CHAPTER-2

REVIEW OF LITERATURE
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The first report on Indian termites was done by Konig (1779). Unfortunately, his specimens were lost. There was no further addition to our knowledge on Indian termites until the work of Holmgren (1912, 1913a). In 1917, Holmgren and Holmgren worked out a large collection of termites, subsequently, Silvestri (1922), Snyder (1933), Margabandhu (1934), Snyder (1949), Ratanlal and Menon (1953), Ahmad (1958), Mathur and Sen-Sarma (1961), Roonwal (1959, 62b, 70, 73, 75) Roonwal & SenSarma (1956, 60) have also reported their works. Taxonomy and zoogeographical studies of Indian termite fauna including termite fauna of Assam was studied extensively by Roonwal and Chhotani (1962a, 65, 77). Das (1959) published some observations on the control of termites attacking live wood of tea in Assam. Regarding the termite control perspective in India, following references can be cited- Das (1958), Dantharayana & Fernando (1970), Agarwala (1972), Rajagopal & Veeresh (1978).

A review of literature suggest that considerable work ranging from merely descriptive studies to the infrastructure of termite control have been carried out both in India and abroad. Termites are considered as good candidates for control with the help of pathogens because they live in a conducive environment-humid, minimal diurnal temperature fluctuations, crowded and with considerable social interaction (Delate et al., 1995; Creffield, 1996). Most of the species maintain symbiotic relationship with micro-organisms which are essential for digestion (Logan et al., 1990; Berchtold et al., 1999). Many other micro-
organisms have been associated with termites or termite nests (Holt, 1998), however only a few of these are potential pathogens (Logan et al., 1990). Fungi belonging to entomopathogenic species have been isolated from termites or termite nest material and many of these are highly virulent to termites (Zoberi & Grace, 1990; Milner et al., 1998a, b). In the recent time Mukhopadhyay et al. (1996) attempted on the potentiality of insect predators for regulating pest populations of tea in North Bengal. The studies on the biocontrol potential against termite species in India are very meager with the exception of reports by Sannasi (1969), Khan et al. (1993), Padmaia and Kaur (2001) from Southern India. Attempts have not yet been made systematically to work out the potential of biocontrol agents against any species of tea pest including termite occurring in the Barak valley of Assam. Keeping the above facts in view, and the present state of our knowledge on this particular group of insect pests and also realizing the importance of the problem and paucity of literature, the present work has been taken up.

Biological insect pest control is the use or encouragement by man or living organisms or their products for the population reduction of insect pests (Coppel and Mertins, 1977). Biological control is especially desirable because it is safe, permanent and economical. It has been advocated as the first line of attack and is now officially designated as the preferred method of pest suppression.

In recent years, the shortcomings of conventional control methods have promoted policy makers and scientists to evaluate the potential of biological control of termites, to determine the potential of natural enemies
(predators, parasitoids, pathogens) to suppress termite population (Culliney & Grace, 2000).

Although termites are an important part of the food chain for many animals such as insects, birds, reptiles and mammals (including man) (Rajagopal, 1984), the impact of natural enemies on termite population dynamics is only partially understood (Wood & Johnson, 1986; Culliney & Grace, 2000). In a review by Ochiel (1995), at least 10 vertebrates and 17 invertebrate natural enemies of termites in Africa were listed. In Kenya, two species of ants have been reported to prey on Microcerotermes michaelseni (Lepage & Darlington, 1984). Kenne et al. (2000) concluded, that under certain conditions the predatory ant Myrmicaria opaciventris Emery (Hymenoptera: Formicidae) can be used as a biological control agent against termites. While control of termites exist in nature and numerous studies have shown the importance of natural enemies, but few have been used so far as biological control agents. This is partly due to the lack of specificity and difficulties in rearing the natural enemies of termites (Beard, 1973).

In the first attempt for mass production and artificial application, the entomopathogenic agent taken was the fungus, Metarhizium anisopliae (Metschnikoff, 1879).

Fungi are the most promising entomopathogens for the development of a microbiological termiticide (Milner & Staples, 1995). Wide laboratory and field studies have been conducted using entomopathogenic fungi as biological control agents against termites. In his review Gitonga (1996) reports, that fungal species
of at least 11 genera from four fungal families, (i.e. Deuteromycetes, Zygomyceytes, Ascomycytes and Mitosporic) have been tested against termites. The tested fungal species belonged to the genera Metarhizium, Beauveria, Paecelomyces, Aspergillus, Verticillium, Nomuraea, Conidiobolus, Basidiobolus, Absidia and Cordycepioideus.

