

**“Rearing and Evaluation of Performance of some
common Lepidopteran Tea Pests on Natural and
Artificial Diets from Darjeeling Region”**

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Supervisor's Certificate

This is to Certify that Ms. Bina Pradhan, M.Sc. has worked on a Ph.D. Programme entitled "Rearing and Evaluation of Performance of some common Lepidopteran tea pests on Natural and Artificial Diets from the Darjeeling Region" under my supervision and guidance, and that she has fulfilled the requirements related to submission of Ph.D. thesis. She has carried out her work under the Fellow Improvement Programme of the University Grants Commission as a teacher fellow attached to the Department of Zoology, University of North Bengal. Her research work embodies original findings based on a well planned investigation. The dissertation submitted herewith is for the fulfillment of the degree of Doctor of Philosophy in Science (Zoology) of the University of North Bengal, and has not been submitted for any degree whatsoever by her or anyone else. I sincerely wish Ms. Pradhan and her endeavour success.

Ananda Mukhopadhyay, Ph.D.
Professor.

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(Bina Pradhan)

... dedicated to my parents.

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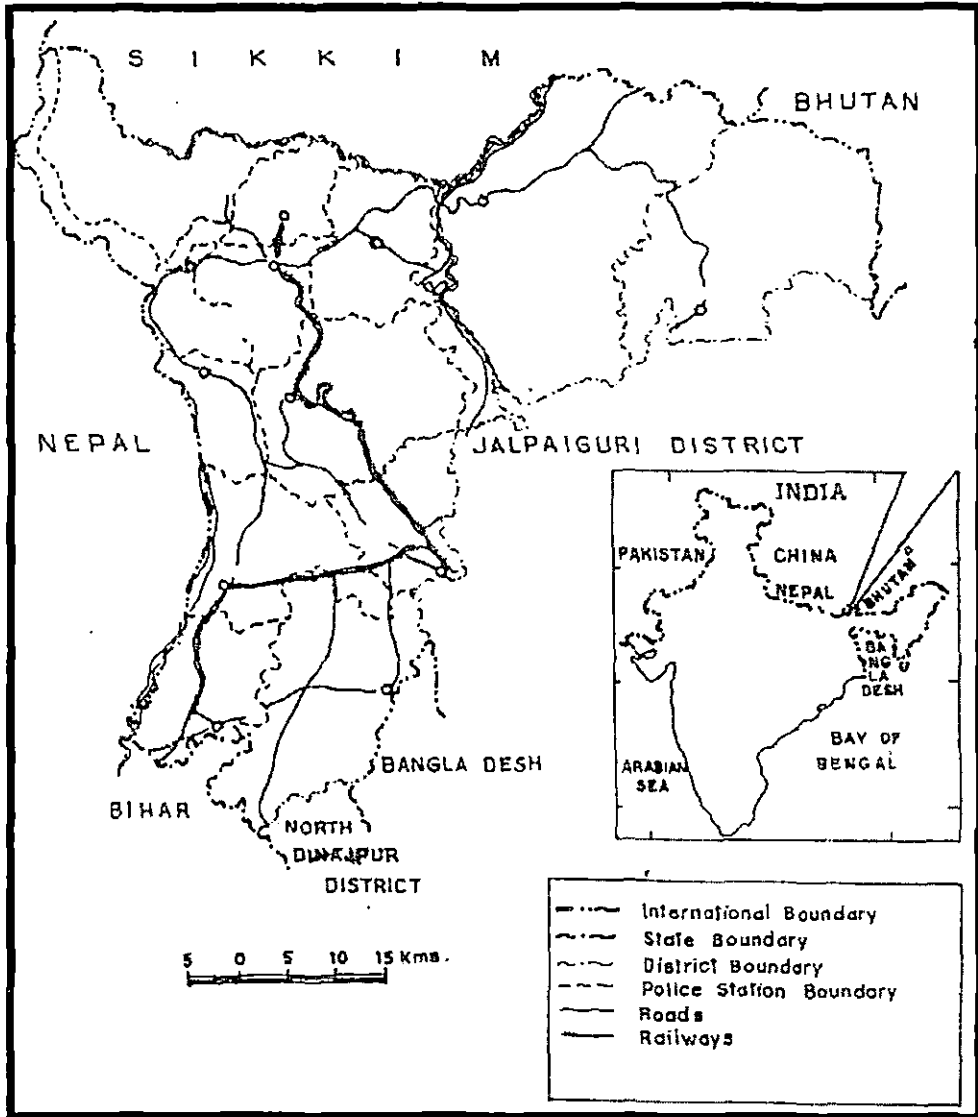


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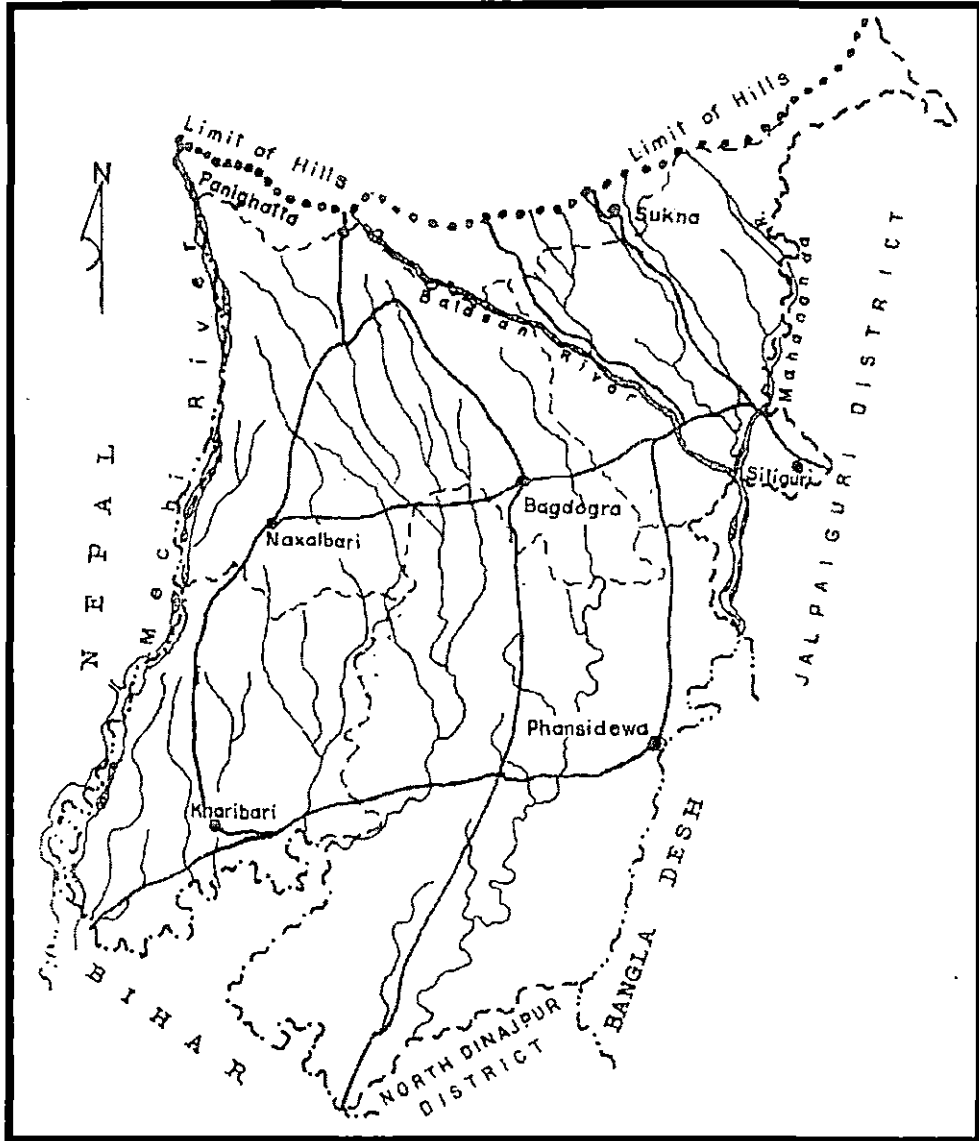


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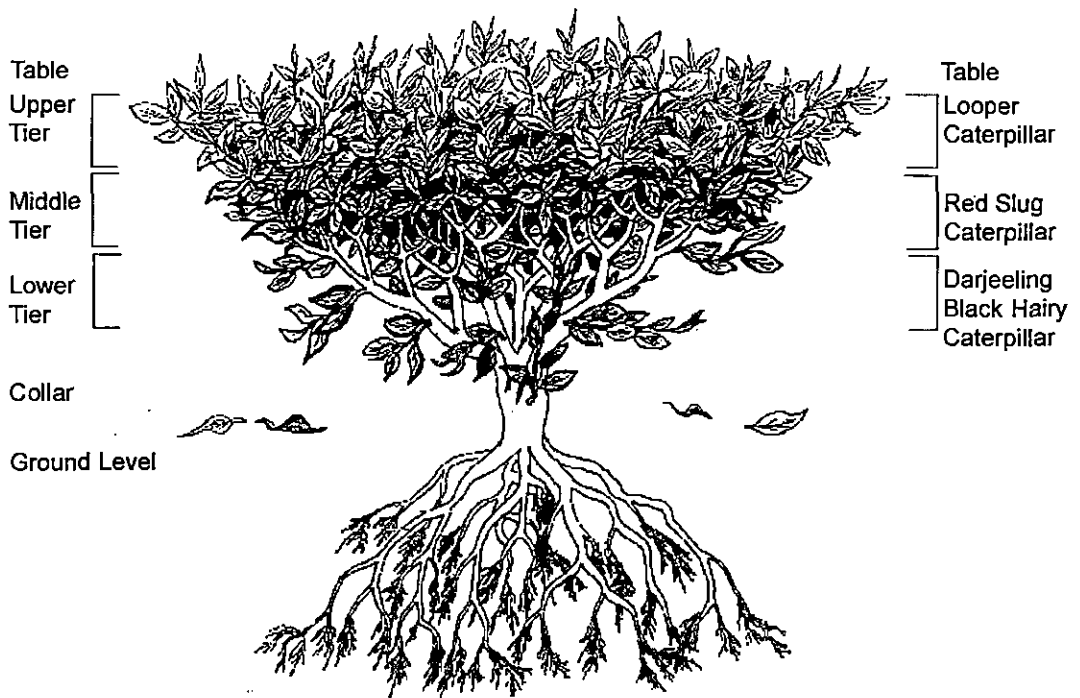


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Plate 1. View of a Terai Tea Garden in Darjeeling District.

INTRODUCTION

1. Introduction

Tea has made a reputation as a cheap and readily available beverage and is being recognized as a health drink as well. It is accepted as a socializing factor in almost all circles as it is non-alcoholic and non-carbonated and spreads across the globe surpassing all economic barriers due to its affordability as well as embracing the class factor. This great popularity of tea, draws attention of almost all tea producing countries from the economic point of view.

Tea, *Camellia sinensis* (L.) O. Kuntze, cultivation in India has a long history and is confined to specific locations, of which the Districts of Darjeeling and Jalpaiguri of West Bengal and a large part of Assam of N.E. India has gained importance both for quality and high yield. A few words on the historic advent of tea plantation, the physiognomy of the tea-growing regions of N.E. India, and economics of tea will help in understanding the background of tea plantation - its problems and prospects from this part of India.

Information regarding the indigenous tea in the Assam areas was known since 1815. Major Bruce was possibly the first man to start a tea nursery in 1826 on the garden attached to his bungalow at Sadiya, Assam. The first samples of tea manufactured by primitive methods was sent to Calcutta in 1836, which Lord Auckland acknowledge as of Good Quality. In 1837 the Assam Tea Company was established and in 1838, 8 chests containing 350 lbs were dispatched to England for sale.

The Makaibarie and Aloobarie gardens were planted in 1857 in the Darjeeling hills. Following these, Puntunghar in 1861 and Champta in 1862 were laid in the Terai and Singel, Manja, Fallowdhi, Atulpur, Sal Kotee, etc. on the slopes. By 1914, Assam had 762 tea gardens followed by Darjeeling and Duars with 156 and 118 gardens respectively (Dozey, 1922). This was followed by rapid growth in the Nilgiris, Travancore-Wynaad and the Annamalais. From the modest beginning in 1838, tea today plays a major role in the economics of India, occupying a leading position both in production and export.

The tea growing regions of Darjeeling district of West Bengal is located between 26° 31' and 27° 13' North latitude and 87° 59' and 88° 30' east longitude covering an area of 3149 sq. km (Fig. 1). The Northern part of the district has the distribution of eastern Himalayan range while the southern part consists of a stretch of alluvial plain at the base of the hills and is known as the Terai.

The Terai is situated 91 meters above sea level with an average rainfall of 350 cm. and an average temperature of maximum 30°C and minimum 12°C. The soil is moderately acidic, rich in organic material and is suitable for tea plantation (Fig. 2). Besides heavy rainfall, Terai and its adjacent Duars regions are well watered by a number of major rivers and a host of rivulets. The major rivers from east to west of Terai and Duars are: Siltorsha, Torsha, Jaldhaka, Teesta, Mahananda, Balason and Mechi.

By 1914, the Darjeeling & Duars region had 274 tea gardens covering 1.55 lakh hectares (Dozey, 1922) which grew to 3.31 lakh hectares by 1960 and was expected to reach a mark of 4.60 lakh hectares by 2000 (as projected in the

Annual Report & Statistics, 1997). India has been exporting tea ever since the plantations went on production. West Bengal has the second largest tea growing areas, in the country, and produces about 300 million kg of tea annually (12th October 2003, The Telegraph – Daily Newspaper). For over a century, India was the largest exporter of tea in the global market but today it commands only 16% of the world market trailing behind countries like Sri Lanka with 22%, Kenya-20% and China 17%.

Tea had been accepted as a general beverage for centuries but today with intensive pharmacological studies taking place around the globe it is appreciated for its contributions in maintenance of health. First and foremost is its antioxidant properties which detoxifies and helps in the general upkeep of the body. Flavonoids in tea help in the prevention of heart diseases, cancer, dental problems and cataract as well (Chen, 1990 & 1993).

Tea as a perennial and monoculture crop growing over extensive areas provide an inexhaustible resource for colonization by several guilds of insects and mites, many of which easily attain the pest status in such a stable ecosystem. Each tea growing region has its own distinctive pest fauna though they may be found in other areas as well. More than a thousand species of arthropods are known to attack tea all over the world though only about 300 insects and mites are recorded from India (Muraleedharan et al., 2001).

Insects may consume every anatomical part of the plant but show specialization with regard to the feeding sites they occupy (Shoonhoven et al., 1998). Every part of the tea plant has a specific guild of pests. They may be

grouped as per their feeding activity on stems, roots and foliage. Some sucking insects such as thrips, jassids and aphids cause extensive damage to the plant by making the shoot unproductive. The tea mosquito bug (*Helopeltis theivora*) is a serious pest both in South and N. E. India. The major root pests of tea are grubs of cockchafer and termites. Several species of cerambycid root borers damage the roots of old plants particularly in Darjeeling (Banerjee, 1993). Among the leaf attackers, mites are most widespread. Distribution of folivores, such as flushworms, leaf rollers, bunch caterpillars are more in the lower elevations of Darjeeling. In the Terai and Duars regions of Darjeeling foothills and plains, there are often outbreaks of defoliators such as *Buzura (Biston) suppressaria* Guen. (Looper caterpillar) and *Eterusia magnifica* Butl. (Red Slug caterpillar) causing extensive damage of the foliage. *Euproctis latifascia* Wlk. (Darjeeling Black Hairy caterpillar) though sporadic in distribution yet causes severe damage to the mother leaf of nursery plants and by consuming the mature maintenance leaves at the lower tier of tea bushes. Hence, the need for introduction of Integrated Pest Management in tea is greatly required (Barbora et al., 1994) in N. E. India.

