REVIEW OF LITERATURE

3. Review of Literature

3. 1. Pests and lepidopteran defoliators of tea

Tea provides a stable microclimate and continuous supply of food for rapid buildup of more than 300 insects (Banerjee, 1987b). The monographs by Green (1890) and Watt and Mann (1903) are the earliest contributions to the study of tea pests. Information on tea pest biology in N. E. India is given by Hainsworth (1952), Das (1965), Banerjee (1983 a, b) and that of South India and Sri Lanka by Muraleedharan (1983) and Cranham (1966) respectively.

Chen and Chen (1989a) had estimated a total of 1034 species of arthropods associated with tea plants. Among the arthropod tea pests, Lepidoptera was the largest order containing 32% of the pest species followed by Hemiptera with 27%. The dynamics of insects have enabled them to attack every part of the tea plant, the maximum number of which are occurring on foliage (Muraleedharan and Chen, 1997).

The common looper *Buzura (Biston) suppressaria* Guen. caterpillar is one of the most destructive pests of tea and in recent years, its activities have greatly increased and become endemic to many gardens where it was unknown in the past (Anonymous, 1994). In the earliest record of tea pests by Cotes (1895), this pest was reported to have been collected first from Nowgong district of Assam. Subsequently Antram (1911) had reported looper caterpillar as one of the common pests of tea. Besson (1941) in 'The Ecology and control of the forest insects of India and the neighbouring countries' recorded looper caterpillar on alternate hosts such as *Acacia modesta, A. catechu, Aleurites montana, Bauhinia variegata, Cassia auriculata, Carissa diffusa, Dodonaea viscosa, Lagerstroemia indica, Dalbergia assamica, Derris robusta, Albizzia chinensis, A. odoratissima, A. lebbek, Cajanus indicus* and *Priotropis cytisoides* .

Danthanarayan and Kathiravetpillai (1969) related the outbreaks of looper (*Ectropis bhumitra* Wkr.) with the presence of shade trees and use of dieldrin which killed many species of hymenopterous insects in Sri Lanka. Looper caterpillar was not considered to be a pest of major importance until 1990, when it caused considerable damage to tea in the Duars and Cachar. Since then it has occurred from time to time and has been responsible for considerable losses in many estates of Upper Assam and Duars (specially Eastern and Central Duars) (Anonymous, 1994). Borthakur (1975) had also reported looper caterpillar as one of the major pests of tea. Banerjee (1983b) outlined that the absence of natural enemies was the major contributing factor in looper outbreaks.

Hill (1983) in 'Agricultural insect pests of the tropics and their control' had mentioned looper as an active defoliator of Indian and South East Asian tea. Das (1984,1987) had also suggested control measures against defoliators of tea and shade trees. Growing resurgence of pest and their resistance in N. E. India had prompted Das et al. (1988) to suggest non-conventional approach in tea pest management. Chen and Kunshan (1988) in China, were successful in controlling of tea looper by the field release .of the laboratory reared parasitic wasps, *Trichogramma dendrolini.* Singh et at. (1990) had reported olfactory behavioural response in both sexes of the moth, *B. suppressaria* Guen. possibly mediated by pheromone. Muraleedharan (1991) has a given account of the biology of looper caterpillar and their occurrence in shade trees in the book 'Pest Management in Tea'. Further, Muraleedharan (1993) had recorded rare occurrence of looper caterpillar in the tea growing areas of south India.

A sketchy account of natural occurrence and control measures of looper caterpillar is given in the book 'Pests of tea in North - East India and their control' (Anonymous, 1994). The book also includes names of other members of the family geometridae that are known to occur on tea; these are *Buzura (Biston) bengaliaria* Guen., *Boarmia scienaria* Hbn., *B. acaciaria* Boised., *Medasina strixaria* Guen., etc, but none of them has attained the status of a pest (Anonymous, 1994). Chakravartee (1995) had mentioned that looper infestations may become devastating within a short period, so timely control of looper is very important.

