2. REVIEW OF LITERATURE

2.1 TEA CROP AND ITS PESTS

Tea plants have a rhythmic growth pattern, dormancy and flush, coinciding with either management practice or environmental conditions or a combination of both (Manivel 1980). The permanent leaves below the plucking surface are known as maintenance foliage. These maintenance foliage produce photosynthates which are supplied to other parts of a plant, which respire and grow actively with the help of these photosynthates (Kabir 2001). The fresh flush above the maintenance leaves are harvested for tea manufacturing.

As mentioned earlier, tea bushes being a monoculture provide habitat for 1031 arthropod species and 82 nematodes species over the world (Chen and Chen 1989). In Asia, tea is affected by a total of 230 species of insects and mites (Muraleedharan 1992). However, Hazarika et al. (1994) reported that in NE India, 173 arthropods and 16 nematodes are considered as pests of tea. Among them few important pest species from plantations of NE India are:

a. Sucking insects: Tea green leaf hooper (*Emposca flavescens*) (Homoptera: Cicadellidae); Tea aphids (*Toxoptera auranti*) (Homoptera: Aphididae); Tea Mosquito bug (*Helopeltis theivora*) (Heteroptera: Miridae); Thrips (*Taeniothrips setiventris*) (Thysanoptera: Thripidae); Scale insects (*Lacenium uride*) (Hemiptera: Coccidae)

b. Borers: Red borer (*Zeuzera coffeae*) (Lepidoptera: Cossidae); Shot hole borer (*Xyleborus fornicates*) (Coleoptera: Scolytidae)

c. Root feeders: Root grub (*Holotricha impressa*) (Coleoptera: Scarabaeidae); Termites [*Odontotermes obesus*, *O. parvidens*, *Nasutitermes* sp., *Microtermes obesi*, *Euhamitermes lighti*, *Synhamitermes quadriceps*, *Pericapritermes assamensis*, *Malaysiocapritermes holmgrenii* and *Heterotermes indicola*] (Blatodea: Termitidae)

d. Non-insect arthropods (Mites): Red spider mites (*Oligonychus coffeae*) (Acari: Tetranychidae), Scarlet mite (*Brevipalpus californicus*) (Acari: Tenuipalpidae), Purple mite (*Calacarus carinatus*) (Acari: Eriophyidae)

e. Defoliators and perforators: Tea tortrix (*Homona coffearia*) (Lepidoptera: Tortricidae); Bunch caterpillar (*Andraca bipunctata*) (Lepidoptera: Bombycidae); *B. suppressaria*, *H. talaca*, *H. infixaria*, (Lepidoptera: Geometridae), *Etrusia magnifica* (Lepdioptera: Zygaenidae) etc.

2.2 FOLIVORES OF TEA FROM DARJEELING TERAI-DOOARS PLANTATIONS IN NORTH BENGAL

The major defoliators reported from Darjeeling Terai-Dooars tea plantations are as follows:

Red slug caterpillars (*Eterusia magnifica*) (Zyganidae: Lepidoptera) feed on the mature leaves of the tea bushes and the bark of young stem (Anonymous 1994). They remain under the mature leaf or stem of the bushes and sporadically infest the plantation from November till April.

Flush worm (*Lespeyrasia leucostoma*) (Lepidoptera: Tortricidae) attacks the pluckable shoots and leads to the formation of a nest like structure due to folding of leaf. Their occurrence in the tea plantation is recorded during January to May.

The tea leaf roller (*Caloptilia theivora*) (Lepidoptera: Gracillaridae) is known to infest tea from the dawn of plantation in NE India. Watt and Mann (1903) considered it to be a troublesome pest. It had never been serious in Assam and Bengal but occasionally caused considerable damage to tea in foothills of Dehra Dun area. During 1988 the intensity of attack of this insect was found to be quite high in a few estates of Jorhat Assam circle when about 40-60% of the shoots in young and mature tea were found to be badly affected.

Infestation of Bunch caterpillar (*Andraca bipunctata*) mainly occurs sporadically during March to November in tea plantations of NE India (Anonymous 1994), normally in four broods. Young larva of bunch caterpillar feeds on young leaves and leads to the removal of epidermis only. Whereas, the mature larva eats the entire leaf and can lead to the complete defoliation of tea bush.

Arctonis submarginata (Lepidoptera: Lymantridae) reported recently from the Darjeeling Terai is a tea pest which feeds on the mature leaves of the bushes (Mukhopadhyay et al. 2007).

The Darjeeling black hairy caterpillar *Euproctis latisfascia* (Lepidoptera: Lymantriidae) is an important pest attacking old leaves of tea bushes and mother leaves of nursery cuttings in Darjeeling foothills, Terai and NE India (Anonymous 1994).

The various species of loopers (Lepidoptera: Geometridae) are the actual or potential pests of tea and will be discussed in the next section in details.