Some authors have recently reviewed the biological control of termites, i.e. Grace (1997), Milner (2000a), Culliney & Grace (2000) and Rath (2000). All of them suggested that the greatest potential for biological control of termites appears to lie on entomopathogenic fungal pathogens, particularly on the two well-studied fungi, B. bassiana and M. anisopliae. Metarhizium anisopliae and B. bassiana are the most widely tested entomopathogenic fungi against the termites. These tests were conducted against 15 species of termites from three families of lower termites, i.e. Kalotermitidae, Hodotermitidae, and Rhinotermitidae, and one higher termite family, i.e. Termitidae. Among the 15 species, 11 species belong to the lower termite families and four species to the higher termites.

Milner and Staples (1996) reported about the species of fungi found to be pathogenic to termites. The general biology, pathology and ecology of the two most widely studied species of entomopathogenic fungi, Metarhizium anisopliae and Beauveria bassiana, have been reviewed by Ferron (1981), McCoy et al. (1988), Glare & Milner (1991) and Goettel (1992). Both the fungi have been used on a commercial basis for the control of insect pests in a number of countries, and isolates of both have been registered with the US-EPA (Cook et al., 1996).
While both *M. anisopliae* and *B. bassiana* have been reported as infecting a wide range of insect hosts (700 in case of *B. bassiana*, cited in Cook *et al.*, 1996), individual isolates are found to be considerably more host-specific (Goettel *et al.*, 1990). It has been observed that there are several reports of fungal isolates that are only pathogenic to only one host under the field conditions (Cook *et al.* 1996). However, the reports also suggest that some isolates can be highly virulent to previously unencountered hosts. Edgington *et. al.* (2007) have used oil formulations of *B. bassiana* for the control of Sunn pest (*Eurygaster integriceps*). Candidate strains of *B. bassiana* were identified for use in integrated pest management of the banana weevil *Cosmopolites sordidus* in Uganda (Tinzaara *et al.* 2007). In his review Zimmermann (2007) reported that the entomopathogenic fungi of the species *B. bassiana* and *B. brongniartii* are considered to be safe for use in insect pest control. Ugine *et al.* (2007) reported the use of *B. bassiana* for the control of western flower thrips *Frankliniella occidentalis*, infesting greenhouse *Impatiens* crop. Dry formulations of *B. bassiana* have been used as microbial control agent against insect pests of agricultural crops (Al-Mazraawi *et al.* 2007). Rao *et al.* (2006) reported the combine treatment with two entomopathogenic fungi *B. bassiana* and *Nomuraea rileyi* (Hypocreales) on *Spodoptera litura*. Mohan *et al.* (2007) studied the combine treatment of *B. bassiana* and neem oil against *Spodoptera litura*. The comparison of application methods for suppressing the Pecan Weevil with *B. bassiana* under field conditions was demonstrated by Shapiro-ilan *et al.* (2008). Combined treatment with *B. bassiana* and diatomaceous earth was evaluated.
against the bean weevil *Acanthoscelides obtectus* and rice weevil *Sitophilus oryzae* (Bello *et al.* 2006). Nguyen *et al.* (2007) reported the efficacy of stains of entomopathogenic fungal species, i.e. *B. bassiana*, *M. anisopliae* and *Paecilomyces fumosoroseus* against *Helicoverpa armigera*. The effect of repeated conidial sub-culturing of *Metarhizium anisopliae* on its virulence against *Helicoverpa armigera* was reported by Nahar *et al.* (2008). In his review Zimmermann (2007) reports that the entomopathogenic fungi of the species *M. anisopliae* are considered to be safe for use in insect pest control with minimal risk to vertebrates, humans and the environment. Bak *et al.* (2007) showed that the residual effect of the treatment of *M. anisopliae* against Sahelian grasshoppers is possible if it is used in a repetitive treatment strategy in control operations. Kabaluk *et al.* (2007) studied the environmental and behavioral constraints on the infection of wireworms by *M. anisopliae*. Wright *et al.* (2005) reported the isolation of a strain of *M. anisopliae* from the alates of Formosan subterranean termite, *Coptotermes formosanus* and its virulence to the workers of the said termite species. Rath *et al.* (1995b) in their field experiments observed that *M. anisopliae* isolate DAT F-001, which was highly virulent to redhead pasture cockchafer (Coleoptera: Scarabaeidae: *Adoryphorus couloni*), was not pathogenic to any other invertebrate. Sun *et al.* (2008) illustrated the interactions of *Metarhizium anisopliae* and tree-based mulches in repellence and mycoses against the *Coptotermes formosanus*. However, Rath and Tidbury (1996) have shown that the same isolate was highly virulent to *Coptotermes acinaciformis* and *Nasutitermes exitiosus*. 
Considerable works on the biocontrol potential of entomopathogenic fungus have been explored by several workers all over the world (Hanel, 1982; Kramm et al. 1982; Hanel and Watson, 1983; Zoberi& Grace 1990; Khan et al.1993; Delate et al.1995; Sunderbabu &Jayaraj, 1995; Jones et al. 1996; Padmaia and Kaur, 2001). Investigations of Rath (2000) can be cited who showed that termite species are highly susceptible to entomopathogenic fungal species *Metarhizium anisopliae* and *Beauveria bassiana*. The commercial products of these fungal isolates are currently available in the U.S.A. Strasser et al. (2002) summarized the efficacy of specific secondary metabolites of *Beauveria, Metarhizium, Tolypocladium* as possible biocontrol agents against a wide variety of insect pests.