Eterusia magnifica Butl. (Red slug caterpillar) is one of the major pests of tea in the Terai, Duars, and N. E. India. Early in 1906, Mann and Antram had reported approximate time of occurrence of different broods of caterpillars and adults of red slug. Hutson in 1932 had reported the occurrence of different species, *E. singala* from Sri Lanka, while Rau (1952) reported occurrence of *E. virescens* Butl. on tea from South India. During nineteen fifties and sixties this pest was recorded to be a sporadic pest (Anonymous, 1994). Hill (1983) in 'Agricultural insect pests of the tropics and their control' has reported *Eterusia magnifica* as defoliators from India and South East Asia. Muraleedharan (1991) has given brief biology of this pest and suggested its control measures. Again in

1993, Muraleedharan had mentioned about rare occurrence of this folivore in the tea growing areas of South India. An account of biology of red slug is available in the treatise 'Pests of tea in North - East India and their control' (Anonymous, 1994). Chakravartee (1995) had mentioned that a destructive pest like red slug should not be allowed to grow to an epidemic stage and hence control measures should be undertaken once the pest is seen in tea.

Euproctis latisfascia Wlk. was reported as one of the major defoliators. In severe outbreaks these pests completely defoliated tea bushes. Watt and Mann (1903) had reported that amongst lepidopteran pests lymantrid caterpillar, *Euproctis latisfascia* Wlk. (Darjeeling black hairy caterpillar) was a severe defoliator of young and mature tea plants, particularly a destroyer of the mother leaves of cuttings in a nursery. Banerjee (1993) has mentioned that during heavy monsoon in N. E. India, when a deterioration in the nutritional quality of young leaves and buds occur, abundance of looper caterpillar and *Euproctis* sp. (Lymantridae) can be observed. This pest has often been reported to cause damage to young tea plants in Darjeeling. Incidence of this caterpillar was also reported from tea estates of N. E. India. A brief biology of Darjeeling black hairy caterpillar is available in the book 'Pests of tea in North - East India and their control' (Anonymous, 1994).

Books consulted for relevant information related to these lepidopteran pests were "Tea Production and Processing" by Banerjee (1993), "Tea culture, processing and marketing" (eds. Mulky and Sharma, 1993).

3. 2. Host Preference

The diversity of host plant selection is overwhelming as each insect species show a series of adaptations to its host plant. Insect adaptations to their host plant may involve physiologic and behavioral strategies for meeting the physical and chemical defenses of the host plant (Bernays and Chapman, 1994). Verchaffelts significant discovery (1911) undoubtedly provided a major clue on the role of secondary plant compounds in determining the host plant selection of phytophagous insects.

Dethier (1941) demonstrated the role of terpenoids contained in essential oils of Apiaceae in host-plant acceptance of black swallowtail (*Papilio polyxenes*) caterpillar. Jermy (1958,1966) had drawn attention to the role of deterrents, secondary plant substances inhibiting feeding or oviposition and advocated the view that host plant selection is mainly based on avoidance of deterrents present in non-hosts.

According to Kennedy (1965) host selection is a caternary process involving, dispersal, host finding, host recognition, host acceptance or consumption and host suitability for food or oviposition; which was later supported by Miller and Stricker (1984). According to Reese (1979), it is the various interactions between allelochemicals and nutrients that may affect the plants suitability as insect food. According to Miller and Fenny (1983), and Berenbaum et. al. (1989) different individual compounds of the same chemical class may have very different effects on insect herbivores and occur within a single plant thus the chemical composition of an individual plant may be important in whether it is a suitable host plant or not.

Miller and Fenny (1983) and Bentley et al. (1984a) had pointed out that in lepidopterans the chemical composition of an individual plant is the deciding factor in its suitability as and consequent host plant. Selection of an ideal host plant decides the fitness or fecundity of an insect (Mitchell, 1981).