2.3 TEA LOOPERS

The age old looper pest, *Biston* (=*Buzura*) *suppressaria* was known to occur on tea of NE India since 1900 (Das 1965). Das (1957) reported that initial migration of *B. suppressaria* to the tea plantations occurred from forest trees. Recently two more looper species, *Hyposidra talaca* and *Hyposidra infixaria* earlier reported to feed on forest plants and weeds from India, Malaysia and Thailand (Browne 1968; Mathew et al. 2005; Winotai et al. 2005; Das and Mukhopadhyay 2008; www.mothsofborneo.com) have also been found to infest tea plantations of Himalayan Terai (Basu Majumder and Ghosh 2004; Das et al. 2010). Besides occurrence of these *Hyposidra* species invading tea in recent past, existence of the older species, *B. suppressaria* continues in certain pockets of the tea plantations especially in the Dooars. The invading pest species presently have a wide distribution on forest and wild plants of the South Asia as well as part of Palearctic region including China, Taiwan (Browne 1968; Holloway 1993) and Japan (Nasu et al. 2004). Recently, in NE India, they emerged as destructive defoliator of tea, consuming both young and mature leaves, initially being reported from Terai-Dooars region of North Bengal and Assam (Basu Majumder and Ghosh 2004; Das and Mukhopadhyay 2008; Chutia et al. 2012). In peak seasons these loopers occur in the tune of about 200 individuals or more per bush and as a result the quantum of crop loss appears to be substantial (Das et al. 2010). The caterpillars of these species prefer to feed upon the pluckable leaves. But if the pluckable leaves are not available, they even feed on the mature leaves or maintenance leaves, hence resulting into crop loss in terms of pluckable leaves and photosynthetic surface area of the maintenance leaves. *Hyposidra* spp. were found prominently even during the winter months due to lack of obligatory winter diapauses with at least eight broods per year (Das et al. 2010).

Recently, less-known looper species, named *Ectropis* sp. was found invading the tea plantations of Darjeeling Terai. The geometrid, *Ectropis* Hübner belongs to the tribe Boarmiini and is represented by approximately 100 species around the World (Holloway 1993; Sato 2007). In Borneo, four species of *Ectropis* have been recorded (Holloway 1993). From Indonesia, eight species are known (Sato 2007) while from Indo-Malayan and Singapore region just one species, *E. bhurmitra* has been recorded, however, the species seems to have a broad Asia-Pacific distribution. The species was first recorded from Sri Lanka (type locality) and subsequently it was recorded in India, Taiwan, the Philippines, Thailand, Peninsular Malaysia, Borneo, Sumatra, Java, Sulawesi, Buru, New Guinea, and the Solomon Islands (Sato 2007). The leaf-eating twig caterpillar of *E. bhurmitra* is reported to cause moderate damage, leading to full defoliation and death of tea bushes (Danthanarayana and Kathiravetpillai 1969). Its presence on the teak tree, *Tectona grandis* (Lamiaceae) as a minor defoliator has been noted (David and Ramamurthy 2012). In North Bengal region, the species was initially reported from the Dooars tea plantations (Basu Majumder 2008). Prasad and Mukhopadhyay (2013) studied the life-cycle traits along with the degree-day dependent development of *Ectropis* sp. for the first time during summer and winter seasons of Terai under laboratory conditions.

Other less known species having looper stages are *Ascotis* sp. and *Cleora* sp. which are reported from tea plantations of both North Bengal and Assam, but yet to attained a major pest status (Anonymous 2011). Globally, *Boarmia* (=*Ascotis*) *selenaria* is known as a serious pest in a number of crops: peanuts (reported from Madagascar by Frappa 1939), margosa (Beeson 1941 reported from India), citrus (reported from South Africa by Buitendag 1965; from Sicily by Mariani 1937), tea (from Formosa by Hu and Chen 1967; from India by Andrews 1921), teak leaves (reported from Burma by Garthwaite 1940), white mulberry (reported from Japan by Hoths 1917; Tomizawa 1922) and coffee (reported from East Africa by Abasa 1972).

2.4 FOOD UTILIZATION EFFICIENCIES

Quantitative analysis of consumption and utilization of host plants by insect herbivores is a commonly used estimate in studies of plant insect interactions (Scriber and Slansky 1981). Analysis of nutritional indices can lead to the understanding of the behavioural and physiological basis of an insect response to host plants (Lazarevic and Peric Mataruga 2003). Food consumption and utilization link plant attributes with insect performance (Slansky 1990). The gravimetric technique is often used to determine food utilization efficiencies of an insect, after the methodologies developed by Waldbauer (1968), Petrusewicz and MacFadyen (1970), Slansky and Scriber (1985) and Muthukrishnan and Pandian (1987).