The damage potential and recurrence of many pests are well known from tea plantations for long and many newly recruited region specific pests are now being recorded, but due to inappropriate measures taken in their control, the pest problem has further intensified. Although about Rs.15 crores is being spent in N. E. India alone for the control of pests and diseases, it has been found that about 6 to 14% of tea is lost due to insects, mites and weeds (Banerjee, 1976).

Normally 10% of the total crop is lost annually due to pests but this could rise to 40% in devastating attack by lepidopteran defoliators (Banerjee, 1993).

Routine application of chemical pesticides for the protection of tea crops has been a common and effective practice since the last 50 years but with growing usage of pesticides, the resistance of the insect pests to these chemicals has likely increased (Banerjee, 1968; Sarker and Mukhopadhyay, 2003). Therefore extreme precautionary measures must be adopted before a pesticide is introduced to tea for pest control (Das, 1962), which will also save residue build up. In 1934 there were 10 insect species known to be resistant against pesticides whereas by 1980 the figure rose to 432 and by 1990 about 500 cases were reported (Schulten, 1990). High incidence of pests in tea has led to the indiscriminate use of pesticides leading to problems such as killing of non-target organisms including natural enemies of pests (Anonymous, 2003), human health hazards, enhanced environmental hazards and above all the problems of insecticide resistances. The need for conserving natural enemies of pest (Banerjee, 1967) and an integrated approach for controlling mite pests of tea was emphasized (Banerjee, 1975a). Further, the role of Integrated Pest Management has been stressed by Muraleedharan (2000) for the ever growing pest problems in agricultural crops. It goes without saying that in the same spirit Integrated Pest Management (IPM) in tea requires planning to cover all the serious arthropod pests.

The three folivores *B. suppressaria* (Looper Caterpillar), *Et. magnifica* (Red Slug caterpillar) and *E. latifascia* (Darjeeling Black Hairy caterpillar) that

have been considered in this study are reported as pests of tea, specially from Terai and Duars areas of Darjeeling District and the State of Assam in N.E. India. Planters of Terai and Duars are facing serious problems in combating the outbreaks of these folivores. The outbreaks have caused a considerable loss of foliage and tea production (Mukhopadhyay and Das, 2003).

In view of the growing pest problem in tea and increased resurgence of pests in spite of the use of conventional chemical pesticides, it was felt necessary to undertake the present study on "Rearing and Evaluation of Performance of some common Lepidopteran Tea Pests on Natural and Artificial Diets from the Darjeeling Region". Expectedly this investigation would reveal greater details of the nutritional ecology and aspects of life cycle of three common lepidopteran pests. This knowledge may be used in future to develop non-conventional pest management strategies.

As little is known about the detailed biology of these folivores of tea, that includes their host preference, food consumption and utilization and related performance, an attempt has been made in this study to know more about their conversion efficiencies, growth patterns and survivorship on natural and artificial diets. Research using artificial diet is of great value to nutritional ecology, especially because particular aspects of food quality, either singly or in various combinations can be precisely altered. Artificial diets can be used to determine qualitative and quantitative nutritional requirements and the impact of nutrient levels (including water), allelochemicals and nutrient-allelochemical interaction (Reinecke, 1985; Slansky and Scriber, 1985).

Tea plantation in Terai and Duars regions comprise largely of clonal varieties (Assam Type) released by Tocklai (Tea Research Association). Some of the old and relatively new released clones are: Tv₁, Tv₁₈, Tv₂₅, Tv₂₆, etc. Host preference experiment was conducted using these to find out their predilection for the clonal varieties vis-à-vis the susceptibility of these clones to the folivores in question.

Morphometric studies have been made with the developing stages (instars) of these tea pests in order to help in easy identification of different larval stages of these pests using measurement parameters. Relative growth rates of different body parts were also studied to understand the nature of growth pattern of the three species of folivores during their post - embryonic developmental stages.

To know the adaptive fitness and suitability of diet, bioassay of these three lepidopteran folivores were conducted on natural (tea leaf) and artificial diets, which included detailed study on survivorship, life cycle, food utilization efficiencies, mass budget study etc. Further the biochemical components of the two diets (natural and artificial) and components of the dry body mass of the pest reared on these two diets were analyzed in order to know the relation. Such comparative study on bio-ecology, food utilization efficiencies and performance of these folivores on two different kinds of diets (natural and artificial) appears to be essential to achieve more perfection in successful rearing and commercial application of the control technologies based on mass production. Such a facility

can be used in opening up new prospects of non - conventional pest management programmes in tea.

The success of artificial rearing of lepidopterans has contributed greatly towards pest management research and has enabled the artificial rearing of its pathogens and parasites. The efficient rearing has made it possible to conduct a sterile technique program, either using chemosterilants or irradiation. Research on the development of crops resistant to lepidopterous pests increased after the advent of practical artificial diets for rearing lepidoptera (Davis and Guthrie, 1992).

Under non-conventional control methods besides nutritional ecology and dietetics, insect rearing on artificial diet appeared to be promising in providing a base for planning various control strategies. Development of insect rearing technology is very much essential in order to conduct and implement new pest control strategies such as those based on a) host plant resistance, b) production of microbial pesticides, c) biological control agents and d) sterile insect technique. Moreover rearing can provide the insect specimens (*pests*) for conducting bioassays in vivo or in vitro. The availability of a large number of laboratory reared insects are also essential for research in the field of physiology, ecology, genetic studies in addition to the development of hormonal and pheromonal manipulation and integrated control programme (Singh, 1977). Many of the advances in entomology during the past century can be attributed to the ability to rear insects successfully on artificial diets.

OBJECTIVES & SCOPE OF STUDY

2. Objectives & Scope of Study

Investigations were mainly conducted to study the following.

1. Preference for the Tea plant variety as food by the three folivorous caterpillars of a) *Buzura (Biston) suppressaria* Guen. (Looper), b) *Eterusia magnifica* Butl. (Red slug) and c) *Euproctis latifascia* Wlk. (Darjeeling Black Hairy lymentrid);
2. Lifecycle stages, survival and performance of the above folivores on the best preferred tea clone (Tv) with their morphometrics and growth patterns;
3. The indices of nutritional ecology on consumption, digestion, utilization using natural diet (tea leaves) and chemically defined diets (artificial diets);
4. The growth, maintenance and developmental success of the folivores on both the natural and artificial diets; and
5. The dietary components present in the food (leaves and synthetic diets) used by the folivores and their conversion into the basic nutritional components of the body mass.

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 al. (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 latifascia 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 latifascia* 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). Verchaffel's 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 catenary 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. Slansky 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 (Waldbauer 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) (Panochloridae: 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 *Oncopeltus 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 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 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), Martínez 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 vomitaria* (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 artificial 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 *Ecdytoplopha 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* (Lepidoptera: 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 CO₂ and temperature reported

that CO₂ 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 and 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 Ananthkrishnan (1992).

MATERIALS AND METHODS

4. Materials and Methods

4. 1. Survey of tea plantations and collection of lepidopteran pests

Three folivorous lepidopteran pests of tea, *Buzura (Biston) suppressaria* Guen. (Looper Caterpillar), *Eterusia magnifica* Butl. (Red Slug Caterpillar) and lymentrid, *Euproctis latifascia* Wlk. (Darjeeling Black Hairy Caterpillar) were mainly considered for the present study.

Tea plantations of Terai and tea gardens in and around North Bengal University campus were surveyed for collecting these pests (Plate 1). Names of the tea estates which were frequently surveyed for insect materials during the course of study were Matigara, Maruti Kamalpur, Chandmani, Atal, Gangaram and Dagapur. These gardens had mostly matured tea bushes of Tocklai varieties (TV₁₈, TV₂₅, TV₂₆) that produced vigorous flush in Terai agro-climate. Usually larval stages of loopers and hairy lymentrid and adults in case of red slug were collected (handpicked) from tea bushes and trunks of shade trees in the morning hours. The collected larvae and adults were brought to the laboratory in polythene packets and containers.

4. 2. Source of natural food (Tea leaves) for laboratory rearing (culture) and experimentation with the lepidopteran folivores

Natural food (tea leaves) which was provided for rearing and for various experiments were collected from the experimental tea plot of Department of Zoology at North Bengal University campus which was about 12 years old. The

clonal varieties Tv₁, Tv₁₈, Tv₂₅ and Tv₂₆ of the experimental garden were kept under usual cultural practices with organic manure and no pesticidal application.

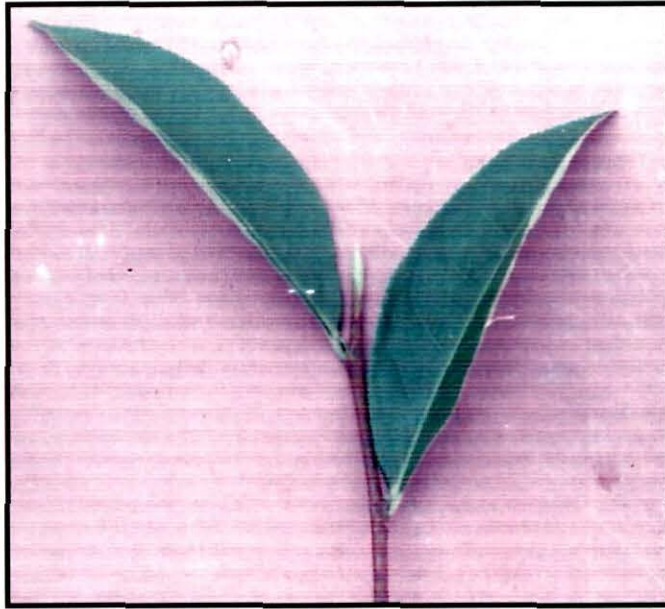
Tv₁: It is one of the earliest clones released by 'Tocklai Experimental Station', Assam (India) in 1949. Tv₁ is a standard clone, having high yield potential and high quality. It has a compact frame with acute branch angle (<50°). Leaves are erect, medium sized with pubescence on lower surface and sunken stomata. Surface matt in nature. Fairly draught tolerant. It is a hybrid of Assam × China origin.

Tv₁₈: It is of Cambod origin. More or less of compact frame with glossy medium sized leaf. Leaf axil with an angle of 50° to 70°. It has a high yield potential but of average quality. Leaf has pinkish pigmentation in the petiole.

Tv₂₅ & Tv₂₆: These are high yield clones of Assam × Cambod origin. Morphologically both the clones are similar in nature, having compact frame and glossy medium sized leaf. Both the clones are fairly drought tolerant having high yield potential but of average quality. Leaf axil being >70° (Plate 2).

4. 3. Mass Rearing on Natural and Artificial Diets.

Laboratory rearing of immature stages were conducted in transparent buckets (27.5 cm.×27cm.) containing several twigs with leaves of host plant immersed in water in a conical flask (250ml), plugged by cotton and covered by muslin cloth. The larvae were transferred daily into sterilized and clean buckets along with fresh clean food. Mass rearing was continued till the emergence of adults in aseptic conditions to avoid contamination.



Tv₁



Tv₁₈



Tv₂₆

Plate 2. Clonal Varieties of Tea.

Freshly emerged adults and collected adults were sexed, paired and allowed to mate in glass chimneys (19.5 cm x 8.5 cm), containing a twig with leaves of the host plant immersed in water in a conical flask to elicit oviposition. Two strips of brown paper were also stretched inside the chimneys as egg-laying surface. A cotton swab moistened with diluted honey with water (1:1) was hung inside the chimney as food for the adults. The chimneys were covered with muslin cloth. The eggs were transferred onto towels (tissue paper) and placed in plastic containers (9.5 cm x 5 cm.) covered by lid with fine holes. The eggs were kept in BOD incubator till the emergence of neonates.

The larvae from IIIrd instar onwards in case of *B. suppressaria* and *Et. magnifica* and neonates of *E. Latifascia* were mass reared on artificial diets in plastic containers (9.5cm x 5cm) in batches of five per container. The larvae were transferred into freshly disinfected containers on alternate days and fresh food (artificial diet) were supplied. Rearing was continued till the adults emerged which were then transferred to glass chimneys (with similar conditions as in the case of mass rearing of adults on natural diet) for oviposition (Plate 7) .

In order to reduce contamination of insect diets with pathogens or microbial contaminants, sterilization of eggs was accomplished by surface sterilization with 0.3% Al (NaOCl) solution for 5 min. (Leppla et al., 1984) and thorough rinsing with distilled water which was followed by drying under laminar air flow hood prior to infestation of the diets with the freshly laid eggs. Aseptic condition was maintained as far as possible to avoid contamination.

4. 4. Preparation of Artificial diets:

The lepidopteran tea pests considered in the present investigation were reared for the first time on artificial diets. As no defined diet of any related species of the above pest species were known, several combinations of diet components (formulations) had to be tried. After several trials, the artificial diet used for geometridae: *Alsophila pometaria* (Lyon, 1970) was found suitable for rearing immature stages of *Buzura suppressaria* and *Eterusia magnifica*. For *Euproctis latifascia*, a diet for *Lymantria dispar* (Magnoler, 1970) was found suitable. Details of diet composition are given in Table I and Table II.

Glassware used for preparation of diets were autoclaved. Preparation and dispensing of diets were done under the laminar flow hood to avoid contamination. Glucose was the carbohydrate used. Ascorbic acid was incorporated because it is widely accepted that it is required for normal development of phytophagous insect species (Farinos et al., 1999). Minerals were supplied by Wesson's salt mixture (Sigma) and wheat Germ (Sigma), the latter also being the source of cellulose. The Brewer's yeast powder (Sigma) was used to supply vital nutritional factors because it is a good source of micro - and macronutrients needed for some insect species (Tsitsipis, 1989). Sorbic acid, methyl p-hydroxybenzoate (Sigma) were incorporated to inhibit microbial growth of yeast, bacteria and filamentous fungi in diets. Linoleic acid was incorporated in the diet as it is considered useful for successful pupal eclosion (Fraenkel and Blewett, 1946a ; Sivapalan and Gnanpragasam, 1979b). Tea infusion was used in the diet because host plant material as fresh or ground whole plants, plant

Table 1. Components of the Artificial Diet (Lyon, 1970) used for rearing of *Buzura suppressaria* and *Eterusia magnifica*.

Components (g)	
Vitamin – Free Casein	98.00
Glucose	98.00
Wesson's Salt Mixture	28.00
Cholesterol	8.40
Potassium Sorbate	3.36
Choline Chloride	2.80
Wheat Germ	140.00
Alphacel	84.00
Wheat Germ Oil	7.50
Agar	70.00
Sodium Alginate	14.00
Potassium Sorbate	14.00
Vanderzant's fortification Mixture	40.00
Linoleic Acid	6.00 ml
Tea Infusion with Distilled Water	2100.00 ml

Table 2. Components of the Artificial Diet (Magnoler, 1970) used for rearing of *Euproctis latisfascia*.