Most researches on the biological control of termites have been focused on the potential use of entomopathogenic nematodes (EPNs) and fungi (Milner & Staples, 1995). Mankowski et al. (2005) examined the attachment and infectivity of two entomopathogenic nematode species *Steinernema carpocapsae* and *Heterorhabditis indica*, on the soldiers and workers in two subterranean termite species, *Coptotermes formosanus* and *C.vastator*. Entomopathogenic nematodes are also reported to be used against different insect pests. Koppenhofer et al. (2008) evaluated the entomopathogenic nematodes *Steinernema scarabaei* and *Heterorhabditis bacteriophora* and *H.zelandica* for the control of white grub, *Phyllophaga Georgiana* (Coleoptera: Scarabaeidae) in cranberries. Shapiro-ilan et al. (2008) studied the application of nematode-infected cadavars from hard-bodied arthropod for insect suppression.
In the review by Gitonga (1996) on the biological control of termites indicated that five EPN species from three families caused 4.8 to 100% mortality in *Reticulitermes* spp. (Isoptera: Rhinotermitidae), *Cryptotermes* spp., (Isoptera: Kalotermitidae) and *Microcerotermes* spp. (Isoptera: Termitidae) *in vitro* (Stadykov *et al.*, 1973; Epsky & Capinera, 1988; Mauldin & Beal, 1989; Wu *et al*., 1991; Khan *et al.*, 1994). In the field study *Steinernema* spp. and *Heterohabditis* spp. provided limited control of subterranean termites, but have generally not proved successful for long-term suppression (Mauldin & Beal, 1989). Therefore, Mauldin and Beal (1989) concluded that EPNs are not very effective for termite control. Pearce (1997) states that though many hundreds of infective juveniles were released from termite cadavers after infection by a single nematode, chances for re-infestation are generally very low because of the high mobility of all the growth stages of termites. In addition, EPNs need free water to survive (Pearce, 1997). Wang *et al.* (2002) studied the potential of EPNs for the control of eastern subterranean termite *R. flavipes* and observed that although nematodes are able to reproduce in termites; but they were rarely seen emerging from the dead termites. This was due to the fact that mites associated with *R. flavipes*, often consumed the nematode-killed termites. Moreover, healthy termites frequently ate dead termites, thus preventing the EPNs to reproduce in their hosts. Therefore, the authors concluded that due to the limited mobility of EPNs in termite mounds, mainly because of the walling-off behaviour of termites (Fujii, 1975), and the low rate of reproduction in dead termites, it is rather unlikely
that EPNs will reach and maintain a large enough density to eliminate a termite colony in the field.

Kaya (1993); Kaya and Gaugler (1993); Ehlers (1996); Hominick *et al.* (1996); Peters (1996); Fenton *et al.* (2002), suggested the current status and future use of entomopathogenic nematodes of the genera *Steinernema* and *Heterorhabditis*, which may provide an environment friendly and economically viable alternative. Their abundant occurrence in Indian soil have been reported by Rajkumar and Sivakumar (1997) from Kanyakumari district (TamilNadu) and by Karunakar *et al.* (2001) from Coimbatore (TamilNadu), India.