Dethier (1982a) has shown that larvae of lepidoptera have a battery of sensilla that may have as much discriminating capacity as those of adults in locating their host. Bernays and Chapman (1987) and Schoonhoven (1987) have stressed upon the role of allelochemicals as attractants, stimulants, repellants and deterrents on insect feeding behavior and selection of host plant. Slanskey and Rodriguez (1987) had also stressed upon the role of chemicals in host plant selection. According to Sanjayan and Ananthkrishnan (1987) insects prefer to feed on host plants which provide them with their necessary nutrients in required concentration. Barbosa & Krischik (1987) surveyed the chemistry of the host plants of *Lymenteria dispar* and suggested that alkaloids acting as deterrents were the primary determinants of host preference and suitability in *L. dispar*. Chemicals appear to play the major role in the orientation of many insects. These compounds induce feeding and / or oviposition by the specialized insects including *Pieris rapae, Delia radicum*, and *Psylliodes chrysocephala* (Traynier and Truscott, 1991; Roessingh et al., 1992). Dietary self selection by insects, a newly discovered dimension of insect feeding behavior is central to the understanding of how insects interact with their host plants (Waldbaurer and Friedman, 1991).

Hunter and Price (1992) realized the importance of heterogeneity of plant characteristics which are responsible for adaptation in some insects to a particular host plant. The scenario of host plant selection process is highly complex and involves a subtle interplay of orientation factors, feeding factors, ovipositional factors, plant nutrients and allelochemical factors alongwith environmental factors (Panda and Khush, 1995). Shoonhoven et al. (1998) had mentioned that the majority of herbivorous insects are host specialist i.e. they use only one or a few related plant species as host. As this was the first attempt to study host / varietal preference of the three folivores in question, literature related to these folivores were not available, however other literature on host plant selection by phytophagous insects is extensive.

3.3. Allometric growth

Allometric growth study is a tool for taxonomists to recognize the relationship between various age classes of the same species. Huxley (1924) and Huxley and Tessier (1936) proposed the allometric of heterogenic growth pattern. Matsuda and Rohlf (1961) studied the relative growth of five species of gerridae and compared on this basis two gerrid populations. Matsuda (1961a) had given an account of the relative growth rate of gerridae (Heteroptera) with certain hypothesis on allometry. The same author (1962a) also compared the relative growth of the two species of Tropobates (Gerridae: Heteroptera). He also studied the relative growth of legs and antennal segments of some species of

Heteroptera, and again in the same year (1962c) he studied the relative growth in two strains of *Pycnoscelus surinamensis* (Lin) (Panechloridae: Blattaria). Matsuda (1963a) estimated the relative growth of antennal segments in two species of *Orthotylus* (Miridae: Heteropteran); the same author (1963b) had accounted the evolution of relative growth in Arthropods. Matsuda (1966) had emphasized the taxonomic significance and evolution of relative growth in some animals.

Some more works on relative growth on different groups of insects are by Kumar (1966), Mukherjee (1972) and Williams (1972). Brown (1977) studied the morphometrics with metamorphosis of *Oncopoltus fasciatus* with two other insects.

3. 4. Life-tables & Survivorship

Literature on life-table of insects is quite numerous and varied. Morris and Miller (1954) were the first to adapt life-table format for the study of natural insect population. Since their development for natural population, life tables have been widely used in insect population studies. Mukerji and LeRous (1969) have suggested that estimates of metabolic activity in conjunction with life-tables would provide a precise method of analyzing relationship existing between the rate of increase of an organism and its success in an ecosystem.

A life and fecundity table is a convenient way of describing insect population dynamics. Age specific life tables are known as horizontal dynamics or cohorot life tables (Harari et al., 1997). Such tables describe the

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developmental time and survival rate of each stage. Southwood (1978) figured out that the life-table is one of the most useful numerical aids for the population biology study particularly to determine age distribution and mortality rate in natural population. Harcourt (1968) and Horn (1988) suggested that a knowledge of the number of immature stages of a given insect pest and the mortality factors affecting each stage might assist in the pest management procedure later.

Southwood (1978), Martinez and Katthain (1999) were of the opinion that in most of the insect species, the mortality rate is a characteristic of the stage that is not uniform for all the developmental stages. Prakash and Rao (1999) added that life-table study of an insect pest is essential to utilization in developing its effective IPM. Several works have been conducted on life history and survivorship study of lepidopterans including some of the tea pests such as the tea flushworm, *Cydia leucostoma* (Meyrick) by Kumaravadivelu et al. (2000). Though thorough hunting of literature was done during the course of study through internet and other sources, it seems no life-table and survivorship study has been conducted on the three lepidopteran tea pests considered in this study on natural and artificial diets.