Components (g)	
Vitamin Free Casein	2.80
Wesson's Salt Mixture	1.00
Glucose	1.98
Cholesterol	0.02
Wheat Germ	5.70
Sodium Alginate	0.50
Alphacel	1.40
Choline Chloride	0.10
Sorbic Acid	0.08
Methyl p-hydroxybenzoate	0.08
Agar	2.28
Ascorbic Acid	0.50
Aureomycin	0.01
4M KOH	0.47 ml
Linoleic Acid	0.50 ml
Sunflower Oil	0.25 ml
Vitamin Solution	1.00 ml
Distilled Water	20.00 ml
Tea Infusion with Distilled Water	62.00 ml

parts or extracts have been, and are still used to induce feeding and increase vigor in laboratory-reared fastidious insects (Doss, 1980; Schoonhoven et al., 1998).

Hot infusion of tea was prepared by thoroughly washing fresh tea leaves, cutting into small pieces and simmered in distilled water for 5 minutes. Wheat germ was roasted for a while to improve the taste. To prepare the diet, gelling agent agar was dissolved in hot tea infusion and mixed thoroughly in a beaker, and the mixture was cooled to 50° C, then the rest of the ingredients were added gradually when the medium was still hot and mixed thoroughly into a fine paste till there were no lumps. The preparations (diets) were then allowed to cool to room temperature after which diets were transferred to plastic containers with lids and kept in a refrigerator for future use. Maximum precautions were taken during diet preparation to avoid contamination and the working areas as well as the containers used for rearing were disinfected by 0.4 % sodium hypochlorite solution on a daily basis.

4. 5. Host plant selection:

The laboratory eclosed larvae of *Buzura suppressaria*, *Eterusia magnifica*, and *Euproctis latisfascia*, were used for host plant preference experiments. Fifteen replicates each, of the two different categories (specimens) considered for the study were:

- i. the early instars represented by IIIrd stage larva, and
- ii. advanced instars represented by Vth or VIth stage larva.

Each category of larval stage used were starved for twelve hours only; further starvation was not done to avoid emaciation and death out of starvation.

In the first set of experiments, three tocklai clones (varieties) TV₁, TV₁₈ and TV₂₆ were selected. Leaf discs of each variety were cut from the same portion of tea leaves of same maturity and were placed at reasonable distances in petridishes (15 cm. in diameter) on the moistened filter paper with wet cotton balls to prevent wilting of leaf disc. In the center of each petridish, a single larva of each category of the experimental insects was released and allowed to feed for 12 hours (Jermy, 1961 ; Jermy et al., 1968). After 12 hours of feeding, leftover leaf discs were oven dried and weights were recorded.

Dry weights of food consumed were determined by subtracting dry weights of leaf discs after consumption from the dry weights of an intact leaf disc of equivalence. For two different categories of three lepidopteran insect pest species, similar experiments were conducted to ascertain preference for the host variety. The values obtained based on feeding were converted into percentage and was converted into arc sin for statistical analysis. The mean values are based on fifteen replicates.

4. 6. Morphometric & Allometric growth study:

Measurements of the life cycle from egg to adult stage of each of the lepidopteran tea pests were done based on ten specimens of each stage. The body length, interocular distance and head length of various stages were

measured using oculometer fitted in Wild M₃ binocular wherever needed. The structures and colour of the various stages were also noted.

Post embryonic development in insects is punctuated by a series of moults and ecdyses, each preceded by a period of active growth (Wigglesworth, 1965). The extent of growth at each moult can be predicted using certain empirical laws. Huxley (1924) and Huxley and Tessier (1936) proposed the allometric or heterogenic growth pattern. They suggested the term allometry for denoting the growth of a part that is growing at different rate from that of the body as a whole (or any stable part). They further suggested that the growth relation could be calculated using the equation $y=bx^k$ (where, y is the allometrically growing segment or part; 'b' is a constant, denoting initial growth index, and is the theoretical value of 'y' when standard measurement x equals unity; k is another constant, denoting growth ratio and indicates the value at which 'y' grows in relation to the standard measurement 'x' (any stable part or the whole body).

The value of 'b' and 'k' are calculated by the method of least squares. When $k=1$, 'y' grows at the same rate as 'x' i.e. isometry, when $k<1$, 'y' grows slower than 'x' i.e. negative allometry. When $k>1$, 'y' grows faster than 'x' i.e. positive allometry. The other form of the equation $y=b x^k$ is: $\log y=\log b + k \log x$, means that if the logarithms of the size are plotted, a straight line is expected and from the slope of which the value of 'k' can also be determined.

In the present study the width of head was chosen as the standard measurement because it is the most stable part of the body and least subjected to change in size owing to changes in physiological state of the individual. By computing the mean of ten measurements of ten individuals of each stage for all three folivores, based on different body parts the values of 'k' and 'b' were calculated. By using value of k (equal to gradient value of the straight line equation) and b (intercept on ordinate i.e. log b) the regression equations could be formulated and the regression lines for all the three variables could be pooled for three species. Matsuda (1960) after his extensive study of relative growth in Gerridae hypothesized that when growth ratio (k) increases, the initial growth coefficient (b) decreases and vice versa.

4. 7. Post-embryonic Development period on Natural and Artificial Diets:

The development and life cycle of three species, *Buzura suppressaria*, *Eterusia magnifica* and *Euproctis latisfascia* were studied by rearing in the laboratory conditions of $28 \pm 2^\circ\text{C}$, $75 \pm 5\%$ Relative humidity and 12 hours L:D. To study stadial periods, twenty neonates were separated and reared in batches of four in plastic containers (26 cm×8.5 cm.). Twigs of host plant with leaves were offered as food everyday. Daily observations were made to find out change in the instar by detecting the head capsule and exuvium. Duration of pupal and adult stages was recorded. Similar study was conducted for all the three folivores on artificial diets (with IIIrd instar onwards for *B. Suppressaria* and *Et. magnifica* and neonates of *E. latisfascia*). Individual rearing on artificial diet was conducted in (9.5cm×5cm) plastic containers towed with tissue paper. Artificial diets meant

for each folivore was provided everyday. Daily observations were made to find out changes. Duration of all the stages was recorded.

4. 8. Survivorship study:

Survivorship studies were conducted with immature stages of three lepidopteran tea pests reared on natural (specific host plant) and artificial diets under laboratory condition as mentioned earlier. Rearing on natural diet was conducted in (26 cm.×8.5 cm) plastic containers, 100 newly hatched neonates were separated in small batches of ten for each observation. Observations were made on the preferred host plant of each species at the time interval of 24 hours (x). The number of individuals alive during a particular age interval (lx) and the number of larvae dying within the age interval (dx) were recorded. The rate of mortality (qx) was also calculated.

A survivorship study was conducted in case of Darjeeling black hairy caterpillar on artificial diet with 100 newly hatched larvae separated in small batches of five and reared in (9.5cm.×5cm.) plastic containers.. However, in case of red slug and looper caterpillars studies were conducted from IIIrd instar onwards on artificial diets. This rearing technique had to be adopted for two of three species as several attempts to rear the Ist and IInd instars on artificial diets met with high mortality and partial success. Rearing on artificial diets was conducted in (9.5 cm.×5 cm.) plastic containers. For comparison of the observed survivorship curves, a figure with four hypothetical situations was adopted from Pearl (1928) and Dash (1995).

4. 9. Daily food consumption and larval weight :

In order to find out the daily food consumed and weight changes in late instars of the caterpillars of the three species in question on two different diets (tea leaves and artificial diet), freshly ecdysed IVth and Vth instar stages (10 replicates each) of looper and red slug and Vth and VIth stages of black hairy caterpillars were kept throughout the stadia period under observation. Experiment was conducted inside the BOD incubator under conditions mentioned earlier.

Daily preweighed fresh food (tea leaves with twig) was offered to each individual kept in (26cm×8.5cm) plastic containers. After 24 hours of feeding, leftover food and excrement were removed, oven dried and weighed. Dry weight of the actual food consumed was calculated by subtracting the dry weight of the leftover food from the dry weight of an equivalent amount of the food offered. In a similar manner, daily consumption of food and larval weight change (based on dry weight) was recorded for folivores reared on artificial diet. Larval weight change (based on dry weight) was calculated by drying a larva of similar weight (reared on two different diets) in the oven at 50° C for 72 hours.

4. 10. Reproductive performance:

In order to find out the reproductive performance of all the three species on natural and artificial diets, pupae from the mass culture were separated and kept individually in plastic containers (9.5cm. x 5 cm.) till the emergence of the adults. Freshly emerged adult moths of the three pest species were sexed and

reared in glass chimneys containing a twig of host plant dipped in water for rearing and oviposition. A cotton ball soaked with diluted honey (1:1) was hung from the wall of the chimney as food. Two strips of brown paper were stretched in the chimney as an alternate surface for laying of eggs. Fecundity alongwith pre and post oviposition and egg laying periods were observed for six pairs of each species. Pupae and freshly emerged adults of the three lepidopteran tea pests from mass culture (natural and artificial diets) were sexed, oven dried and weighed (n=6).

4. 11. Dry Mass budget:

Freshly eclosed IVth and Vth instars of looper and red slug and Vth and VIth instars of black hairy caterpillars (15 replicates for each species) were used for assessment of dry mass budget. Experiment was conducted in the environmental chamber at 28±2°C, 75±5% R.H. and 12 hours L:D. For experiment with natural food, each larva was kept / reared singly in (26cm.x8.5cm) plastic containers and provided with known quantity of food (tea leaves with twig).

Daily record of weight of larva, food offered, food not consumed and excrement produced were taken. Control was run concurrently by keeping the tea leaves with twig immersed in water in conical flask plugged by cotton ball. The food not consumed, the faecal matter and the control leaves were then dried to constant weight at 50°C. Dry weight of food consumed was determined by subtracting dry weight of the eaten twig with leaves of host plant from the dry weight of an equivalent intact twig with leaves of the same age.

Similar methodology was adopted for mass budget assessment for all the three pest species on artificial diets. Experiment was conducted in (9.5cm×5cm) plastic containers under similar conditions. Dry weight of food consumed in case of a larva reared on artificial diet was determined in a similar way by subtracting the dry weight of the left over food from an equivalent food (initially offered to the larva). Gravimetric technique was used to determine food consumption, growth ratio and post ingestive food utilization efficiencies (all based on dry weight) after Waldbaurer (1968), Slansky (1985), Slansky & Scriber(1985), Petruszewicz and Macfadyen (1970), Muthukrishnan & Pandian (1987) and Farrar et al.(1989).

Units used: weights in mg; time in days; and efficiencies in percentage.

a. Assimilation (As) = Food consumed (C) – Faeces (Fu)

b. Production (P) = Final body weight (W₂) – Initial body weight (W₁)

c. Respiration (R) = As – P

d. Maintenance Cost = R / P

e. Production Index = P / As

f. Approximate Digestibility (AD)

$$= \frac{\text{Wt.of food ingested} - \text{Wt.of faeces}}{\text{Wt.of food ingested}} \times 100$$

g. Efficiency of Conversion of Ingested food (ECI)

$$= \frac{\text{Wt. gained by the insect}}{\text{Wt.of food ingested}} \times 100$$

h. Efficiency of Conversion of Digested food (ECD)

$$= \frac{\text{Wt. gained by the insect}}{\text{Wt. of food digested}} \times 100$$

i. Relative Consumption Rate (RCR) = $\frac{C}{\overline{BA} \times T}$

j. Relative Growth Rate (RGR) = $\frac{P}{\overline{BA} \times T}$

Where \overline{BA} = Arithmetic Mean of Body Weight of a stage and T = Feeding Period in Days.

4. 12. Biochemical analysis:

Biochemical analysis of the basic dietary components of three clonal varieties and final larval stages of the three tea pests under study were conducted. In all cases, an equal amount of dry weights of natural (tea leaf) and artificial diets and larval body mass were used for the analysis of the biochemical components which were subsequently converted into percentage for convenience of comparison. The methods adopted are described below:

4. 12. 1. Preparation of dry leaf powder: (Banerjee and Haque, 1985)

Young and matured leaves of Tv₂₆ (preferred by Looper and Red Slug Caterpillars respectively) and senescent leaves of Tv₁₈ (preferred by Hairy Caterpillar) were collected from the tea experimental plantation of Zoology Department, at North Bengal University campus. These leaves were cleaned, and oven dried at 50° C for 48 hours. Later each category of leaves were

crushed to fine powder in a grinder and kept in sealed polythene packets in desiccator over silica gel for further analysis.

4. 12. 2. Preparation of dry powder of late instars of *B. suppressaria*, *Et. magnifica* and *E. latifascia*

From the mass rearing on natural (tea) diets a good number of healthy Vth instar stages of Looper Caterpillar and Red Slug, and VIth instar stage of hairy Caterpillars were selected and kept hungry for 12 hours to completely empty their gut content. Subsequently these were cold narcotized and oven dried at 50° C for 72 hours. Fine powder of dried larvae of each species was made separately by grinding and kept in sealed polythene packets over silica gel in a desiccator. Similarly, healthy samples of final larval instars of lepidopteran pests reared on artificial diets were processed, powdered and kept sealed in polythene packets.

4. 12. 3. Analysis of Biochemical components

4. 12. 3. 1. Total Nitrogen.

The method as described in AOAC (1990) was followed. Approximately 2g of sample was accurately weighed, placed in a digestion flask and was added with 7.0 g catalyst (CuSO₄ : K₂SO₄, 1:9) and 25ml concentrated H₂SO₄. The flask was gently heated until frothing ceased, the content was boiled briskly until the solution became clear, and then the boiling was continued for about 1 hour. The solution was transferred quantitatively to a round bottomed flask and the volume was made up to 100 ml. with distilled water. A layer of 40 % W / V aqueous NaOH (approx. 100 ml.) was added carefully till the solution of flask turned black.

The flask was immediately connected to a distillation apparatus and the tip of the condenser was immersed in standard 20 ml. 0.1 (N) H₂SO₄ containing about 2 drops of methyl indicator (0.5 % W / V methyl red in ethanol). The flask was rotated to mix the contents thoroughly and heated until all the ammonia had distilled. The receiver was removed and the tip of the condenser was washed with distilled water. The remaining acid in the receiver was titrated with standard 0.1 N NaOH solution. The value of blank was determined (Water + Catalyst + 25ml. H₂SO₄ = digested) in order to make correction factor.

Total Nitrogen (%) = {[ml.of standard acid ×.1(N) of standard acid] – [(ml. of standard NaOH – correction factor) ×.1(N) of standard NaOH]} × 1.4007 / Wt. of sample (g)

4. 12. 3. 2. Fat:

Fat content was extracted using a glass soxhlet (AOAC, 1990). Round bottomed flask was oven dried and kept in a desiccator for cooling. The weight (W₁) of the round bottomed flask was taken. A cellulose thimble (dry and fat free) was taken in which ~ 2 g of sample was placed and put in the soxhlet. Fat was extracted by using petroleum ether (with boiling range 40 - 60° C) in the round bottomed flask fitted with the soxhlet containing the thimble with sample on a heating mantle at 60° C for 5 h. The round bottomed flask with the extract was dried for 1 h at 100° C to evaporate ether and moisture, cooled in desiccator and weighed (W₂). Fat was calculated in percentage.

$$\text{Fat (\%)} = (W_2 - W_1 / \text{sample weight}) \times 100$$

4. 12. 3. 3. Total ash:

2 g of sample was accurately weighed into a previously dried and weighed crucible. This was placed in a Muffle furnace and heated to 550° C for 3 h. The crucible was transferred directly to a desiccator, allowed to cool to room temperature and weighed immediately (AOAC, 1990).

$$\text{Ash (\%)} = W_2 - W_0 / W_1 - W_0 \times 100$$

Where W_0 = Wt. of crucible

W_1 = Wt. of crucible + sample (before heating)

W_2 = Wt. of crucible + sample (after heating)

4. 12. 3. 4. Moisture

Moisture of natural (tea leaf) and artificial diets and larval body mass were calculated by subtracting the final weights from the initial weights. Drying was done at 50°C for 72 hours or till the constant weight was attained. The moisture is expressed in percentage of the fresh weights of natural (tea leaf) diet, artificial diet and larval body mass.