These entomopathogenic fungi and entomopathogenic nematodes of Indian origin perhaps can be successfully utilized and therefore has been attempted in the present research work. These known species along with other possible strains occurring in this unexplored geographical area will be searched with a view to develop possible biocontrol agents against the termite species occurring endemically as a serious pest of tea in Southern Assam (Barak valley).

Most of the pathogenic entobacteria are found in the families Bacillaceae, Pseudomonadaceae, Enterobacteriaceae, Streptococcaceae and Micrococcaceae (Tanada and Kaya, 1993). Although there are many different types of bacteria that are known to infect insects, only members of two genera of the order Eubacteriales, *Bacillus* (Bacillaceae) and *Serratia* (Enterobacteriaceae), have been registered to control insects. Bacillus is by far the most important microbial pesticide genus. *Bacillus thuringiensis* is a spore-forming, gram positive bacterium of ubiquitous occurrence, with as many as 50
serotypes or 63 serovars (Thiery and Frachon, 1997). There are several reports on the efficacy of entomopathogenic bacteria and viruses against the caterpillar pest of tea (Kariya, 1977; Sato et al. 1986; Tabashnik et al., 1990; Tabashnik et al. 1991). The efficacy of *Bacillus thuringiensis* on tea insect pest have been reported by Muraleedharan & Radhakrishnan (1989); Muraleedharan (1993). The effectiveness of *Bacillus thuringiensis* strains against *Spodoptera frugiperda* was reported by Polanczyk et al. (2000). Chandrashekar et al. (2005) reported the susceptibility of American bollworm, *Helicoverpa armigera* to *Bacillus thuringiensis* var. kurstaki. Cai et al. (2005) studied the toxicity of *Bacillus thuringiensis* to *Spodoptera exigua*. Liao et al. (2002) examined the toxicity of *B. thuringiensis* insecticidal proteins for *Helicoverpa armigera* and *H. punctigera*. Luttrell et al. (1998, 1999) reported the relative activity of commercial formulations of *B. thuringiensis* against selected noctuid larvae. Mohan and Gujar (2002) observed the susceptibility of diamondback moth, *Plutella xylostella* to *B. thuringiensis* spore-crystal mixtures. Wu et al. (1999) reported the geographical variation in susceptibility of *Helicoverpa armigera* to *B. thuringiensis* insecticidal protein in China. Ioriatti et al. (1996) reported the effectiveness of *B. thuringiensis* on three species of apple leafrollers.

*Bacillus thuringiensis* Berliner has been shown to cause 75-100% mortality in *R. flavipes*, *R. virginicus* (Banks), and *R. hesperus* (Banks) (all Isoptera: Rhinotermitidae) *in vitro* (Symthe & Coppel 1965; Stadykov, 1970; Khan et al., 1985, Grace & Ewart, 1996). Castilhos et al. (2002) evaluated the susceptibility of *Nasutitermes ehrhardtii* (Isoptera: Termitidae) to *Bacillus*.
*B. thuringiensis*. However, no field data on *B. thuringiensis* efficacy for termite control is available so far (Milner & Staples, 1995).

Plants are a valuable source of new natural products. Plant products are considered as safer and alternative to toxic synthetic chemicals currently in use. Many chemicals in plants are found to either inhibit or induce insect feeding, which adversely affect the metamorphosis and growth in a number of insect pests (Bowers et al. 1976; Kubo et al. 1982; Redfurn, 1982; Staal, 1986; Selvasundaram, 1990; Krishnayya and Rao, 1995; Gujar, 1997). This approach may help in enhancing natural entomopathogenic enemy activity in crop fields and may find a role in the Integrated Termite Pest Management in tea as well.