3. 5. Artificial Diet

Rearing of insects has been part of human history for more than 5000 years if bee keeping and silk production is taken into account. The first insect reared axenically on artificial diet from egg to adult was *Calliphora vomiteria* (Bogdanov, 1908). Papers on rearing *Drosophila* sp. appeared in early 1900's. Nutritional and rearing studies of European corn borer and pink bollworm followed in the 1940s. Rearing of the European corn borer (*Ostrinia nubilalis*) on an artificial diet was first reported by Botteger (1942). This was followed by Beck et al. (1949). Insect rearing proliferated in the mid 1950's, and grew to a major dimension in the next two decades. This expansion occurred because insect rearing was required in order to test, develop and implement new pest control technologies. Technology for rearing lepidoptera in the laboratory on artifical diets improved significantly during late 1960's and 1970's.

One of the most important advances in rearing lepidopterous and other phytophagous insects in the laboratory was the use of wheatgerm in the formulation of diets as reported by Adkisson et al. (1960) for *Pectinophora gossypiella* and Berger (1963) for *Heliothis* species. Their formulations with some modifications are the basis of diets for many other insects. By the mid 1970's, every entomological research facility in the world utilized some laboratory reared insects.

Singh (1977) noted that 754 species of arthropods had been reared on artificial diets; of these, 27 were arachnids and the remaining were insect species belonging to 10 orders consisting of 19 families of Coleoptera, 24 of Diptera, 11 of Hemiptera, 8 of Hymenoptera and 27 of Lepidoptera. Singh and Moore (1985) reported similar numbers. Larval rearing on artificial diets (Ito, 1981) for the improvement of larval culture are undertaken in Japan. Such studies were less popular in India (Prasanth, 1989; Mathew et al., 1990) because of high cost of artificial diet.

Dickerson et al. (1979) compiled a list of approximately 1000 colonies of 488 insect species representing 109 families and 15 orders with all the relevant information (such as insects availability, diets etc.) related with the insects. Successful use of cooked beans in the diet of *Scotia segetum* Den. and Schiff (Podmanicka and Weisman, 1974) and *Spodoptera frugipeda* (Parra and Carvalho, 1984) has been reported.

Tiwari and Bhattacharya (1987) formulated several semi-synthetic diets for Bihar hairy caterpillar, *Spilosoma obliqua* Walker. Singh (1977), El-Guindy et al. (1979) and Klein et al. (1981) used soybean in the diet of lepidopteran insects. Salloum and Isman (1988) reported that first generation field strain larvae of the variegated cutworm, *Peridroma saucia* (Hubner) gained about three times more weight when fed on artificial diet compared with larvae from a laboratory colony reared for 12 generations on the diet.

Slansky and Wheeler (1992b) highlighted the importance of dietary factors on the performance of field strain and laboratory strains of Velvetbean caterpillar (Lepidoptera: Noctuidae) when fed foliage and artificial diet.

Singh and Bhattacharya (1994) formulated semi-synthetic diets using some other commonly available commodities which were not used earlier and this diet could support the complete growth and development of Bihar hairy caterpillar, *Spilosoma obliqua* Walker. Oscar and Bruce (1997) compared the postembryonic development of tufted apple moth *Platynota idaeusalis* (Walker) among a lima bean-based diet and four different host plant species. Artificial diet proved to be the best diet for *P. idaeusalis* in survivorship and in all the developmental parameters studied. Gupta et al. (1998) were successful in partial larval rearing of *Earias vittella* (Fabricus) on artificial diet. Jyoti et al. (1999) were successful in rearing banded sunflower moth (Lepidoptera: Cochylidae) and sunflower moth (Lepidoptera: Pyralidae) with modified sunflower moth diet which incorporated sunflower leaf tissue. Garcia et al. (1999) had compared the development of *Ecdytolopha aurantiana* (Lima) among four artificial diets with different protein sources based on biological characteristics and fertility life table in order to have the insect available throughout the year for research.