The Biochemical estimates were based on five replicates and the values presented are the percentage of mean.

4. 13. Statistical Analysis

Studies on Host Plant Selection, Allometric Growth, Post – embryonic development period on Natural & Artificial Diets, Daily Food Consumption and Larval Body Weight, Reproductive Performance and Dry Mass Budget were

subjected to statistical treatment as per requirements for computation of Mean, Standard Deviation, Standard Error, Regression, Student's t – test, LSD and ANOVA from the Systat Package and Excel was used for Graphics.

RESULT AND DISCUSSION

5. Result and Discussion

5. 1. Host Preference

The host plant range selected by a phytophagous insect species is probably one of its major biological characteristics and is constrained by several morphological, physiological and ecological factors. One of the most striking features of insect - plant relationship is the fact that most of these insects are specialists and have strong feeding preferences that result in various degrees of host specificity (Schoonhoven et al., 1998).

The act of host selection depends upon the physical and chemical characteristics of the plants; the selection of a plant involves catenary process of events in response to stimuli elicited from the plants and perceived by the insect. The physical characteristics of plants include thickness, roughness, presence or absence of trichome etc., while the chemical characteristics include both primary and secondary metabolites (Panda and Khush, 1995).

Acceptance and successful utilization of a host plant by phytophagous insects depends upon the coordinated interaction between the insect and the plant (Ananthakrishnan, 1992). The mechanism of host plant selection in phytophagous insects is a complex phenomenon involving host habitat finding, host finding, host recognition, acceptance and host suitability (Dethier, 1954).

Host preference studies with early and late instar caterpillars clearly indicated that *Buzura suppressaria* had a significant preference for Tv₂₆ (tea clonal variety) over the other two varieties (Tv₁₈ & Tv₁). Preference of *Eterusia*

magnifica was significantly different for all three varieties where it was evident that both early and late instars had a high preference for Tv₂₆ variety. *Euproctis latisfascia* (early and late instars) showed significant preference for Tv₁₈. The three lepidopteran folivores, in general showed less preference for Tv₁ clone. Data on host preference for early and late instars are presented in Tables 3 & 4 respectively.

Insect herbivores possess sensitive receptor systems that allow them to detect a variety of phytochemicals. Within a host range the choice of a particular food is usually dependent on its phytochemical composition. Some specialized insects feed on plants generally containing a particular category of allelochemicals, other more generalized insects may avoid consuming certain plants because of their allelochemical contents and may choose others because of their energy and / or nutrient contents (Slansky, 1992).

Tv₁ has a high non-digestible component in its leaves as compared to Tv₁₈ and Tv₂₆ (Bhuniya, 1999). The toughness of leaf tissue and the amount of secondary metabolites increase as leaves mature, which decrease the nutritional quality of the leaves for folivorous larvae (Fenny, 1968,70; Swain 1979, Hunter and Lechowicz, 1992). Most insect ecologists agree, that plants with tough tissue generally act as an antiherbivore defense (Fenny, 1970; Feller, 1995). The *crude fibre which consists of cellulose and lignin cannot be easily digested by enzyme secreted by insects* (Soo Hoo and Frenkel, 1966) as such Tv₁ leaves with higher non-digestible components mainly comprising cellulose fibres and lignin were less preferred by all the three species of folivores.

Table 3. Host preference in percent (Pr) of three folivores (early instars) on three clonal varieties.

Tea Clonal Variety	Looper		Red Slug		Hairy Caterpillar	
	Percent	Mean \pm SE	Percent	Mean \pm SE	Percent	Mean \pm SE
TV ₁	9.69	0.166a \pm 0.032	11.49	0.197a \pm 0.022	13.20	0.227a \pm 0.011
TV ₁₈	7.63	0.131a \pm 0.021	17.07	0.292b \pm 0.016	30.87	0.510b \pm 0.018
TV ₂₆	26.90	0.126b \pm 0.063	30.68	0.506c \pm 0.025	17.31	0.295a \pm 0.023
LSD		0.0470		0.0457		0.0208

* Values transformed in arc sin for statistical analysis. Means followed by the same alphabet in each column are not significantly different at 5% level using ANOVA and LSD

Table 4. Host preference in percent (Pr) of three folivores (late instars) on three clonal varieties.

Tea Clonal Variety	Looper		Red Slug		Hairy Caterpillar	
	Percent	Mean \pm SE	Percent	Mean \pm SE	Percent	Mean \pm SE
Tv₁	16.02	0.274a \pm 0.027	14.90	0.255a \pm 0.024	23.13	0.390a \pm 0.021
Tv₁₈	15.25	0.261a \pm 0.028	20.77	0.353b \pm 0.016	41.04	0.647b \pm 0.032
Tv₂₆	39.13	0.620b \pm 0.034	45.18	0.700c \pm 0.027	25.92	0.434c \pm 0.024
LSD		0.0314		0.0240		0.0279

* Values transformed in arc sin for statistical analysis. Means followed by the same alphabet in each column are not significantly different at 5% level using ANOVA and LSD

Tough leaves may take longer time to consume and therefore result in slower growth rates of insect herbivores (Stevenson et al., 1993). Variation in leaf toughness within and among species of the host plants is often associated with variation in levels of herbivory (Speight et al., 1999). Stevenson et al. (1993) negatively correlated between leaf toughness with insect development. Bergvinson et al. (1995a, b) established that leaf toughness was having a negative influence on insect preference and Sagers and Coley (1995) indicated that leaf toughness resulted in less defoliation by insect herbivores. It was further observed that larval and adult insects might avoid individuals or species with tough leaves, thereby leading to lower levels of phytophagy (Roces and Hoelldobler, 1994).

Leaf toughness is also known to be accompanied with a decline in water content, decline in nitrogen content, increase in condensed tannin concentrations and decline in hydrolysable tannin concentrations (Fenny, 1970; Hunter and Schultz, 1995). It is likely that many of these above factors come to play in selection of the tea clone as host. Tv₂₆ with higher moisture and less fibre contents than the other two clones (Tv₁₈ & Tv₁) was therefore a preferred variety for two of the folivores, *B. suppressaria* and *Et. magnifica*. Please refer to tables on biochemical components and moisture of leaf (Tables 22 & 23).

5. 2. Life-cycle & Morphometrics

5. 2. 1. *Buzura suppressaria*

Under the laboratory condition, *Buzura suppressaria* on natural diet laid eggs in clusters on the axils of the leaf or on tissue paper toweling the rearing jars or on the cotton wads used for plugging the mouth of the conical flask containing the tea twig. The freshly laid eggs were bluish green in colour, slightly cylindrical in shape with an average mean of 0.272 mm length and 0.174 mm breadth which became dark before hatching. Incubation period was 3 - 4 days. The life cycle of looper caterpillar was completed through five larval stages. Average mean width of head capsule of Ist, IInd, IIIrd, IVth and Vth instar measured 0.302, 1.44, 1.85, 2.31, 2.62 mm respectively.

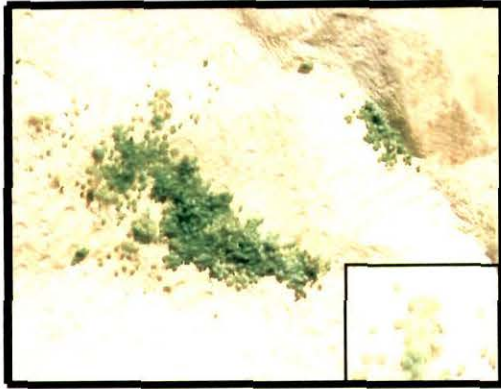
The neonates after one or two days of hatching became active and spun silken threads, by which they started swinging around. This may be a mode of dispersal when they are in the natural habitat on shade trees of tea plantations. The first instar larva was black with black head and with two white lines running along the dorsal surface from behind the head to the end. Its duration was 5 - 6 days. All the larval stages had three pairs of thoracic legs, a pair of prolegs on the abdominal segment and a pair of claspers at the hind end of the body. The body colour of larva changed with age, it turned from black to green to light brown and finally to dark brown, blending completely with the background colour of the twigs / stems. First and second instar caterpillars were found nibbling the edges of leaves, making tiny holes. Stadia period for IInd and IIIrd larval stages ranged between 5 - 7 days for both the stages. Third instar larva started chewing

margins of the leaves making small cuts and nicks. Fourth instar larval duration was 6 - 8 days. Fifth instar attained the maximum length and its duration was 7-10 days. Mean length of the body of Ist, IInd, IIIrd, IVth and Vth measured 2.90, 3.50, 15.15, 19.65, and 30.55 mm respectively. The total larval development took about 33 - 37 days. The larvae stopped feeding, eliminated water, shrunk before entering into prepupal stage which lasted for 3 - 4 days. Pupa was brown in colour and had serrated ridges one on each side of the anterior end and measured on an average 19.43 mm. Pupal period lasted for 9 - 15 days.

Adults of both the sexes exhibited great variety of melanism (Plate 8). It ranged within different shades of brown and creamy white colours. Male moths were smaller in body size 17.25 mm long than females 21.08 mm long. Means of wing span of male and female were 32.50 mm and 43.08 mm respectively. Antenna of female moth was filamentous, while in males it was plumose. Mating took place at night and males died after the mating. Males lived for 4 - 5 days and females for 6 - 7 days. The total life cycle took 52 - 60 days (Table5, Plate 3).

5. 2. 2. *Eterusia magnifica*

Eterusia magnifica laid eggs in masses, covered with buff coloured scales and hairs, on the blade and axils of leaves (TV₂₆) under the laboratory conditions during night. Freshly laid eggs were yellow in colour which turned green before hatching. Eggs were oval in shape and measured on an average 0.957 mm in length and 0.492 mm in breadth. The incubation period was for 5 - 6 days. Red slug developed through five larval instars. The head was dark brown. Head width



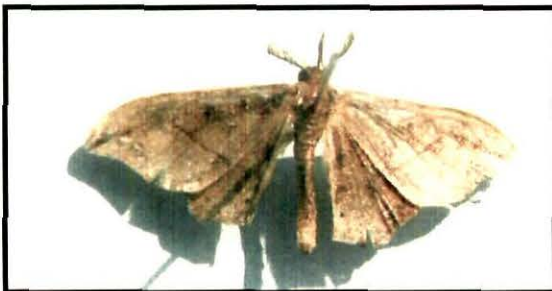
(a)



(b)



(c)



(d)



(e)

Plate 3. Different Stages of *Buzura suppressaria* .

- (a). Eggs ; (Mag. X 4).
- (b). 1st Instar ; (Mag. X 21).
- (c). 5th Instar ; (Mag. X 3).
- (d). Adult Male ; (Mag. X 2) and
- (e). Adult Female . (Mag. X 1.5).

of Ist, IInd, IIIrd, IVth and Vth instars on an average measured 0.232, 0.288, 0.930, 1.56, 2.23 mm respectively.

The first instar larva was brown in colour, having tubercles, bearing hairs and pores on its back. It had three thoracic legs and five pairs of prolegs, the last being the largest and acting as a clasper. Each pair of legs were provided at the end with disc like structures for attachment to the plant surface. The structures of larval stages remained unchanged till it reached the advanced instars. The first and second larval duration were 3 - 4 and 5 - 7 days respectively. The first and second instar larvae were found nibbling the epidermal surface of the leaf. Third instar larvae started feeding from the side of leaf blade, its duration was 6 - 8 days. Brown coloured ring like band appeared on the dorsal surface of the body. Duration of fourth and fifth instars were similar and ranged 7 - 9 days. These could eat entire leaf blade and parts of stem (twig) as well.

The full grown larvae were slug like and brick red in colour, when disturbed exuded thick clear fluid from the tubercles which was neither poisonous nor irritant to the of a handler. Mean body length of Ist, IInd, IIIrd, IVth and Vth measured 1.32, 2.52, 5.35, 10.28 and 20.54 mm respectively. The total larval period ranged from 33 - 41 days. Pupation took place in closely woven, pinkish cocoon usually in the folds of leaves. The pupa was brown in colour and measured on an average 14.8 mm in length. The pupal period lasted for 10 - 14 days. The moth emerged during day or night through one end of the cocoon, leaving the pupal skin projecting out.



(a)



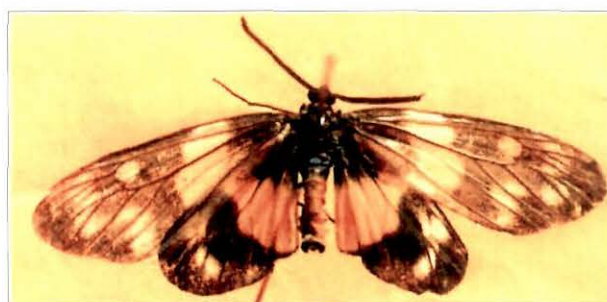
(b)



(c)



(d)



(e)

Plate 4. Different Stages of *Eterusia magnifica*.

- (a). Eggs ;
- (b). 1st Instar ; (Mag. X 28).
- (c). 5th Instar ; (Mag. X 2).
- (d). Adult Male ; (Mag. X 1.3) and
- (e). Adult Female (Mag. X 1.3).

The moths were brilliantly coloured with an average wing span of 50.6 mm in males and 58.46 mm in females. The males were slightly smaller 17.6 mm than females 20.60 mm in body length. The head, thorax, abdomen and two basal segments of abdomen were black and the remainder of the abdomen were pale yellow except black tip at the end in males. The antenna of male was unipectinate and that of female was long filiform but with a feathery tip. The forewings had a purple brown colour with a greenish tinge, a basal spot, a median white band broken up usually into five spots, a white spot at the end of the cell and an irregular row of submarginal white spots. The hind wing was black at the base followed by a yellow band, wide on the inner margin and had a few sub-apical white spots, the apical area being largely marked with brilliant blue. Male and females lived for 5 - 6, and 6 - 7 days respectively. The total life cycle lasted for 50 - 63 days (Table 5, Pláte 4).

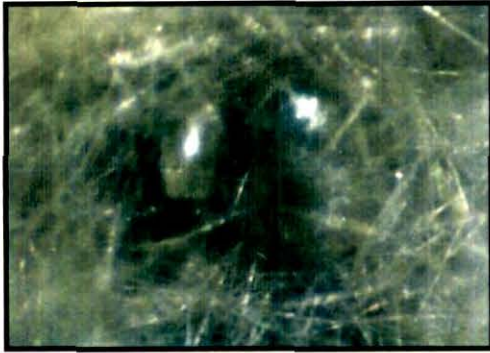
5. 2. 3. *Euproctis latisfascia*

Euproctis latisfascia (Darjeeling Black Hairy Caterpillar) laid eggs in masses covered with buff coloured hairs. The eggs were metallic green in colour, spherical and measured 0.697 mm in diameter. The incubation period was of 7 days. Life cycle of *E. latisfascia* was completed through six larval stages. The head capsule width of Ist, IInd, IIIrd, IVth, Vth and VIth instars on an average measured 0.325, 0.418, 1.20, 1.64, 1.76 and 2.64 mm respectively. First instar larvae were brownish in colour with fine black hairs distributed all over the body. There were three pairs of thoracic legs and four pairs of abdominal prolegs with

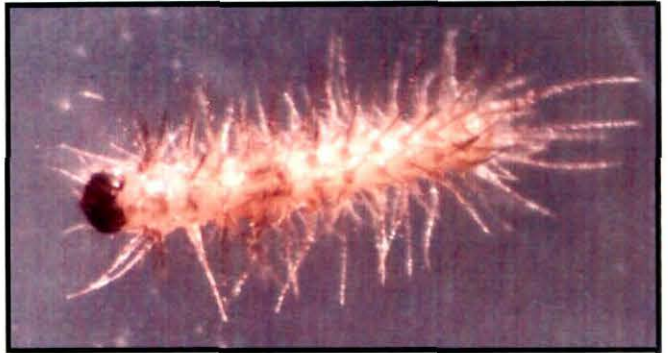
cushions at the end. A pair of claspers were present at the end of the abdomen. The first instar duration was 3 - 4 days.