The study of nutritional indices could have some practical applications including comparison of the insect's performance on different host plants (Klein and Kogan 1974), measuring the effects of physiological stress on insects (Dauglas and Reese 1986), estimation of the quantity of food consumed by larvae with the purpose of forecasting damage by insects (Kozhanchikov 1950) and determining the host-plant resistance (Klein and Kogan 1974). According to Bhat and Bhattacharya (1987), the feeding indices can be used to show the effect of plant on insect metabolism and interactions between insects and their food sources. As an example, feeding indices for *Spodoptera frugiperda* were calculated on 9 Bermuda grass types and based on these results, resistance and susceptible varieties were distinguished (Jamjanyn and Quisenberry 1988). One of the easiest methods to control carob moth was the use of resistant varieties (Shakeri 2004). Feeding indices may be used as the method for establishing resistant varieties. Rath (2010) performed food utilization experiment on *Antheraea mylitta* (Lepidoptera: Saturniidae) fed on *Terminalia arjuna* (Combretaceae) leaves to compare the food utilization efficiencies with same species reared on the other host plants and to see the host suitability. Calculation of the basic nutritional indices (e.g. approximate digestibility (AD), efficiency of conversion of ingested food (ECI) and efficiency of conversion of digested food (ECD) has opened new opportunities of research on the power of feeding (Andreeva 2010).

Feeding indices demonstrate the digestion efficiency or utilization of diet or diet ingredients and in fact illustrate the conversion of food to the biomass of insects. These indices can provide valuable information about the positive or negative impact of ingredients or whole food (Cohen 2004). Among nutritional indices, ECI may vary with the digestibility of food and the amount of the digestible portion of food which is converted to body mass and metabolized for energy needed for vital activity (Abdel-Rahman and Al-Mozini 2007). ECI is an overall measure of an insect's ability to utilize the food ingested for growth and development, and ECD is a measure of the efficiency of conversion of digested food into growth (Nathan et al. 2005). Change in ECD also indicates the overall increase or decrease of the proportion of digested food metabolized for energy. Therefore, no change in ECI and ECD values indicate that ingested secondary biochemicals may not be causing any chronic toxicity (Koul et al. 2004).

The nutritional requirements of an insect change during development and such changes are typically reflected in changes of food consumption and feeding behaviour (Barton Browne 1995). Larval feeding efficiencies of beet armyworm were evaluated on excised leaves of five common host plants in southern Texas by Greenberg et al. (2001). East et al. (1989) studied the consumption rates of larvae of *S. exigua* (Lepidoptera: Noctuidae) on cabbage.

A higher maintenance costs is the result of a low ECD and lead to low growth rate. The assumption underlying this interpretation is that growth is carbon-limited, in which case any carbon allocated to energy metabolism is not available for the production of new tissue (Pradhan et al. 2006).

Closely related species feeding on the same host plant under similar environmental conditions (temperature, photoperiod, humidity and availability of food) may follow different strategies of growth and reproduction (Muthukrishnan and Pandian 1987). The young larvae are more selective feeders and choose more digestible foliage from the inter-vein portions of the leaf than the older larvae which feed more indiscriminately (Bailey 1976). The first instar larvae feed only on tender green parts of the leaves of the host plants which can be digested easily. As the larvae mature, they start consuming the resistant fibrous part of host plant, thereby resulting in the decline of AD as obtained in *Prodenia eridaniee* and *P. sexta* (Lepidoptera: Noctuidae) (Waldbauer 1968) and *P. ricini* (Chockalingam 1979). Silkworm showed an appreciably greater AD on mulberry. The high value of AD indicated its good digestibility or nutritional quality of its food reflecting the compatibility of the insect and its host (Waldbauer 1968; Scriber and Slansky 1981). The maximum food was ingested by the last or last two to three instars of lepidopteran larvae. It has been reported that *Bombyx mori* (Lepidoptera: Bombycidae) (Hiratsuka 1920) consumed about 97% of their total food intake during the last two instars. It may be attributed to the fact that the last instar larvae accumulated the matter to tide over the non-feeding pupal period. Besides defecation, assimilation and conversion of food to body substance, the metabolism also increases significantly during the last instar larvae. This may be due to the increased activity of the larvae during the period (Hiratsuka 1920; Waldbauer 1968).

2.5 DEVELOPMENTAL TRAITS

Total developmental period, larval period, pupal period, weight of pupa and adult, ratio of male and female and survivorship during development stages are the important parameters for assessing the performance of insects on a diet. These parameters also indicate the efficiency of a diet to sustain the life-cycle of an insect.

Shorter development period, heavier pupa and adult, more emergence of adult i.e., higher survival, less deformed adults are the indications of the suitability of any diet.