Sundaramahalingam and Chockalingam (2000) studied the influence of dietary protein on larval duration, mortality, survival, growth and fecundity of *Pericallia ricini* using artificial diet with four different levels of protein. Bernadi et al. (2000) determined the adequate diet for rearing *Corenra cephalonica* (Lepidopotera: Pyralidae) for mass production of *Trichogramma*. Abdullah et al. (2000) based on the comparative study of artificial diet and soybean leaves on growth, development and fecundity, reported that mass rearing of beet armyworm larvae, *Spodoptera exigua* (Hubner) (Lepidoptera: Noctuidae) was more successful on artificial diet than soybean leaf.

The development of a suitable artificial diet of insect is based on a good understanding about the relationship between insect and plant. A thorough knowledge of the development and growth of pest species on artificial / semi-synthetic diet helps in biological, nutritional, biochemical, host plant resistance and toxicological studies of insects. This could be ultimately used for developing safer and economical pest management programmes. In the past, fundamental and applied fields of Entomology were severely affected due to lack of suitable artificial diets (Vanderzant, 1974; Singh, 1977).

Insect rearing on artificial diets can be used for:

1) Developing insect-resistant strains of plants (William et al., 1980);
2) Bioassaying the effectiveness of insecticides (El. Guindy et al., 1979);
3) Producing entomophagous insects using hosts, in absence of artificial diet (Marston, 1975);
4) Studying nutritional requirements (Moore, 1980);
5) Mass rearing for sterilization and subsequent release in pest control programs (SMT) (FAO/IAEA, 1974);
6) Releasing en mass predators or parasites of pest insects (Focks et al., 1978);
7) Growing pathogens such as viruses (Bell et al., 1981);
8) Evaluating the nutritional quality of cereals inexpensively (Vohra, 1978);
9) Supplying insects in large number for bioassays;
10) Using for production of hormones or pheromones (Richmond, 1980);
11) Supporting basic research in morphology, physiology, biochemistry etc. based on laboratory bred insect source (Singh, 1977);

Literatures on these three pests based on artificial diet were not available as probably studies on them have not been done till now though the book "Artificial diets for insects, mites and spiders" (P. Singh, 1977), and a good collection of valuable articles on various aspects of insect rearing on artificial diets compiled and edited by Anderson and Leppla (1992) in the book entitled, "Advances in Insect Rearing for Research and Pest Management" were of great help during the course of study.

3. 6. Dry mass budget

Food is an important component of the environment in which an insect lives. Feeding is an active, dynamic process with numerous feedback interaction and consequences throughout an insect's life, affecting and being affected by survival, growth, reproduction and movement. Mass budgets have proved very useful in nutritional ecology research and food utilization efficiencies which are often considerably different and reflect adaptations to different food characteristics. Moreover, budgets for nutrients and elements can provide additional insight into the adaptive significance of arthropod physiology and behaviour (Slansky, 1985; Slansky and Scriber, 1985). Waldbaurer (1964) had worked on the food utilization by larvae of tobacco hornworm, *Manduca sexta* (Johan) (Lepidoptera: Sphingidae) and had summarized that information on consumption and utilization of food (plants as well as artificial diets) by insects is of importance in physiology, nutrition, ecology and economic entomology.

Premkumar et al. (1977) had worked on the food utilization by larvae of *Spodoptera litura* F. (Noctuidae: Lepidoptera) and had suggested that a clear picture of comparative nutrition of insects could not emerge until quantitative studies were made. Singh (1977) is of opinion that the effect of variation in diet can be measured in terms of growth, development, reproduction, mortality, longevity and morphological abnormalities.

Barbosa et al. (1981) and Moscardi et al. (1981) had worked on various lepidopterans on nutritional aspects and have found that feeding and development in the larval stage may also influence performance by the adult through effects on adult size, nutrient reserves and timing of oviposition. Scriber and Slansky (1981) had summarized that food utilization efficiencies based on dry weight have proven useful in broadening the understanding of the nutritional ecology of insects in different feeding guilds. That the amount, rate and quality of food consumed by larvae influence their growth rate, developmental time and final body weight and larval survival were suggested by Barney and Rock (1975), Hatchett et al. (1976) and McWilliams and Beland (1977). Results published by Hough and Pimentel (1978) and Barbosa and Greenblatt (1979) showed that the fecundity of the gypsy moth (*Lymantria dispar* L.) was strongly influenced by various host plants on which it was reared.