The larval instars, in general, were brownish black with transverse rows of tubercles on each of the thoracic and abdominal segments. The tubercles were beset with tufts of black hairs. The thoracic segment was circled by two prominent white rings and a reddish patch on the dorso-median surface of the abdomen. Two whitish streaks were also found extending on the entire length of the dorsal surface. Early instars fed mainly on epidermal surface of leaf while the later instars fed on veins and other leaf parts. As the larvae grew, the hairs became profuse. Skin rash was caused by the urticating hairs of the larval forms. The second, third, fourth, fifth and sixth larval duration were of 6 - 9, 7 - 9, 6 - 9, 8 - 10 and 8 - 10 days respectively.

The body length of Ist, IInd, IIIrd, IVth, Vth and VIth on an average was 2.20, 3.20, 8.13, 10.58, 18.81 and 20.20 mm respectively. The total larval period was 49 - 55 days. Pupa was brown in colour, oval in shape and pupal case was woven by brown silken threads and on an average measured 10.33 mm. The pupal duration was 17 - 24 days. Adults emerged at night; males and females were more or less of similar lengths, measuring on an average 16.3 mm and 16.46 mm with an average wing spans of 26.4 mm and 30.5 mm respectively. Life span of the adult male was 3 - 5 days while for the female it was 4 - 6 days. Mating took place during daytime and lasted for 5 - 6 hours. The total life cycle was of 74 - 81 days (Table 5, Plate 5).



(a)



(b)



(c)



(d)



(e)

Plate 5. Different Stages of *Euproctis latifascia* .

- (a). Egg ; (Mag. X 13).
- (b). Ist Instar ; (Mag. X 17).
- (c) . VIth Instar ; (Mag. X 2.5)
- (d). Adult Male ; (Mag X 1.2). and
- (e) Adults Mating.

Table 5. Morphometric Data (Mean \pm SD)* of *Buzura suppressaria*, *Eterusia magnifica* and *Euproctis latisfascia*.

<i>Stage</i>	<i>B. suppressaria</i>	<i>E. magnifica</i>	<i>E. latisfascia</i>
<i>Egg</i>			
a) Length	0.272 \pm 0.10	0.957 \pm 0.01	0.697 \pm 0.00
b) Width	0.174 \pm 0.01	0.492 \pm 0.01	X
Ist Instar			
a) Body Length	2.900 \pm 0.09	1.320 \pm 0.04	2.200 \pm 0.10
b) Head Length	0.341 \pm 0.01	0.285 \pm 0.01	0.343 \pm 0.00
c) Width of Head Capsule	0.302 \pm 0.00	0.232 \pm 0.00	0.325 \pm 0.00
IInd Instar			
a) Body Length	3.500 \pm 0.23	2.520 \pm 0.12	3.200 \pm 0.26
b) Head Length	1.550 \pm 0.05	0.474 \pm 0.01	0.462 \pm 0.00
c) Width of Head Capsule	1.440 \pm 0.05	0.288 \pm 0.01	0.418 \pm 0.00
IIIrd Instar			
a) Body Length	15.150 \pm 1.950	5.350 \pm 0.09	8.13 \pm 0.81
b) Head Length	1.970 \pm 0.08	1.020 \pm 0.02	1.27 \pm 0.01
c) Width of Head Capsule	1.850 \pm 0.05	0.930 \pm 0.00	1.20 \pm 0.00
IVth Instar			
a) Body Length	19.65 \pm 1.100	10.280 \pm 0.266	10.58 \pm 0.280
b) Head Length	2.29 \pm 0.06	2.040 \pm 0.12	1.78 \pm 0.04
c) Width of Head Capsule	2.31 \pm 0.05	1.560 \pm 0.07	1.64 \pm 0.00
Vth Instar			
a) Body Length	30.55 \pm 3.230	20.540 \pm 0.270	18.81 \pm 1.604
b) Head Length	2.77 \pm 0.06	2.720 \pm 0.06	2.06 \pm 0.02
c) Width of Head Capsule	2.62 \pm 0.03	2.230 \pm 0.00	1.76 \pm 0.00
VIth Instar			
a) Body Length			20.20 \pm 0.200
b) Head Length	X	X	2.75 \pm 0.02
c) Width of Head Capsule			2.64 \pm 0.00
Pupa Length	19.43 \pm 0.95	14.80 \pm 0.434	10.33 \pm 0.36
Adult Moth			
1. Male			
a) Length	17.25 \pm 1.89	17.60 \pm 2.30	16.30 \pm 2.66
b) Wing span	32.50 \pm 2.82	50.60 \pm 6.50	26.40 \pm 4.80
2. Female			
a) Length	21.08 \pm 1.56	20.60 \pm 1.09	16.46 \pm 4.80
b) Wing span	43.08 \pm 3.85	58.46 \pm 4.04	30.50 \pm 0.35

* Standard Deviation of the Mean of 10 Replications.

5. 3. Allometric growth

Matsuda (1960) stressed the importance of allometric growth ratios in his study on Gerridae and further suggested that the growth ratios were more stable characters and that the differences in the growth ratios of the parts of the body of related insects indicate their phylogenetic line. This stable character like colour and structure may be used as a valid criterion on which systematic conclusions may be based.

In the present study the larval growth pattern of the three folivores differed by comfortable margins. The 'b' (slope) and 'k' (intercept) values of the three species, despite feeding on tea leaves were distinct, so also were their regression curves (Figs. 4 & 5). These indicated not only their taxonomic distinctness but also their usefulness in identifying the species based on the larval morphometrics from the field populations of the folivores in question. Many workers such as Ananthakrishnan (1961) on the Thysanoptera; Mohan Rao and Tonabi (1970) on Coleoptera; Mukherjee (1972) on Miridae and Ananthasubramanium and Anathakrishnan (1975) on Membracidae have stressed the importance of differential growth rate as a valid taxonomic tool in study of various insect groups.

The intercept values (b) of the three species of the folivores were found to be more reliable in distinguishing them when head length was computed against their head width, than body lengths against head widths as per data available in Table 6.

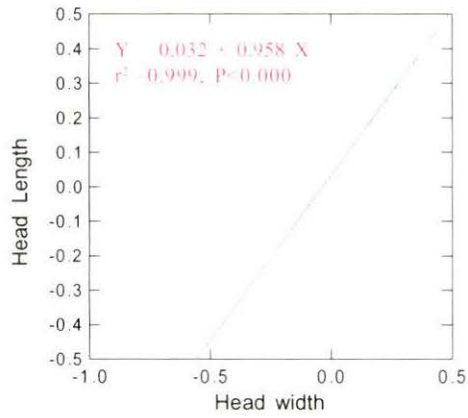


Fig.(a). *Buzura suppressaria*

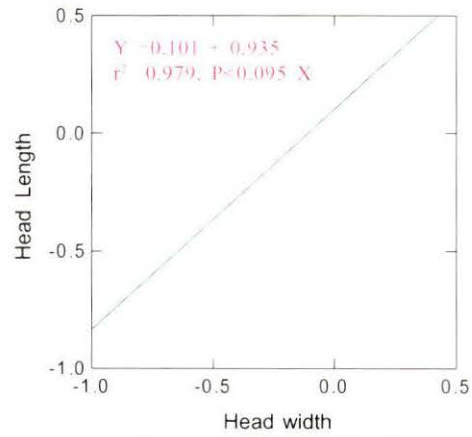


Fig.(b). *Eterusia magnifica*

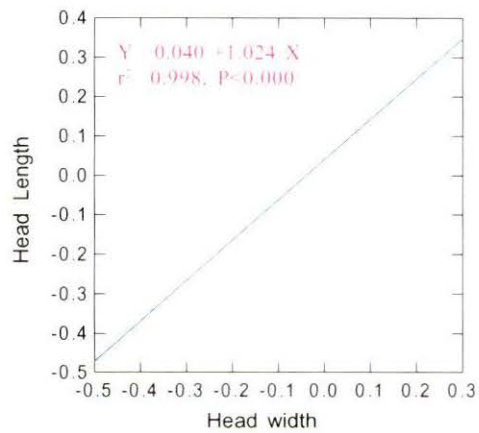


Fig.(b). *Euproctis latifascia*

Fig : 4. Comparison of Relative Growth of Body parts (**Head Width vs Head Length**) of three folivores.

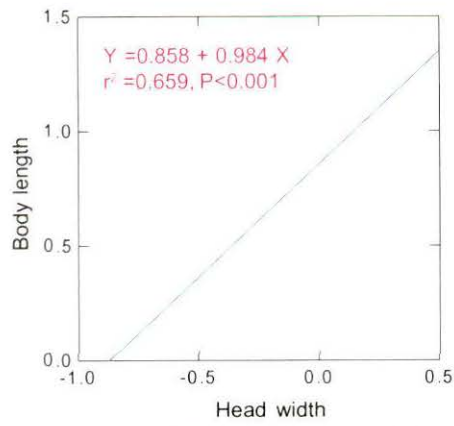


Fig.(a). *Buzura suppressaria*

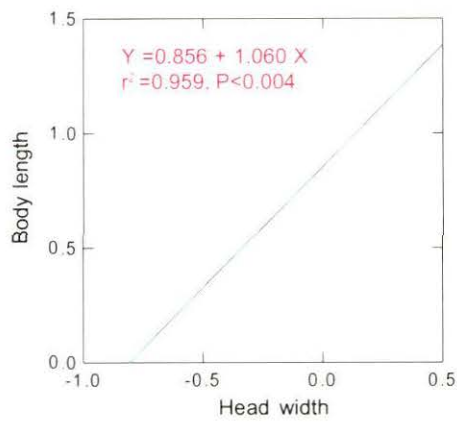


Fig.(b). *Eterusia magnifica*

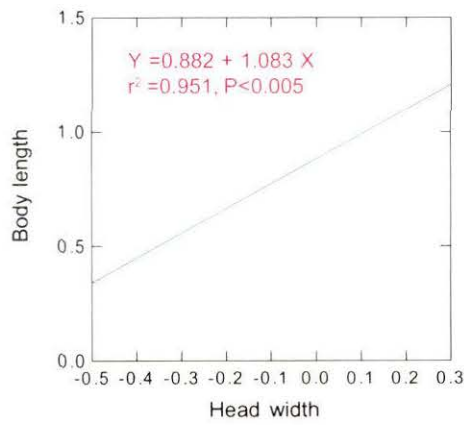


Fig.(c). *Euproctis latifascia*

Fig : 5. Comparison of Relative Growth of Body Parts (**Head Width vs Body Length**) of three folivores.

Table 6. Allometric Growth in *Buzura suppressaria* (Looper), *Eterusia magnifica* (Red Slug) and *Euproctis latisfascia* (Black Hairy Caterpillar)

	Head Width					
	Intercept (b)			Slope (k)		
	Looper	Red Slug	Hairy Cat.	Looper	Red Slug	Hairy Cat.
Head Length	0.0324	0.1011	0.0406	0.9577	0.9354	1.0237
Body Length	0.8578	0.8559	0.8820	0.9837	1.0598	1.0834

5. 4. Post-embryonic Development period on Natural and Artificial diets

The length of time an insect spends in a particular life stage and indeed the total time taken for one generation, depend on a wide range of factors that the species or population has encountered during its evolution (Speight, 1994). As compared to natural (tea leaf) diet developmental periods of most of the stages were found significantly shorter on artificial diets in all three folivorous species. Attempts to rear Ist and IInd instars of looper and red slug caterpillars were met with high mortality on artificial diets. However, successful rearing of these (on artificial diet) was possible from third instar onwards. Third and fifth larval and pupal duration of *B. suppressaria* on artificial diet was significantly shorter than on natural diet (Table 7). As a consequence its total larval duration as well as life cycle was also shorter on artificial diet.

Et. magnifica somewhat showed a similar trend with total larval duration and life cycle of the species on artificial diet being shorter as compared to that on natural diet. This was mainly due to a shorter period of development required particularly by the IIIrd and IVth instars on artificial diet (Table 8).

Most of the developmental stages of *E. latisfascia*, particularly the second, fourth, fifth and sixth instar larvae showed significantly longer duration on natural diet. The pupation also took longer for those reared on natural diet. Therefore the total life cycle was shorter on artificial diet than on natural diet (Table 9). Generally insects prolong their development on suboptimal food as has been observed in most lepidopterans feeding on natural diets (host plants) (Waters & Barfield, 1989).

Table 7. Development Period (days) of *Buzura suppressaria* (Guen.) on Natural (tea leaf) and Artificial Diets at 28°C and 75% R. H.

Stages	Duration (days) (mean \pm SE)	
	Natural diet	Artificial diet
Eggs	3.300 \pm 0.105a	3.300 \pm 0.105a
I st instar	5.200 \pm 0.116a	5.200 \pm 0.116a
II nd instar	6.100 \pm 0.123a	6.100 \pm 0.123a
III rd instar	5.800 \pm 0.117a	4.850 \pm 0.167b
IV th instar	6.600 \pm 0.152a	6.450 \pm 0.135a
V th instar	8.150 \pm 0.196a	7.100 \pm 0.124b
Total Larval period	35.150 \pm 0.309a	33.000 \pm 0.362b
Pre-pupa	3.250 \pm 0.990a	3.150 \pm 0.082a
Pupa	12.050 \pm 0.320a	10.950 \pm 0.211b
Adult	6.142 \pm 0.274a	5.500 \pm 0.341a
Total development period	56.533 \pm 0.729a	52.500 \pm 0.778b

Means followed by same letter are not significantly different at 5% level.

Table 8. Development Period (days) of *Eterusia magnifica* (Butl.) on Natural (tea leaf) and Artificial Diets at 28°C and 75% R.H.

Stages	Duration (days) (Mean ± SE)	
	Natural diet	Artificial diet
Eggs	5.500 ± 0.115a	5.500 ± 0.115a
I st instar	3.600 ± 0.112a	3.600 ± 0.112a
II nd instar	5.950 ± 0.198a	5.950 ± 0.198a
III rd instar	6.800 ± 0.172a	6.200 ± 0.172b
IV th instar	8.100 ± 0.191a	7.350 ± 0.150b
V th instar	8.250 ± 0.176a	7.750 ± 0.160a
Total Larval period	38.200 ± 0.541a	36.350 ± 0.455b
Pupa	11.300 ± 0.291a	10.800 ± 0.341a
Adult	5.910 ± 0.192a	6.200 ± 0.249a
Total development period	55.580 ± 1.018a	52.800 ± 1.181b

Means followed by same letter are not significantly different at 5% level.

Table 9. Development Period (days) of *Euproctis latisfascia* (Wlk.) on Natural (tea leaf) and Artificial Diets at 28°C and 75% R.H.

