; Sundararaju, 1996; Sundararaju and Babu, 1998; Prakash and Rao, 1999). However, life tables have not been worked out for *H. theivora* occurring on tea in this part of the country.

The nymphs and adults of *Helopeltis* suck the sap from the tender leaves, stems and also buds after injecting toxic saliva into the plant tissue, which causes the breakdown of the surrounding cells (Ahmed, 1996). Leach and Smee (1933) observed that an adult of *H. bergrothi* could feed on green tea stem for about 20 min. Further, an adult could make 150 feeding punctures in a day (Hainsworth, 1952). The damage to tender stems was not only due to sucking but also due to oviposition. The mechanism of feeding by *Helopeltis* sp. had been studied by Cohen-Stuart (1922) who showed that the proboscis of insect penetrated the vascular bundle resulting in the collapse of tissues. The collapse of parenchyma was seen 1½ h after feeding. Leach (1935) showed that the primary lesions could be recognised on mangoes before the insect stopped feeding, indicating an extremely active feeding process. The development of symptoms following *Helopeltis* feeding was much more rapid than that of other infection and this appeared to be the principal support for the numerous suggestions in literature that the salivary secretions were phytotoxic. This rapidity in feeding was, of course, associated with the extensive damage inflicted by a small population of *Helopeltis*. 
The function of the salivary glands in insects and the nature of the salivary secretions were reviewed by Day and Waterhouse (1953). Baptist (1941) studied the digestive enzymes present in the salivary glands of 20 species of Hemiptera, and Nuorteva (1954) made a similar study on 8 species of Hemiptera injuring wheat.

Many of these insects possess salivary enzymes that are capable of depolymerizing various plant matrix polysaccharides like cellulose and pectin (Miles, 1972; Hori, 1975). The depolymerization of structural polysaccharides by these enzymes causes degradation of plant cell walls, resulting in the maceration of plant tissues and this enables these bugs to imbibe the liquefied products (Campbell and Shea, 1990). Adams and McAllan (1956, 1958) reported the presence of pectinase in the saliva of Aphidoidea. Schaller (1968) found protease in the salivary enzyme solution. Polyphenol oxidases and peroxidase were found in the salivary glands of various Heteroptera and Homoptera (Miles, 1964; Miles and Slowiak, 1970). Salivary pectinase was reported to aid intercellular penetration of plant tissues, and cellulases involved in the penetration of cell wall (Miles, 1969, 1978, 1987a&b). Both hydrolytic (protease and lipase) and oxidoreductase enzymes (catechol oxidase, peroxidase and catalase) were reported from the saliva of H. antonii. However, only protease from H. corbisieri Schmitz (Kumar, 1970) and polygalacturonase from H. clavifer had been reported (Miles, 1987a). It is possible that protease may be responsible for the extra-intestinal digestion as reported in another mirid, Lygus dispensi L. (Hori, 1970 a & b). Though H. antonii was able to feed on each feeding site for more than five minutes, water-soaked lesion appeared within a minute beyond the point of entry indicating that the components of saliva diffused rapidly among cells causing phytotoxaemia (Sundararaju, 1996).
The salivary glands of insects are ectodermal in origin, and have developed as paired glands from the labial segment. Hemipteran salivary glands consist of two major parts, the principal gland and an accessory gland. The size and number of lobes present in each principal and accessory gland vary, though a bilobular principal gland and a unilobular accessory gland are the most common. Bugnion and Popoff (1910) and Dokroscky (1931) considered that a bilobed principal gland with a unilobular accessory gland is the primitive condition in Hemiptera.

Although a few studies had been conducted on the biology of tea mosquito bug, reports on physiological and biochemical changes in the host plants during infestation are limited. In cashew, infestation by *H. antonii* led to reduction in the sugar content (Rai and Nagaraja, 1988). Further, Nagaraja *et al.*, (1994) observed a reduction in the sugar, chlorophyll and carotenoid contents due to its attack. There was an increase in total phenol content, nitrate reductase activity and leaching of electrolytes after 24 hours of feeding. Loganathan (1992) had reported a reduction in chlorophyll content and photosynthetic rate in tea due to the attack of the eriophyid mite, *Acaphylla theae*.

In addition to direct losses, damage caused to tea leaves by the pests adversely affects the quality of made tea, fetching low prices. Infusion of teas made from the shoots affected by thrips, aphids, flushworm, leaf roller, pink mites and tea mosquito bug were dull when compared to the teas made from healthy leaves (Murthy and Chandrasekaran, 1979; Radhakrishnan, 1989; Selvasundaram, 1990; Kumaravadivelu *et al.*, 1996).