During the past several years there has been tremendous proliferation of published information regarding insect plant interactions (Visser and Minks, 1982; Denno and McClure, 1983). Many papers have focused on various plant chemicals which affect insect growth rates such as secondary plant compounds like tannins and essential oils (Fenny, 1968; Morrow and Fox, 1980; Bernays, 1981), moisture content of plant material (Scriber, 1977; Tabashnik, 1982; Deb et al. 2000), nitrogen concentration of foliage (Slansky and Fenny, 1977; Tabashnik, 1982) and leaf toughness (Fenny, 1970).

Smith et al. (1986) while working on *Malacosoma disstria* (Lepidoptera: Lasiocampidae) determined the instar stages and growth and feeding indices. According to Muthukrishnan and Pandian (1987) age, food quality, water and toxin content of food plant influence the assimilation efficiencies (Ase) in insects. Sanjayan and Murugan (1987) suggested that to understand the nature of food, one must collect the information on the rate of feeding and its effect on growth and development, the amount of food digested and the quantity of food converted into body mass.

Horie and Watanabe (1983) and Mathavan et al. (1987) had studied the nutritional aspects in silkworm with respect to food utilization. The interstrain (silkworm) differences in food utilization efficiency in different conditions have also been studied by Yamamoto and Fugimaki (1982), Remadevi et al. (1992). Mathavan and Pandian (1975), Scriber and Slansky (1981) and Ghosh and Gonchaudhuri (1996) studied the similar pattern of feeding in lepidopterous larvae in general.

Sharma et al. (1999) reported that food consumption per larva as well as per gram body weight increased many folds in the last instar of cabbage white butterfly, *Pieris brassicae* (L), which also supported the observations of Mukerji and Guppy (1970), Smith et al. (1986) and Trichilo and Mack (1989). Atluri et al. (2002) studied the correlation between larval growth and quantity of food consumed. Williams et al. (2003) after working on development of gypsy moth larvae feeding on red maple saplings at elevated CO_2 and temperature reported that CO_2 or temperature induced alterations in leaf constituents had no effect on insect performance.

No study has been conducted in the past on mass budget and nutritional ecology with the three lepidopteran tea pests included in this study, as such no relevant literature was available on this aspect. However, some of the more generalized publications found useful in connection with the study worth mentioning are as follows:

The article on "food consumption and utilization" in the "Comprehensive insect physiology, biochemistry and pharmacology" (Slansky amd Scriber, 1985) has a plethora of information on nutritional ecology of insects.

Some articles of general importance in the area of insect dietetics and nutrition are from Slansky (1982) on "Insect nutrition: An adaptationist's perspective", Slansky and Scriber (1982) on "A selected bibliography and summary of quantitative food utilization by immature insects". Detailed information on food consumption strategy and growth in insects is available from Farrar et al. (1989). Further a comparison between dry weight and energy efficiencies is available from works of Slansky (1985). The book "Nutritional ecology of insects, mites, spiders and related invertebrates" edited by Slansky and Rodriguez (1987) is highly informative. Some related literatures on compensatory feeding and growth response of caterpillars are from Slansky and Wheeler (1992a,b). An article by Slansky (1993) in the book "Caterpillars - Ecological and Evolutionary constraints on foraging" provides a detailed discussion on the fundamental quest for nutrients.

The over views on allelochemic - nutrient interactions in herbivore nutritional ecology (Slansky, 1992) and a response of generalist and specialist insects to quantitative allelochemical variation (Bowers and Puttick, 1988) deal at length with the role of allelochemicals on insect performance.

Some of the valuable articles on plant-animal relationship are available from the classical published book of Schoonhoven et al. (1998) entitled "Insect-plant Biology - From physiology to evolution" and the book by Panda and Khush (1995) on "Host plant resistance to insects". Muthukrishnan and Pandian (1987) in their article "Insecta" in the book on "Animal Energetics" have given a vivid description of all of insect nutrition and their energy budget. The other books consulted were: "Ecological Entomology" by Huffaker (1999), "Ecology of Insects - Concepts and application" by Speight et al. (1999) and "Dimensions of Insect - Plant Interaction" by Ananthakrishnan (1992).