Stages	Duration (days) (mean ± SE)	
	Natural diet	Artificial diet
Eggs	7.000 ± 0.000a	7.000 ± 0.000a
I st instar	3.250 ± 0.123a	3.400 ± 0.134a
II nd instar	7.700 ± 0.179a	6.150 ± 0.196b
III rd instar	7.950 ± 0.170a	7.550 ± 0.170a
IV th instar	8.150 ± 0.196a	7.350 ± 0.182b
V th instar	9.000 ± 0.162a	7.357 ± 0.213b
VI th instar	9.000 ± 0.196a	8.300 ± 0.213b
Total Larval period	51.800 ± 0.696a	47.100 ± 0.706b
Pupa	22.150 ± 0.629a	16.857 ± 0.962b
Adult	4.250 ± 0.583a	4.200 ± 0.583a
Total development period	78.450 ± 0.660a	68.600 ± 1.860b

Means followed by same letter are not significantly different at 5% level

Shorter duration of different stages of life cycle of the three folivores on artificial diet than on natural diet indicates their greater efficiency in utilizing the artificial diet to the optimum. David et al. (1989) showed that *Platynota idaeusalis* developed faster on semisynthetic diet compared to natural diet in the laboratory. Felland and Hull (1992) also reported that larvae reared on artificial diet survived better, developed faster and produced heavier adults. In Velvetbean caterpillar, larvae taken from laboratory when fed on artificial diet had the shortest development time, whereas larvae taken from laboratory fed on foliage took a considerably longer time to reach the prepupal stage (Slansky and Wheeler, 1992).

Suitability of artificial diet can be gauged by comparing the developmental time, survival rate and pupal weight of larvae reared on the diet with those reared on natural diet. These features have proved to be true for *Spodoptera exigua* when reared on artificial diet (Mu & Chu, 1993 ; Abdullah et al., 2000).

5. 5. Survivorship

Evolution has produced several types of survivorship strategies wherein the rates of mortality vary according to the life stage (Speight et al, 1999). Effects of variation of diets can be measured in terms of growth, development, reproductive performance, mortality, longevity and morphological abnormalities.

Survivorship curves are of three general types although intermediate types may occur. These three types are; Type I, highly convex type; Type II, a diagonal straight line type and Type III, highly concave type. In the Type I curve, the

population mortality rate is low until near the end of the life span. In the Type II, the diagonal straight-line curve indicates an age-specific constant survival, in other words, a constant rate of mortality occurs at every age. In the Type III, population mortality is high during the young stages (Pearl 1928) (Fig.6).

In some holometabolous insects the survival rate differs in successive life-history stages and the curve becomes of the stair step type. In the stair step survivorship curve, the initial segments represent the egg population and the two middle flatter segments represent the larval and pupal stages that exhibit less mortality and final steep segment represent the shortlived adult stages (Dash, 1995) (Fig. 6).

Survivorship studies of *Buzura suppressaria* showed high mortality in the 1st larval stage of the life cycle. A greater survival was recorded in the subsequent larval stages with only a moderate mortality till pupal stage when the species was reared on natural diet. Third instar looper when introduced to artificial diet showed a higher percentage of mortality at this starting stage than that on natural diet. Rest of the stages indicated similar percentage of mortality till the pupal stage (Table 10).

Number of adults emerging from pupae on both the diets were also more or less similar signifying that the artificial diet used here was equivalent in supporting survival like the natural diet. The survivorship curve of *B. suppressaria* on both natural and artificial diets by and large followed Type II curve (Fig.7).

Eterusia magnifica showed higher mortality in the beginning of the life cycle on natural diet. In the third larval stage, percentage of mortality was also high on artificial diet. Rest of the stages showed more or less similar percentage of mortality till the pupal stage. The number of adults emerged was slightly higher on natural diet than that on artificial diet (Table 11). Survivorship curves of *Et. magnifica* on both natural and artificial diets were closer to Type II curve (Fig. 8). Such curves established that the artificial diet was in no way inferior to the natural diet as far as development and survival were concerned.

Complete rearing of *Euproctis latisfascia* from egg to egg could be successfully done both on natural and artificial diets. However, its survivorship curve showed variation on natural and artificial diets. The percentage of mortality was higher in the first instar on artificial diet than on natural diet which lessened in the advancing instars (II to VI). Mortality of pupal stage on artificial diet was relatively higher. The number of adult emergence was also higher on natural diet than on artificial diet (Table 12). Survivorship curves of *E. latisfascia*, both on natural and artificial diets, were closer to Type II curve (Fig. 9).

Life tables / Survivorship is a convenient form for describing mortality schedule of a population (Krebs, 1978). Host plant significantly influence vital features such as rate of development, survival, reproductive potential of insects which ultimately determine the population build up (Painter, 1951; Kennedy, 1995). In most of the insect species, the mortality rate is a characteristic of the stage that is not uniform for all the developmental stages (Martinez and Katthain, 1999).

Since the larval stages are the active feeding forms in the lepidopterans, it is expected that dietary influence is also maximum on these trophic stages. The survivorship tables and curves of the immature forms in the present study have provided a basis for comparing the performance of the three lepidopteran tea pests on natural and artificial diets; for it is well known that the survivorship or otherwise the rate of mortality throughout these developmental stages is an index of how well the species have adapted itself to the food (natural and artificial). Survivorship curve of *B. suppressaria* was more of a stair step type but in general followed Type II curve on both the diets. Hence, it may be interpreted that there was a constant rate of mortality during its larval and pupal stages.

Survivorship curve of *Et. magnifica* also showed similarity with that of *B. suppressaria* having a closeness to Type II curve. Survivorship of *E. magnifica* was slightly better on natural diet as compared to that on artificial diet. Nevertheless, judging by the significantly lower total larval duration and life cycle on artificial diet, it could be labeled as a more suitable one for supporting post embryonic development of the species.

E. latisfascia could completely be reared on artificial diet as well as on natural diet. Its survivorship curve on artificial diet closely followed the one on natural diet, and both of these curves toed Type II curve, indicating constant rate of mortality in all the stages irrespective of duration and age.

By and large all the survivorship curves studied for the three lepidopteran species on both natural and artificial diets were close to Type II curve, which has been considered ideal for a large number of species by Krebs (1978). In one

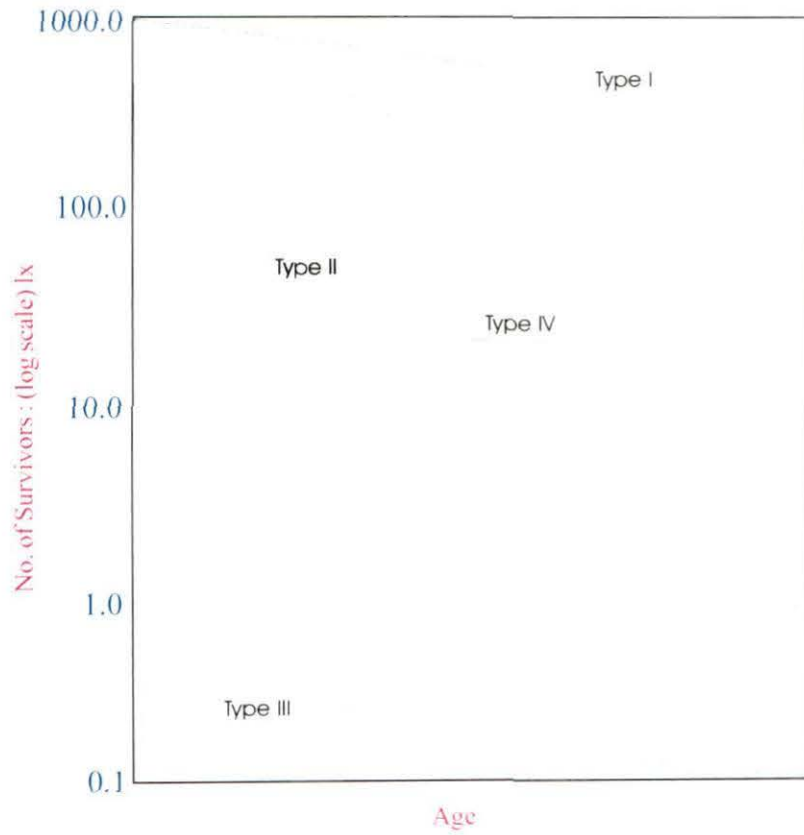


Fig. 6. Survivorship Curve: Type I - Convex; Type II - Diagonal Straight line; Type III - Concave ; Type IV - Stairstep.

Table 10. Survivorship of *Buzura suppressaria* on Natural and Artificial Diets.

X Age Interval	Natural diet			Artificial diet		
	lx No. alive at beginning of X	dx No. dying during lx	100qx dx as a %	lx No. alive at beginning of X	dx No. dying during lx	100qx dx as a %
Egg	100	32	32.00	100	32	32.00
I st Instar	68	12	17.64	68	12	17.64
II nd Instar	56	9	16.07	56	9	16.07
III rd Instar	47	8	17.02	47	11	23.40
IV th Instar	39	5	12.82	36	7	19.44
V th Instar	34	6	17.64	29	5	17.24
Pre-pupa	28	6	21.42	24	3	12.50
Pupa	22	4	18.18	21	4	19.04
Adult	18			17		

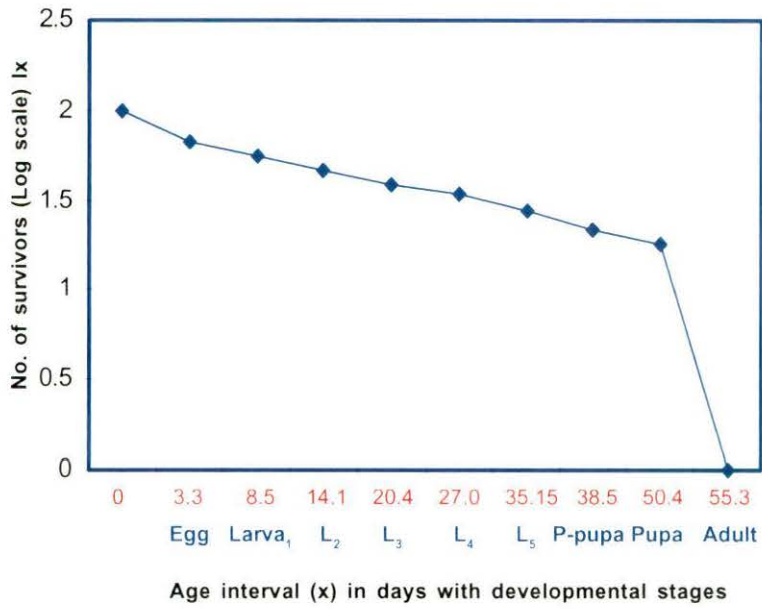


Fig. (a). Natural diet

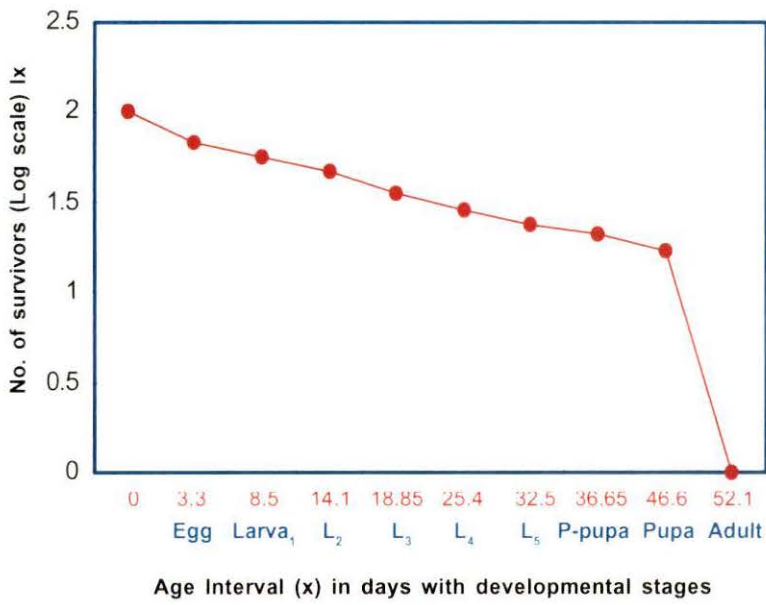


Fig. (b). Artificial diet

Fig : 7. Survivorship Curves of *B. suppressaria* on (a) Natural (tea leaf) & (b) Artificial Diets.

Table 11. Survivorship of *Eterusia magnifica* on Natural and Artificial Diets.

X Age Interval	Natural diet			Artificial diet		
	lx No. alive at beginning of X	dx No. dying during lx	100qx dx as a %	lx No. alive at beginning of X	dx No. dying during lx	100qx dx as a %
Egg	100	37	37.00	100	37	37.00
I st Instar	63	11	17.46	63	11	17.46
II nd Instar	52	5	9.61	52	5	9.61
III rd Instar	47	9	19.14	47	12	25.53
IV th Instar	38	5	13.15	35	6	17.14
V th Instar	33	5	15.15	29	5	17.24
Pupa	28	3	10.71	24	3	12.50
Adult	25			21		

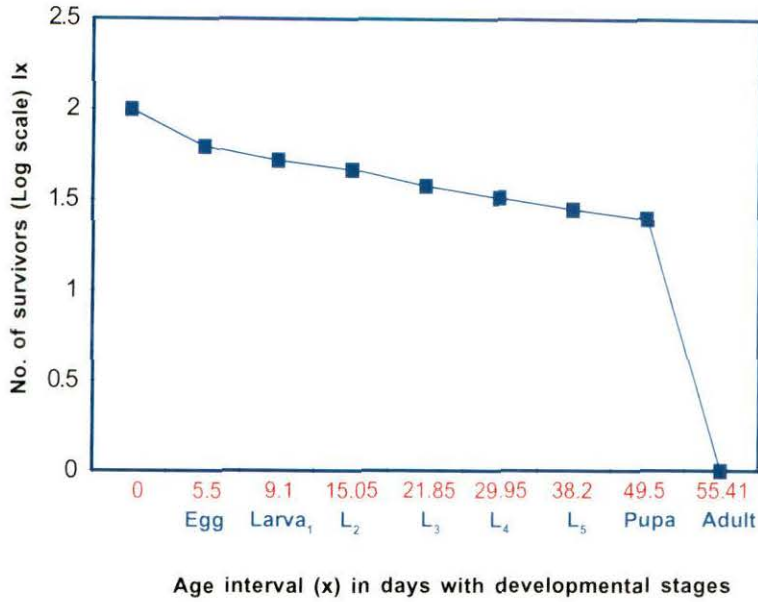


Fig.(a). Natural diet

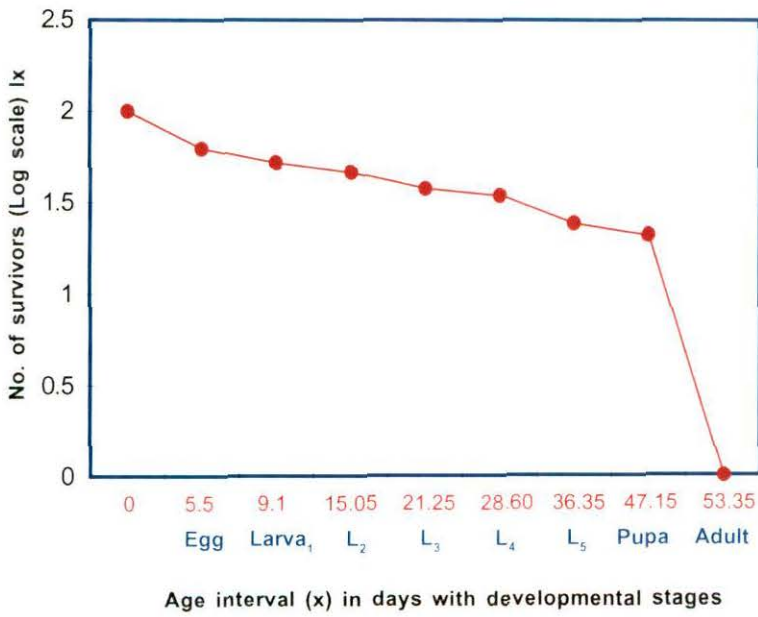


Fig.(b). Artificial diet

Fig : 8. Survivorship curves of *Et. magnifica* on (a) **Natural** (tea leaf) & (b) **Artificial** Diets.