2.5.1 Post-embryonic Developmental Parameters: Growth, development and reproduction of insects are strongly dependent on the quality and quantity of food consumed (Scriber and Slansky 1981). Previously Naseri et al. (2009) examined life history and fecundity of *Helicoverpa armigera* (Lepidoptera: Noctuidae) on different varieties of soybean. The data obtained in the study of developmental time and fecundity of *H. armigera*, helped to estimate its susceptibility of soybean varieties. Farahani et al. (2011) studied the life table parameters of *Spodoptera exigua* and found that the development time varied on different host plant. This observation was further upheld by Azidah and Sofian- Azirun (2006). Incubation period of eggs of *Earias vitella* (Lepidoptera: Noctuidae) varied considerably due to host plant variation, which was shortest on okra and longest in China rose (Syed et al. 2011). Syed et al. (2011) also observed considerable variation in the larval and pupal period of *E. vitella* on different host plants, along with the adult longevity, fecundity and life-cycle duration. Faisal et al. (2011) studied the suitability of different host plants as food for *Eupterote undata* (Lepidoptera: Eupterotidae) and recorded its shortest life-cycle on the host, *Paulownia fortune* (Paulowniaceae) and the longest on *Toona ciliata* (Meliaceae). Itoyama et al. (1999) found that the duration of the final larval stadium of *S. litura* became significantly longer as diet quality decreased.

2.5.2 Survivorship: Literature on life tables is quite numerous and varied. Morris and Miller (1954) were the first to adopt 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. Mukerjii and LeRous (1969) have suggested that estimates of metabolic activity in conjunction with life tables would provide a precise method of analysing 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 or cohort life tables (Harari et al. 1997). Such tables describe the 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 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) and 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 in developing its effective IPM.

Life tables are effective tools for assessing and understanding the effect of abiotic stress on larval growth and survival on synthetic diet, reproductive vigour and population growth (Sandhu et al. 2010). Several works have been conducted on life history and survivorship study of lepidopterans including some of the tea pests such as the tea flush worm, *Cydia leucostoma* (Lepidoptera: Torticidae) by Kumaravadivelu et al. (1996). Life-cycle study was done by Hansen et al. (2004) for *Sitotroga cerealella* (Lepidoptera: Gelichiidae), commonly known as Angoumois grain moth. This is a pest on stored maize in West Africa. Some age-specific life table based studies were also done on *H. armigera* on different conditions by various workers (Jallow et al. 2001; Pascua and Pascua 2002; Ge et al. 2003; Liu et al. 2004; Wu et al. 2006; Fu et al. 2008; Mironidis and Savopoulou 2008; Yin et al. 2009, 2010; Naseri et al. 2009, 2011; Jha et al. 2012). Barrionuevo et al. (2012) studied the life tables of *Rachiplusia nu* and *Chrysodeixis* (=*Psuedoplusia*) *includens* (Lepidoptera: Noctuidae), the two semilooper pest on synthetic diet. Karimi-Malati et al. (2014) studied age specific life table parameters, survivorship of *S. exigua* (Lepidoptera: Noctuidae), beet armyworm.

2.6 ENZYME PROFILE OF LEPIDOPTERA ON DIFFERENT FOOD REGIMES

Digestive enzymes are nearly universal in all the members of kingdom Animalia, but the means of delivering them efficiently to an external food source requires special modifications. In the larval Lepidoptera, the midgut is the primary site of digestion and absorption and midgut epithelial cells are modified to generate pHs depending on the species (Berenbaum 1980; Dow 1984; Appel 1993). The fundamental objective of digestion is to render macromolecules into simple compounds that can be absorbed and circulated (Gilmour 1961; House 1974). The source of the digestive enzymes may be specialized structures, such as maxillary or salivary glands found in many insects, or the midgut, as in some lepidopteran larvae (Evans 1992; Snodgrass 1935; Christeller et al. 1992).

The study on feeding biology and digestive enzyme activities reveals different exploitation strategies by the insect having different food habit. The ability of insects to survive on diverse host plants is an adaptive mechanism for their survival in the ecosystem (Subramaniam and Mohankumar 2006). Polyphagy requires physiological mechanisms to confront the varying chemical complexities posed by different host plants. Herbivores possess various physiological and morphological traits that enable them to exploit their host plants. All herbivores deal with chemicals that are potentially damaging their cellular possesses, these come from various sources including secondary chemicals of plants that can be toxic or anti-nutritive to them

(Duffey and Stout 1996). In addition, physiochemical conditions of the midgut in caterpillars are likely to have a major impact on nutrient digestion and allelochemical activity (Appel and Maines 1995). Lepidopteran larvae have been the subjects of study largely due to their impact on economically important plants. Host-plant allelochemicals exert their anti-herbivore pressure by influencing the growth and nutritional parameters and the herbivore can react by a concomitant increase in detoxifying enzyme activity (Brattsten 1988; Mukherjee 2003). In fact, an insect's ability to detoxify plant allelochemicals is a basic requirement for the selection of host plants (Johnson 1999; Mao et al. 2007).