A large number of predators and parasitoids of tea mosquito bug have been reported (Simmonds, 1970; CIBC, 1983; Ibrahim, 1989; Cadou, 1994).
Watt and Mann (1903) found a reduviid feeding on tea mosquito in Assam. Three species of reduviid bugs *Endochus cameronicus* Miller, *Isyndus lateiventris* Dist. and *Euagora* sp. were tested against *Helopeltis* affecting cocoa at Kuala Lumpur (Lever, 1949). *Crematogaster wrougtoni* Forel (Hymentoptera : Formicidae) was recorded as a predator of eggs and early instars of tea mosquito (Ambika et al., 1979). An egg parasitoid, *Gouatocerus* sp. nr. *bialbifuniculatus* Subba Rao was found parasitising the eggs of TMB while two reduviids, *Panthous bimaculatus* Dist. and *Sycanus collaris* (Fab.) feed on nymphs and adults of TMB (Sundararaju and Raviprasad, 1993). The green ant, *Oceophylla smaragdina* (Fabricius) (Hymenoptera : Formicidae), was reported to reduce the numbers of *H. pernicialis*, attacking cashew plants (Peng et al., 1995). *Erythmelus helopeltidis* was reported as an egg parasitoid of *H. cinchonae* affecting tea from Malaysia (Lever, 1949). A flower inhabiting species of Thomisidae (Crab-spider) was found attacking adult mosquito bug (Sweeney, 1961). In Africa, *Euphorus* spp. (Braconidae), mantids and reduviids were recorded as natural enemies of *Helopeltis* spp., though a significant reduction in the pest population could not be observed (Sweeney, 1967). Investigations by Jeevaratnam and Rajapakse (1961) showed that *Trichogramma minutum* parasitised the eggs of *H. antonii*. *Beauveria bassiana* was also recorded as a pathogen on *H. theivora* under field conditions (Wood, 1994).

Traps using sex pheromones are one of the recent tools employed in insect pest management. Jacobson (1965) reported only two instances of sex attractants in hemipterous insects. The male of *Lethocerus indicus* (Lepeletier & Serville), a giant water bug releases a substance that makes the female more receptive to males. Both the sexes of the bronze orange bug, *Rhocecocoris sulcivenris* (Stall), were reported to produce substances that may
act as sex attractant or aphrodisiac (Scales, 1968). Methyl 2, 6, 10-trimethyltridecanoate was reported as a male produced attractant pheromone of the south American soybean pest, *Euschistus heros* and that of *E. obscurusi* (Mori and Murata, 1994). Thistlewood *et al.*, (1989) found that female mullein bugs emitted a sex pheromone that attracted males to female-baited traps in a manner similar to that found in the mirids *Lygus linolaris* (P.de Beauvois) (Scales, 1968), *Lygocoris communis* (Knight) (Bovin and Stewart, 1982), *Distantiella theobroma* (Dist) (King, 1973) and *Helopeltis clavifer* (Walker) (Smith, 1977; Staddon, 1986). Staddon (1986) also found that female produced compounds, butyl butyrate and hexyl butyrate failed to attract the males of *Combyloma verbasci*.

The presence of a sex attractant pheromone in the adult females of *H. clavifer* (Wlk.) affecting cacao in Papua New Guinea, was demonstrated in the laboratory and field. Pheromone release was found to occur at all times of the day, but the number of males attracted was highest during the first few hours of darkness each day (Smith, 1977). Earlier reports had indicated the presence of a sex attractant in the female of *H. clavifer* (Smith, 1977). Very little information is available on the existence of sex pheromone in *H. antonii* (Sundararaju *et al.*, 1994).
SCOPE OF THE PRESENT STUDY
SCOPE OF THE PRESENT STUDY

The review of literature clearly indicated that information relating to the bioecology, insect-host plant interaction, feeding and natural enemies of *Helopeltis theivora* infesting the tea plants is scanty. In view of these, efforts were made to investigate the following aspects.

Detailed studies were carried out on the life history and life table of *H. theivora*, on three host plants viz., *Camellia sinensis* (tea), *Maesa indica* (weed) and *Camellia japonica* (ornamental *Camellia*). The influence of different temperature and photoperiod on the life history was studied. Observations were made on the varietal susceptibility, feeding behaviour, salivary enzymes and its physiology.

Changes occurring in the plant tissues were studied through anatomical sections. Important biochemical constituents of green leaves such as polyphenols, catechins, amino acids, total soluble sugars, nitrogen, phosphorus and potassium were analysed in both infested and normal tea shoots. The impact of feeding on chlorophyll and carotenoid contents and net photosynthesis of tea leaves was studied. The activity of enzymes such as polyphenol oxidase and peroxidase was also studied.

Black tea manufactured from infested shoots was compared with the tea samples prepared from normal shoots for important quality parameters such as theaflavins, thearubigins, total liquor colour, and high-polymerised substances. Organoleptic evaluation of teas made out of infested and normal shoots was made to confirm the impact on quality.
The population trend of *H. theivora* was observed for five years and the influence of weather factors such as rainfall, maximum and minimum temperature and relative humidity on the natural population was studied. Periodically, surveys were undertaken in the tea areas to explore the presence of natural enemies of this pest.

While studying the behaviour of this *H. thievora*, a strong pheromonal activity was observed. Virgin females attracted males in a large numbers. Wind tunnel studies were carried out in the laboratory to screen the response of males to females. Field studies were also carried out to confirm the pheromonal activity. GC-MS analysis of the volatiles extracted from the virgin females was also carried out.

The information obtained through these studies will help to evolve an integrated strategy to manage this important pest of tea.