Table 12. Survivorship of *Euproctis latisfascia* on Natural and Artificial Diets.

X Age Interval	Natural diet			Artificial diet		
	lx No. alive at beginning of X	dx No. dying during lx	100qx dx as a %	lx No. alive at beginning of X	dx No. dying during lx	100qx dx as a %
Egg	100	27	27.00	100	42	42.00
I st Instar	73	7	9.58	58	22	37.93
II nd Instar	66	16	24.24	36	8	22.22
III rd Instar	50	6	12.00	28	6	21.42
IV th Instar	44	8	18.18	22	4	18.18
V th Instar	36	7	19.44	18	3	16.66
VI th Instar	29	4	13.79	15	2	13.33
Pupa	25	4	16.00	13	3	23.07
Adult	21			10		

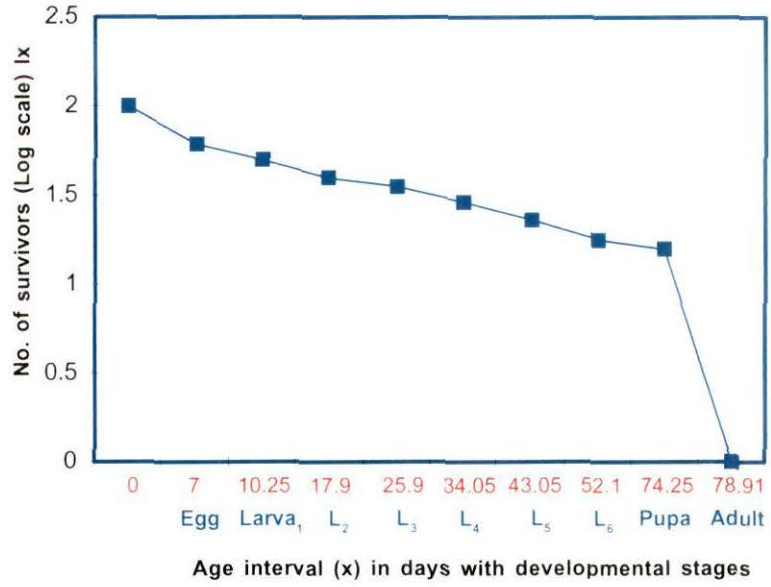


Fig.(a). Natural diet

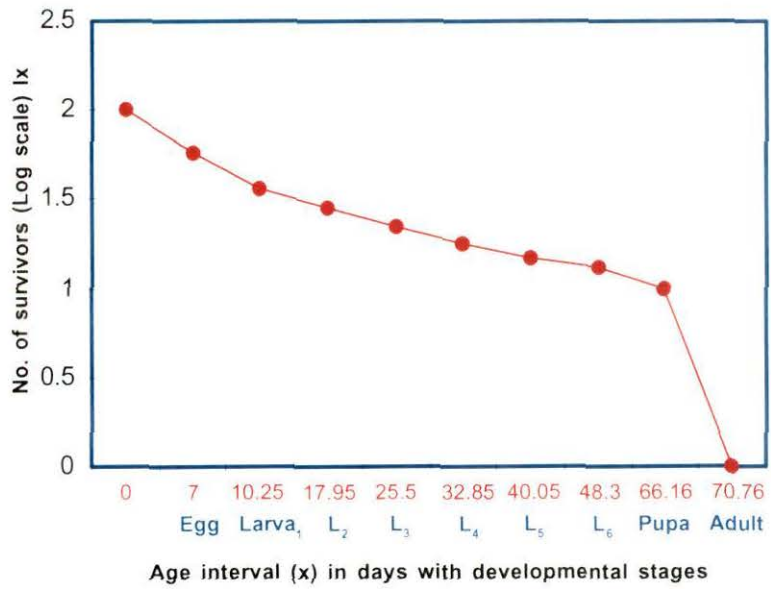


Fig.(b). Artificial diet

Fig : 9. Survivorship curves of *E. latifascia* on (a) Natural (tea leaf) & (b) Artificial Diets.

word artificial diet appeared to be successful in supporting growth and development of all the three species in question as their survival was at par with that on natural diet. Therefore, artificial diet can be used as an alternative food for laboratory rearing of these three lepidopteran tea pests for further research studies and mass production.

5. 6. Daily food consumption and larval body weight

Daily performance of the three tea pests on natural (tea leaf) and artificial diets were recorded for last two larval instars based on food consumption and larval body weight change. Regression curves of weight gained by fourth and fifth instar larvae of *B. suppressaria* against the food consumed per day (Fig. 10 & 11) on both natural and artificial diets showed a linear relationship between these two variables with co-efficient and determination values $r^2=0.923$, $r^2=0.666$ on natural and $r^2=0.882$, $r^2=0.591$ on artificial diet respectively. Similar regression curves were observed for fifth and sixth instars of *E. latisfascia* on both natural and artificial diets, with values $r^2=0.893$, $r^2=0.864$ and $r^2=0.664$, $r^2=0.828$ respectively (Fig. 14 & 15). Larval body weight and food consumption were found highest in the middle of the stadial period in both the instars on natural and artificial diet. However, for *E. magnifica* though food consumption and the corresponding larval body weight change were apparent, their co-efficient values were relatively less, $r^2=0.216$ and $r^2=0.301$ on natural and $r^2=0.248$ and $r^2=0.310$ on artificial diets for fourth and fifth instars respectively (Fig.12 & 13).

Trichilo and Mack (1989), Sood et al. (1993) and others have reported a high correlation between food consumption and mean larval weight in insects. In

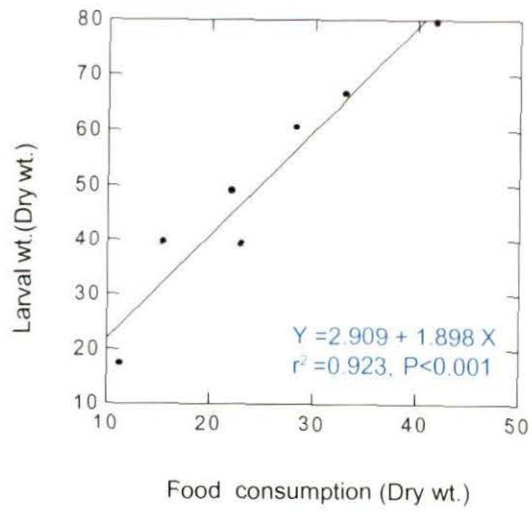


Fig. (a). Natural diet

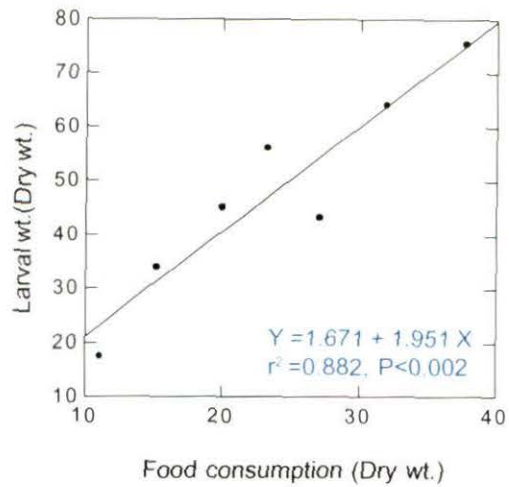


Fig. (b). Artificial diet

Fig:10. Relationship between Daily Food Consumption (mg) and Larval weight (mg) in *B. suppressaria* on (a) Natural & (b) Artificial Diets during the Stadial Period of IVth instar.

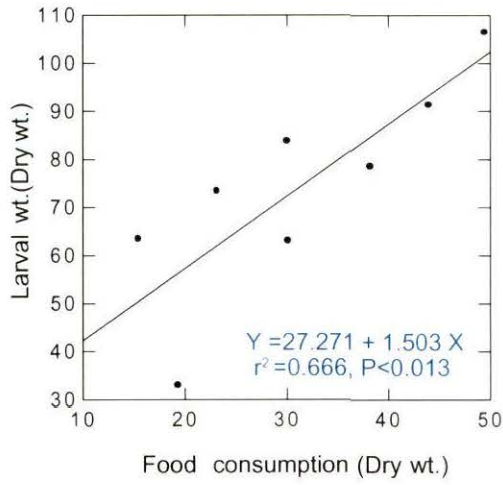


Fig.(a).Natural diet

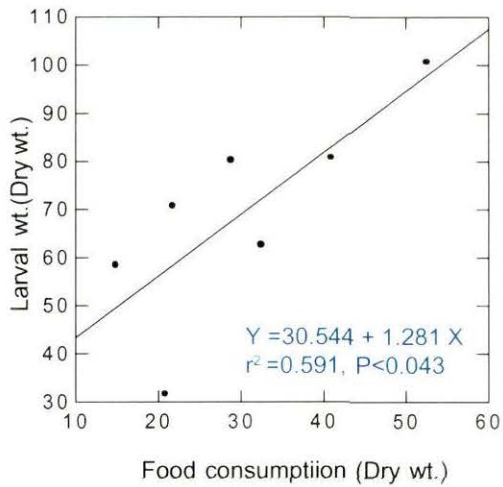


Fig.(a).Artificial diet

Fig:11. Relationship between Daily Food Consumption (mg) and Larval weight (mg) in *B. suppressaria* on (a) Natural & (b) Artificial Diets during the Stadial Period of Vth instar.

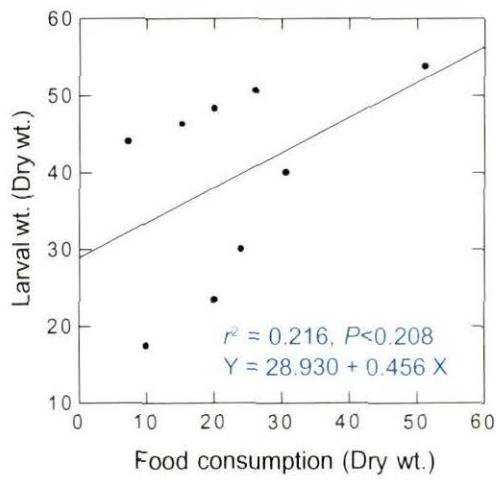


Fig. (a) Natural diet

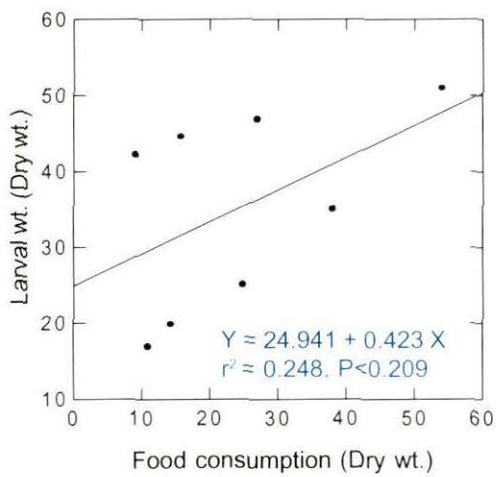


Fig. (b) Artificial diet

Fig:12. Relationship between Daily Food Consumption (mg) and Larval weight (mg) in *Et. magnifica* on (a) Natural & (b) Artificial Diets during the Stadial Period of IVth instar.

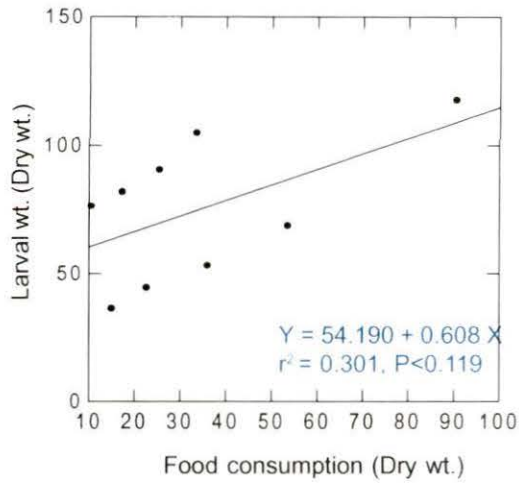


Fig. (a) Natural diet

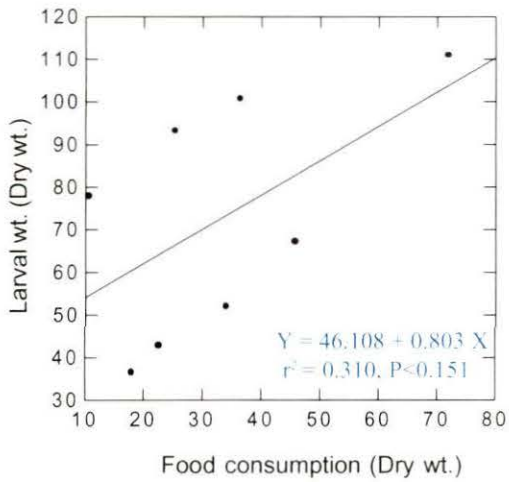


Fig.(b) Artificial diet

Fig:13. Relationship between Daily Food Consumption (mg) and Larval weight (mg) in *Et. magnifica* on (a) Natural & (b) Artificial Diets during the Stadial Period of Vth instar.

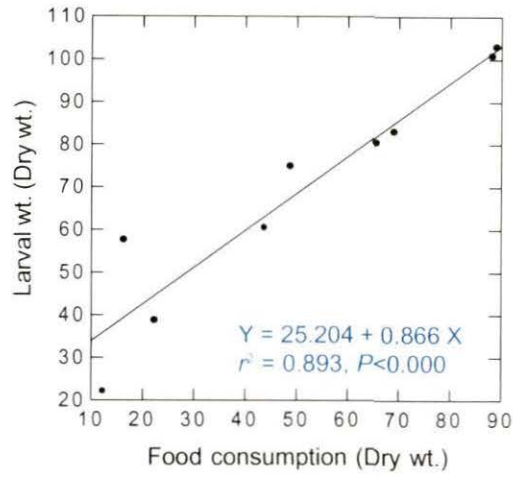


Fig.(a). Natural diet

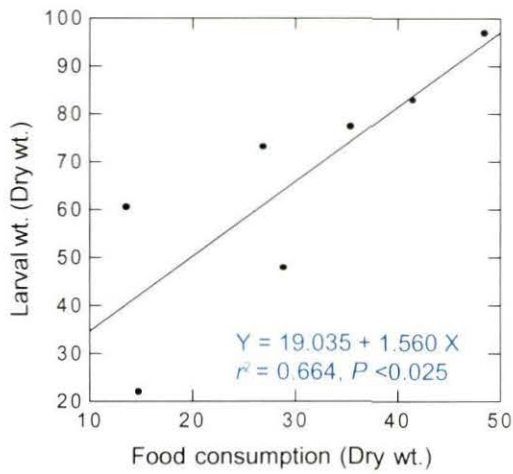


Fig.(b). Artificial diet

Fig:14. Relationship between Daily Food Consumption (mg) and Larval weight (mg) in *E. latifascia* on (a) Natural & (b) Artificial Diets during the Stadial Period of Vth instar.