Few digestive enzymes such as amylase, protease, lipase and invertase were studied in insects by various workers. These are the basic enzymes and reported to be present in most of the insects' guts. Amylase catalyse hydrolysis of α-D-(1,4)-glucan linkage in starch components, glycogen and various other related carbohydrates to serve as an energy source (Franco et al. 2000). Reports on presence of amylase enzyme in lepidopteran guts are available for *B. mori, Diatraea saccharalis* (Lepidoptera: Crambidae)*, Ostrinia nubilalis* (Lepidoptera; Pyralidae)*, S. frugiperda, Chilo suppressalis* (Lepidoptera: Pyralidae) and *Plodia interpunctella* (Lepidoptera: Pyralidae) (Sivakumar et al. 2006; Zibaee et al. 2009; DeSales et al. 2008). Response of midgut amylases of *H. armigera* was studied by Kotkar et al. (2009) on different host plants. Invertase are glycosidase hydrolases that catalyse the cleavage of sucrose into the two monosaccharides, glucose and fructose (Shen 1986; Law et al. 1977). Digestive proteases catalyse the release of peptides and amino acids from dietary protein and they are found most abundantly in the midgut region of the insect digestive tract (Jongsma and Bolter 1997). Most of the midgut proteolytic enzymes in lepidopteran larvae have been shown to be extracellular proteases with high pH optima which are well suited to the alkaline conditions of the midgut (Applebaum 1985). The digestive enzymes are mainly reported from the midgut of different insects (Hori et al. 1981; Lenz et al. 1991). Other important but less studied enzymes from lepidopteran insects are lipases, which catalyse the hydrolysis of triacylglycerol (TAG). Lipases secreted into the midgut lumen of insects break down a variety of dietary lipids, such as triacylglycerol and phospholipids, into fatty acids (Weintraub and Tietz 1973). Among insects, most studies have focused on the roles of lipases in the fat body as compared to the gut digestive system. Grillo et al. (2007) described the role of TAG lipase in lipid digestion in the *Rhodnius prolixus* (Hemiptera: Reduviidae) midgut. The products of digestion are absorbed by the midgut epithelium and then used for synthesizing complex lipids, such as TAGs, diacylglycerols and phospholipids. In *B. mori*, lipases are not only digestive proteins but also act as antivirals against the occlusion derived Nucleopolyhedrovirus (NPV) (Ponnuvel et al. 2003).

The detoxifying ability of insects vary among the species and with the environment as well as with their feeding ecology (Fragoso et al. 2002; John and Graeme 2008; Despres et al. 2007; Mullin 1985, 1988; Hung et al. 1990). Generally, three enzyme systems are known to be involved in the allelochemical as well as insecticide detoxification. In phase I of metabolism, esterase which generally hydrolyse the ester bonds and cytochrome P450-dependent monooxygenases which oxidise the toxic compounds to neutralize their effect are functional, whereas in phase II glutathione *S*-transferases which are involved in conjugation reactions i.e., converting the products of hydrolysis and oxidation into harmless conjugates for elimination from the insect body (Soderland and Bloomquist 1990).

These enzymes have been studied by various workers to mainly establish the insect resistance to the pesticides. In the present study, the purpose of studying these enzymes is to understand their activity in the process of detoxification of the allelochemicals/xenobiotics ingested and bio-energy trade off either to detoxification or production (Cresswell et al. 1992; Karban and Agarwal 2002).

2.7 STUDIES ON SPECIES OF GEOMETRIDS (LOOPERS) REARED ON NATURAL DIET

Till date, various kind of studies on looper stage of geometrid spp., such as detoxifying enzymes assay (Das and Mukhopadhyay 2014), extraction of entomopathogenic NPV and Bacteria which can be used as bio-pesticides (Ghosh et al. 2015; Mukhopadhyay et al. 2007; De et al. 2006, 2007; Das et al. 2006), bioassay of loopers for testing efficacy of various pesticides on loopers have so far been carried out based on specimen reared on natural diet (tea leaf). Das et al. (2010) and Das and Mukhopadhyay (2014) studied the host-based biology of these geometrid pests and their variability along with the detoxification enzymes. Mukhopadhyay et al. (2010) identified the biocontrol potential of both bacterial and viral entomopathogens of *B suppressaria* and *H. talaca*. Simultaneously Mukhopadhyay et al. (2011) characterized NPV from *H. talaca* and showed its virulence. Basu Majumder et al. (2012) tested various insecticide against the *Hyposidra* spp. Das (2015) in her Ph.D. thesis work, studied the bio-ecology and variability in defence enzymes of three geometrid species *B. suppressaria, H, talaca* and *H. infixaria* attacking tea. Nair et al. (2008) studied the biology of *H. infixaria*. Simultaneously, Somchoudhury et al. (2010) observed the performance of *H. infixaria* on eight different host plants and concluded that *H. infixaria* showed better growth and development on mango than on tea. They also studied effects of some common natural enemies and neem formulation on the same pest (Somchoudhury et al. 2011).