Seventy one species of insects belonging to orders Coleoptera, Diptera, Hemiptera, Isoptera, Lepidoptera, and Orthoptera have been reported to be responding to neem extracts and its pure compounds (Warthem, 1979). The number of insect species affected adversely by neem extracts alone have been 123 (Jacobsen, 1986), 198 (Saxena, 1989), 300 (Singh, 1996), respectively, out of which 105 are from India alone (Singh and Kataria, 1991). The ingredients of botanicals have exhibited their bioactivity against the insect pests as repellent, feeding and oviposition deterrent, growth regulatory and sterilant effects. In addition, direct toxicity and impairing of hatchability was also observed (Lal and Srivastava, 2002). Biological activities of *Eucalyptus* species and *Tylophora indica* have been documented against the insect pests. (Stampolous, 1991; Shanthi & Janarthan, 1995; Pal et al. 1996; Singh et al. 1996; Kathuria & Kaushik, 2005). Biological activity of tree marigold, *Tithonia diversifolia*, on
cowpea seed bruchid, *Callosobruchus maculatus* was reported by Adedire and Akinneye, (2004). Adedire (2003) reported the use of nutmeg, *Myristica fragrans* powder and oil for the control of cowpea storage bruchid *Callosobruchus maculates*. Secondary plant compounds of some plants have been successfully used for integrated control of pests in the tropics, Mediterranean and temperate zones (Prakash & Rao, 1997). The repellent effects of *Pongamia pinnata* oil on settlement and oviposition of the common greenhouse whitefly *Trialeurodes vaporariorum* on chrysanthemum was reported by Pavela & Herda (2007). Akinkurolere et.al. (2006) reported the efficacy of crude stem extracts of forest anchomanes, (*Anchomanes difformis*) against pulse beetle *Callosobruchus maculates*.

Nwilene et.al.(2008) reported the effectiveness of red palm oil, neem seed oil and neem powder against termites causing damage to upland rice in Nigeria. Boue and Raina (2003) reported the effects of plant flavonoids on the fecundity, survival and feeding of the Formosan subterranean termite *Coptotermes formosanus*. Badshah et.al. (2005) evaluated the toxic effects of *Polygonum hydropiper* and *Cannabis sativa* plants extracts against termite species *Heterotermes indicola* and *Coptotermes heimi*. Adoyo et.al. (1997) found *Tithonia diversifolia* to be effective in on-farm control of termites in Kenya. Kumudini et.al.(2006) observed that the natural products derived from plants, *Artemisia douglasiana*, *Ligusticum hultenii* and *Centaurea maculosa* were exhibiting activity against Formosan subterranean termite, *Coptotermes formosanus*. Zaheer et.al. (1987) reported the isolation and characterization of termite repellents from the
needle of *Pinus roxburghii*. Lin and Wang (1988) studied the antitermite properties of extracts from *Melia azadirach*. Huang *et al.* (1990) studied the toxicity of the extract from *Ajuga nipponensis* against the termite *Coptotermes formosanus*. Parihar and Singh (1992); Jalees *et al.* (1993) Parihar (1994) and Hutchins (1997) have worked on the different plant extracts for their toxicity, attractancy and repellency in various natural products against insect species. Hutchins (1997) evaluated the natural antitermite properties of tung tree, *Aleurites fordii* extracts. Castor oil, castor cake, castor oil + castor cake (1:1) and castor leaves have significantly reduced the weight loss in termite affected wood of *Mangifera indica* and *Pinus longifolia* (Sharma *et al.* 1990). Ishida *et al.* (1992) purified 11 limnoid compounds from neem oil which exhibited antifeedent property against *Reticulitermes speratus*. Stem and leaves of *Anona reticulata* were also considered to have insecticidal properties, especially against termites. Mokabel and Gowda (2000) reported to have antitermite properties in products of *Pongamia pinnate* Pierre, *Azadirachta indica* A.Juss, *Annona squamosa* L., *Bassia latifolia* Roxb., *Swietenia macrophylla* and *Ricinus communis* L. Beeson (1941), Rao *et al.* (1991) and Gold *et al.* (1991) have demonstrated the termiticidal properties of neem products. Endemic plant extracts from different localities can be exploited along with our known knowledge of active principles from *Ageratum* and Indian neem (*Azadirachta indica*), which are found to be having potent antiallelootropic (anti juvenile hormone) chemicals.

Of the several hundred thousand plant species around the globe, only a small proportion has been investigated phytochemically, biologically and
pharmacologically. When one considers that a single plant may contain up to thousands of constituents, the possibilities of making new discoveries become evident. The crucial factor for the ultimate success of an investigation on the bioactive plant constituents is thus the selection of plant material (Hostettmann, 1997).

Above hypotheses with positive approaches may be exploited in order to determine the plausibilities of the potent biocontrol agent against the termite pests of tea under the agro climatic conditions of Barak valley of Assam.