Growth and survival of this species was studied by Basu Majumder et al. (2011) on four clonal varieties of tea.

NPV of *B. suppressaria* was isolated by Gan (1981). Genomic map of singly-enveloped nuclear polyhedrosis virus of *B. suppressaria* was determined by Liu et al. (1993). Chen et al. (2015), obtained the complete mitochondrial genome of *B. suppressaria*. Genome sequence and analysis of *Busu*NPV and phylogeny with other baculoviruses was carried out by Zhu et al. (2014). Ghatak and Reza (2007) tested the efficacy of *Beauveria bassiana* (Clavicipitaceae) against *B. suppressaria.* From India, Mukhopadhyay et al. (2007) recorded a Baculovirus isolated from *B. suppressaria.* Rahman and Bhola (2012) studied population dynamics of *B. suppressaria* and its larval parasitoid *Apanteles taprobane* (Hymenoptera: Braconidae). Feeding biology and digestive enzyme profile of *B. suppressaria* on tea was studied by Sarker et al. (2007) with a comparison with another tea defoliator *Etrusia magnifica*.

A host of studies related to various aspects of the commonly occurring defoliating pests of tea emphasize the economic and biological importance of these pests. However, in depth study of these pest species is largely hindered due to non-availability of any artificial/ synthetic diet. Only formulation of proper synthetic diets would help in carrying out advanced research and consequent management of these pests more effectively.

2.8 SYNTHETIC (=ARTIFICIAL) DIETS OF INSECTS: THEIR FORMULATION AND UTILITY IN REARING

The usefulness of mass rearing of insects on synthetic diets has been recognized since the eradication of the screwworm, *Cochliomyia hominivorax* (Diptera: Calliphoridae) from the Southern-eastern United States by the sterile male release technique in the 1960s. Insect rearing on their natural host may not be feasible for a number of reasons such as, seasonal availability, excessive cost and variable quality. Therefore, mass-rearing of insects has been tried time and again on synthetic diets. These synthetic diets bear little resemblance to their natural host or food source but nonetheless permit satisfactory growth and development of the mass-reared insects (Vanderzant 1966). The development of synthetic/artificial diets and rearing techniques for mass-production of lepidopteran insects has progressed over the last 50 years and has resulted in large number of literature, establishing diets for hundreds of species (Cohen 2004; King and Hartley 1992; Singh 1977). Insects that are reared on synthetic diets are used in many programs, such as, agents of biological control and sterile insect technologies (Knipling 1979), as feed for other animals (Teffera et al. 2000; Versoi and French 1992), as living bioreactors for production of pharmaceuticals, microbial and macro biopesticides and other recombinant proteins (Hughes and Wood 1998).

To study various aspects of life-cycle, behaviour, feeding nature, their susceptibility and resistance to conventional pesticides and microbial pesticides such as viruses, bacteria, fungi of pests, it is essential to rear the host insects (pests) (Rezapanah et al. 2008). Due to lack of sufficient research funding, synthetic diet-based insect-rearing is uncommon in developing countries. Therefore, economic threat posed to agriculture products by insect pests are poorly studied in these countries (Ahmed 1983). Mass production and availability of disease-free specimen of geometrid species (with looper stages) all through the year based on synthetic diet-rearing would open up newer opportunities for conducting research and experiments on:

1. Sensitivity and toxicity assays with pesticides/ new molecules of xenobiotics
2. Stimulo-deterrent chemicals (Pheromones/ kairomones)

3. Insect-plant interactions related to plant resistance mechanisms/ pathways
4. Neuro-physiological mechanism of insect control
5. Insect cell culture for species of loopers
6. Mass production of biopesticides viz., NPV, *Bacillus* and other strains
7. Production of parasitoids and effective predators

Various synthetic diets have been developed and proposed for the maintenance and continuous rearing of economically important insects (Robert et al. 2009; Ahmad and Hopkins 1992; Cohen 2001, 2004; McKinley 2004; Castane and Zapata 2005). Although, there are some reports of rearing success through complete generations of the economically important insects entirely on a synthetic diet, in many cases there is loss of both fitness and reproductive potential reflected in longer development time and lower fecundity (Coudron et al. 2002). As a result, the cost-saving ratio is diminished. Insect rearing practice 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 synthetic diets improved significantly during late 1960's and 1970's. In spite of the extensive work done during last century, synthetic diet-based rearing technology failed to secure a level which other entomological sub-disciplines have achieved. Cohen (2001) emphasised the recognition of insect-rearing and synthetic diet designing technology as a separate sub-discipline with the same level of importance as others. Singh (1977) compiled most of the synthetic diet formulated for partial or complete rearing of insects, whereas Cohen (2004) suggested modifications and improvement in the synthetic diet formulations.

Although, the synthetic diet-based insect rearing technology lacks the opportunity to gain attention from the different scientific community, different workers still continued to work for the advancement in the formulation of the new synthetic diet. Genc and Nation (2004) tried to improve the performance of *Phyciodes phaon* (Lepidoptera: Nymphalidae) (Phaon Crested butterfly) on semi-synthetic diet by adding freeze-dried host plant leaves equal to 10% by weight. A diet designed for a concerned species can be suitable for a different species with small modifications, as has been observed for the diet of *Harmonia axyridis* (Coleoptera: Coccinellidae) that has been adopted for *Chrysoperla carnea* (Neuroptera: Chrysopidae) by El Arnaouty et al. (2006).

Pradhan et al. (2006) worked on the tea pest, *E. latisfascia* and observed that when reared on synthetic diet, it showed shorter developmental period than that on natural diet with higher values of nutritional indices along with a lower maintenance cost and higher production index. In Taiwan, Shen et al. (2006) studied the performance of *Lymantria xylina* (Lepidoptera: Lymantriidae), a major defoliator of hardwood and fruit trees on synthetic and host plant diets and observed that *L. xylina* survived better with heavier pupal weight and adult size on synthetic diet besides the better nutritional indices than host plant *Liquidambar formosa* (Altingiaceae). They developed this synthetic diet for mass rearing the pest and for production of NPV. *Cactoblastis castorum* (Lepidoptera: Pyralidae) commonly known as the Argentine cactus moth, originates from South America and feeds on most species of *Opuntia*, the cactus been an important cultural and agricultural plant. A successful synthetic diet was developed and used for mass rearing *C. cactorum* in Sterile Insect Technology (SIT) program in South-Eastern United States for its control (Marti and Carpenter 2008; Marti et al. 2008; Carpenter and Hight 2012).

Worldwide, different organization such as USDA, IOBC-MRQA, Wuhan Virology Institute, P.R. China, Food and Agriculture Organization of the United Nations, Rome, OKSIR codling moth mass-rearing facility at Osoyoos, Canada, Institute of Plant and Environment Protection, Beijing Academy of Agriculture and Forestry Sciences, Beijing and many others including Indian organizations such as IARI, New Delhi, IIHR, Bangalore, NBAIR, Bangalore, IIPR, Kanpur have developed synthetic diet-based rearing system for economically important insects and using synthetic diet-reared insects for testing various aspects of non-conventional control measures. Perez and Shelton (1997) checked the resistance level by adding various concentration of *Bt* in the synthetic diet of *Plutella xylostella* (Lepidoptera: Plutellidae) as well as incorporating it in their host plants. The effect of proteinase and amylase inhibitor on the protein and lipid metabolism of *Epiphyas postvittana* (Lepidoptera: Torticidae) larvae was studied by incorporating them into the synthetic diet (Markwick et al. 1998). This type of study can be utilized to develop resistance plant varieties. Song et al. (1999) emphasized on the use of synthetic diet-based rearing of Asian Corn Borer for their IPM and bio-tech researches in China. The effect of temperature on development and life-cycle parameters were studied on the artificial diet/semi-synthetic diet-reared *Copitarsia decolora* (Lepidoptera: Noctuidae) (Gould et al. 2005) and *Maruca vitrata* (Lepidoptera: Pyralidae) (Adati et al. 2004). Ma et al. (2000) studied the biological effects of *Azadirachtin* initially on cotton fed *Helicoverpa armigera*, then subsequently they transferred the survived larvae to untreated synthetic diet for observing the physiological effects and the developmental anomalies. Likewise, Leckie et al. (2008) studied the effect of *Beauveria bassiana* (Helotiales: Sclerotiniaceae) on the mortality, growth and development of larval of *H. zea*, by incorporating the mycelia and spent fermentation broth into synthetic diet. Rizvi and Raman (2015) studied the preference of *E. postvittana* towards the fungal infected *Vitis* than uninfected *Vitis* by observing the difference in performance of *E. postvittana* on three diets: (i) basic diet, (ii) diet with lyophilized leaves of *Vitis* and (iii) diet with mycelial material of *Botrytis cinerea*. A new synthetic diet based on soybean, glycine max powder and fresh water bamboo, *Zizania caduciflora* (Poaceae) was formulated for Asiatic Rice Borer, *Chilo suppressalis* which is an important pest of rice, *Oryza sativa* (Poaceae) in China (Han et al. 2012). Paraiso et al. (2014) compared various life-cycle parameters of *Melitara* spp. (Lepidoptera: Pyralidae) on synthetic diet and natural host plant, *Opuntia* sp. They found that synthetic diet could provide better nutritive value than natural diet. All of these works on different pests were done in order to provide better IPM strategies for controlling the respective pests. Teimouri et al. (2014) compared the feeding indices and enzymatic activities of *Ectomyelois ceratoniae* (Lepidoptera: Pyralidae) on two commercial Pistachio cultivars (Akbari and Kalequchi) and a newly formulated synthetic diet. Sorour et al. (2011) evaluated a simplified semi-synthetic diet based on the combination of starch/agar for mass rearing of *S. littoralis* by comparing larval weight, pupal weight, adult emergence, fertility and development index along with percentage of pupation, survival, fecundity and sex-ratio. Similarly, Sujatha and Joseph (2011) developed a Tapioca-based oligidic diet for *S. litura* and studied its effect on mass rearing performance. They compared the developmental rate, life-history parameters and fertility on synthetic diet and the natural host plant, i.e. castor leaf. The widely distributed, Egyptian cotton leaf worm, *S. littoralis* which is polyphagous in nature, fed on many vegetables, field, ornamental crops and several other economically important host plants. It was felt significant to economically rear important insects to study their life-cycle, behavioural and feeding nature and their susceptibility and resistance to chemical and biological pesticides. For the first time Alfazairy et al. (2012) formulated an agar-free synthetic diet for rearing larvae of *S. littoralis* for nine consecutive generations. The study was aimed to develop a low-cost simplified diet, based on combination of starch and agar for rearing of the cotton leaf worm under laboratory conditions.

Application of a synthetic diet-based rearing can be summarized as in Fig. 2.1. Based on the above review of literature, the present study was contemplated with the main objective of formulating synthetic diets for three species of tea loopers, viz., *B. suppressaria*, *H. talaca* and *H. infixaria*.

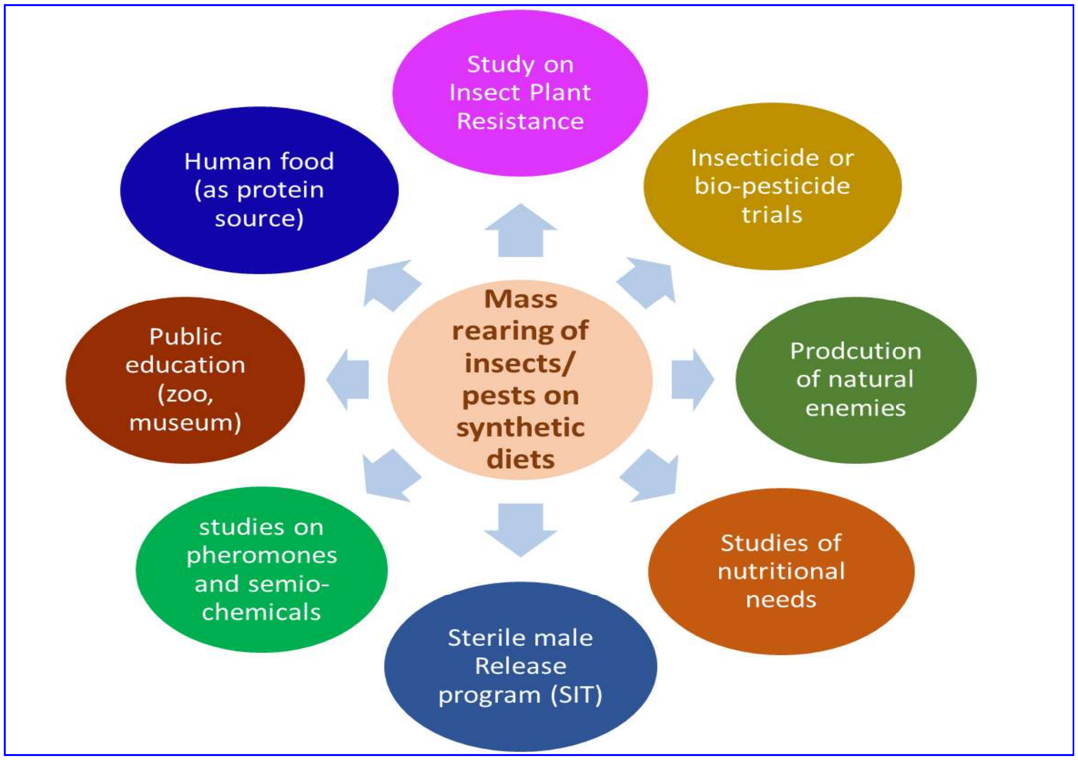

Figure 2.1: Utility of mass rearing of insects/ pests on synthetic diet (Adopted from Parra 2007, 2008)