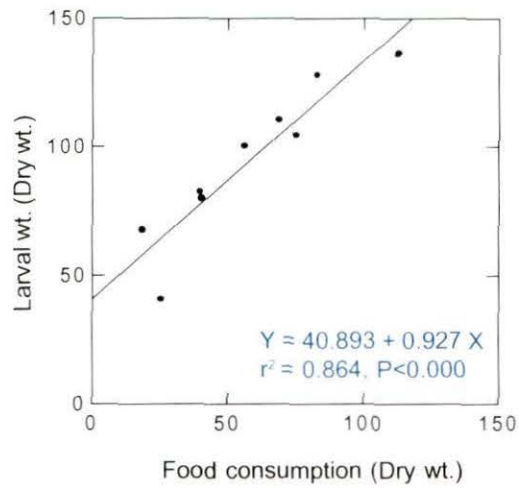


Fig. (a). Natural diet

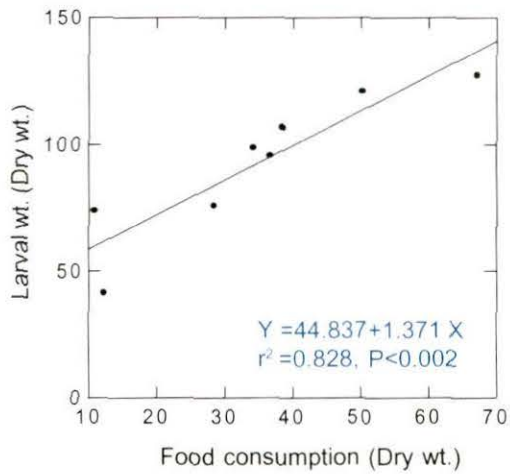


Fig. (b). Artificial diet

Fig:15. Relationship between Daily Food Consumption (mg) and Larval weight (mg) in *E. latifascia* on (a) Natural & (b) Artificial diets during the Stadial Period of VIth instar.

similar finding Mukerji and Guppy (1973) observed a direct linear relationship between mean daily food consumption and growth in larvae of *Pseudoletia unipunctata* and proposed that growth can be predicted from estimates of feeding. A similar result was observed in the present study. It was also observed that the food consumption decreased towards the end of each larval instar followed by decrease in larval body weight. Daily consumption commonly increases rapidly soon after a moult, and shows a peak near the middle of the instar and declines as the next moult approaches which was found to be true in the present study which was also supported by Srivastava (1983) and Simpson (1982) (Figs. 16, 17 & 18) details of which are available in Tables 13 a & b, 14 a & b, 15 a & b respectively.

The amount of food consumed and consequent growth occurring during the larval stage tend to be a representative of those calculated for the entire larval period (Scriber and Slansky, 1981; Ghosh and Gonchaudhuri, 1996) and facilitates accumulation of sufficient energy to tide over during the non-feeding pupal stage (Pandian, 1973).

5. 7. Reproductive performance

Reproduction is one of the primary events in the life cycle of an insect. This involves an integration of several physiological and behavioural events which in turn involve the consumption and utilization of food. Several component processes of reproduction such as attraction and acceptance of mate, mating act, oogenesis, oviposition, fecundity etc. have a definite relationship with nutrition (Ananthkrishnan, 1990).

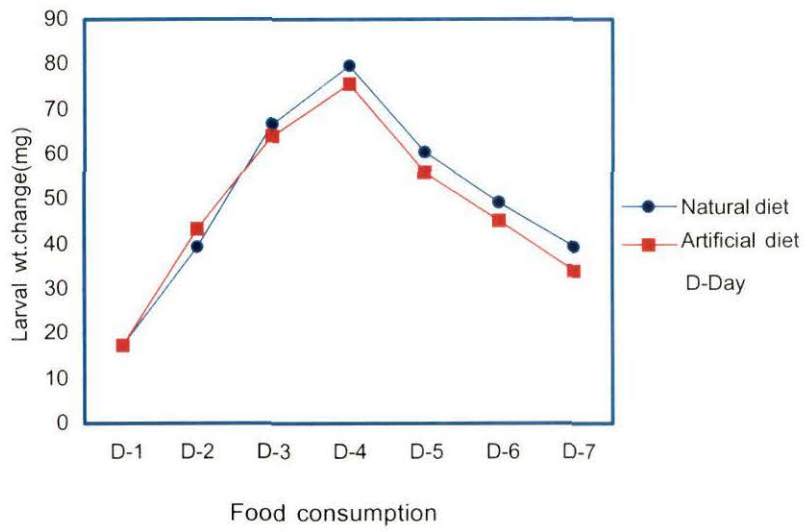


Fig. (a). IVth instar

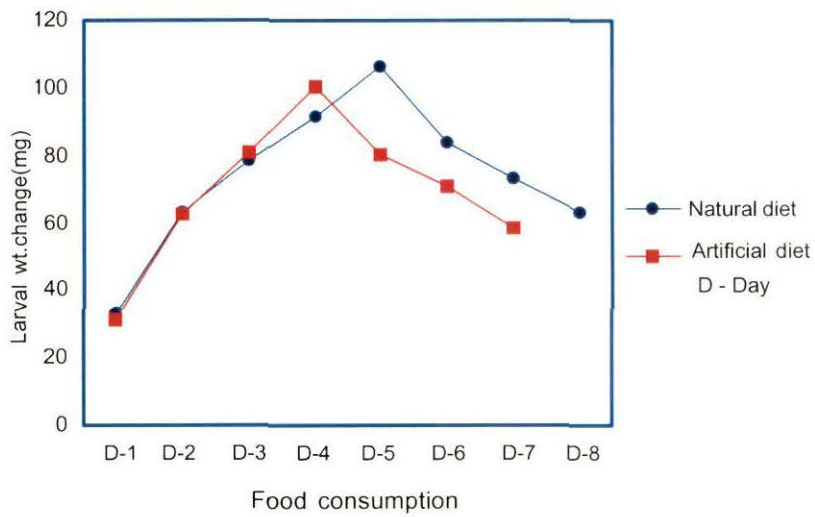


Fig.(b). Vth instar

Fig:16. Difference in Larval Dry wt. (mg) on **Natural & Artificial** Diets during Development at (a) **IVth** and (b) **Vth** instars of *Buzura suppressaria* recorded daywise.

Table 13 (a). Food Consumption and Larval Weight Change (Mean \pm SE) per Day on Natural and Artificial Diets of IVth Instar of *Buzura suppressaria*.

Natural Diet

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Larval Weight	17.6 ± 0.305	39.3 ± 0.700	66.6 ± 1.097	79.6 ± 1.077	60.6 ± 1.641	49.1 ± 1.629	39.6 ± 1.400
Food Consumption	11.3 ± 0.366	23.0 ± 0.869	33.0 ± 0.632	41.8 ± 1.200	28.3 ± 1.011	22.1 ± 0.504	15.4 ± 0.845

Artificial Diet

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Larval Weight	17.5 ± 0.268	43.5 ± 0.909	64.2 ± 1.617	75.6 ± 1.499	56.1 ± 1.224	45.3 ± 1.862	34.0 ± 0.614
Food Consumption	11.1 ± 0.481	27.1 ± 0.504	31.9 ± 0.874	37.7 ± 0.700	23.3 ± 1.145	20.0 ± 0.788	15.2 ± 0.573

Table 13 (b). Food Consumption and Larval Weight Change (Mean \pm SE)per Day on Natural and Artificial Diets of Vth Instar of *Buzura suppressaria*.

Natural Diet

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
Larval Weight	32.9 ± 1.139	63.0 ± 1.163	78.6 ± 1.400	91.4 ± 1.713	106.5 ± 2.400	83.8 ± 1.919	73.4 ± 1.586	63.5 ± 1.351
Food Consumption	19.3 ± 0.667	30.1 ± 0.924	38.2 ± 1.143	43.9 ± 0.566	49.4 ± 1.439	30.0 ± 1.264	23.1 ± 0.546	15.4 ± 0.561

Artificial Diet

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Larval Weight	31.6 ± 0.581	62.7 ± 1.591	80.8 ± 1.793	100.7 ± 1.738	80.3 ± 1.350	70.7 ± 0.869	58.5 ± 1.408
Food Consumption	20.8 ± 0.533	32.4 ± 0.733	40.9 ± 0.657	52.5 ± 1.002	28.8 ± 0.916	21.7 ± 0.700	14.8 ± 0.512

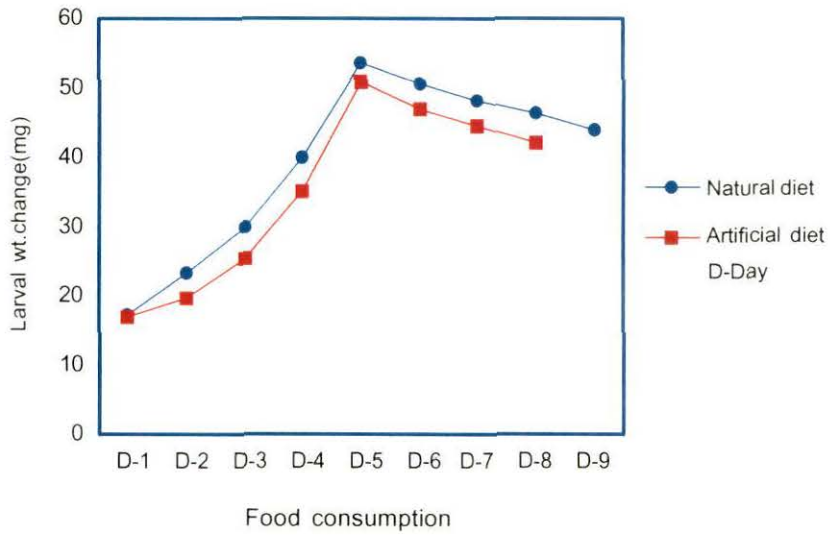


Fig.(a). IVth instar

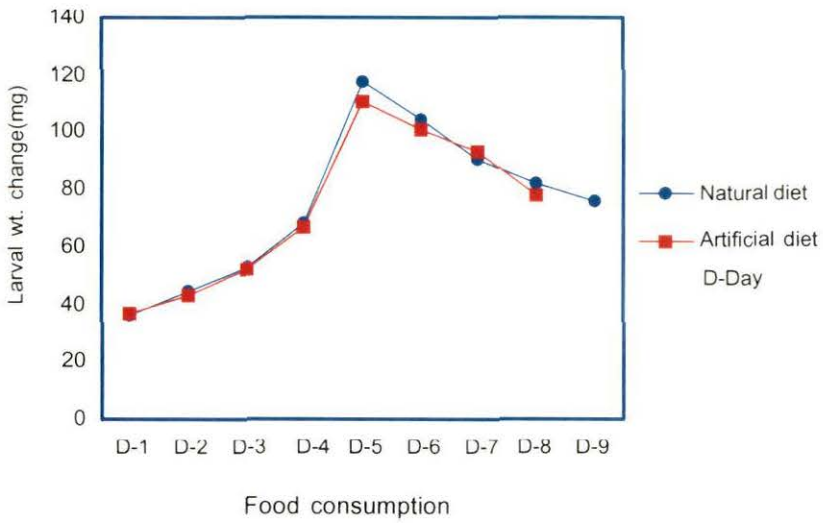


Fig.(a). Vth instar

Fig:17. Difference in Larval Dry wt. (mg) on **Natural & Artificial** Diets during Development at (a) **IVth** & (b) **Vth** instars of *Eterusia magnifica* recorded daywise.

Table 14 (a). Food Consumption and Larval Weight Change (Mean \pm SE) per Day on Natural and Artificial Diets of IVth instar of *Eterusia magnifica*.

Natural Diet

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
Larval Weight	17.42 \pm 0.939	23.42 \pm 1.213	30.00 \pm 1.527	40.00 \pm 1.479	53.71 \pm 1.613	50.57 \pm 0.956	48.28 \pm 1.273	46.28 \pm 0.986	44.00 \pm 1.410
Food Consumption	10.00 \pm 1.000	20.00 \pm 2.576	24.00 \pm 1.185	30.60 \pm 1.874	51.20 \pm 1.860	26.30 \pm 0.931	20.10 \pm 1.026	15.30 \pm 1.136	7.30 \pm 0.980

Artificial Diet

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
Larval Weight	16.94 \pm 1.156	19.82 \pm 1.117	25.11 \pm 0.862	35.11 \pm 1.773	50.97 \pm 1.192	46.91 \pm 1.966	44.60 \pm 1.481	42.22 \pm 1.985
Food Consumption	11.00 \pm 0.795	14.40 \pm 1.103	24.90 \pm 0.932	38.10 \pm 1.432	54.00 \pm 0.949	27.00 \pm 2.675	15.80 \pm 2.079	9.10 \pm 1.384

Table 14 (b). Food Consumption and Larval Weight Change (Mean \pm SE) per Day on Natural and Artificial Diets of Vth instar of *Eterusia magnifica*.

Natural Diet

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
Larval Weight	36.28 ± 0.874	44.57 ± 0.795	53.05 ± 1.234	68.54 ± 1.030	117.48 ± 1.850	104.70 ± 1.390	90.30 ± 1.505	81.90 ± 0.737	76.20 ± 0.416
Food Consumption	15.00 ± 1.751	22.70 ± 2.002	36.10 ± 2.505	53.60 ± 2.789	90.60 ± 1.771	33.50 ± 2.012	25.50 ± 1.002	17.40 ± 1.765	10.60 ± 1.127

Artificial Diet

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
Larval Weight	36.57 ± 0.481	42.85 ± 0.733	52.08 ± 0.727	67.14 ± 1.943	110.94 ± 2.400	100.70 ± 1.247	93.20 ± 1.402	77.90 ± 1.530
Food Consumption	18.00 ± 1.118	22.00 ± 1.920	34.00 ± 2.175	45.70 ± 2.118	71.90 ± 3.778	36.40 ± 4.546	25.30 ± 1.164	10.70 ± 1.390

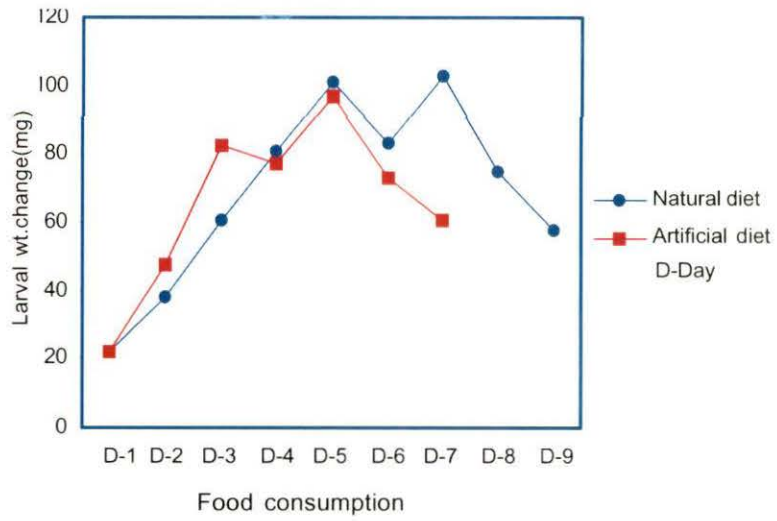


Fig.(a). Vth instar

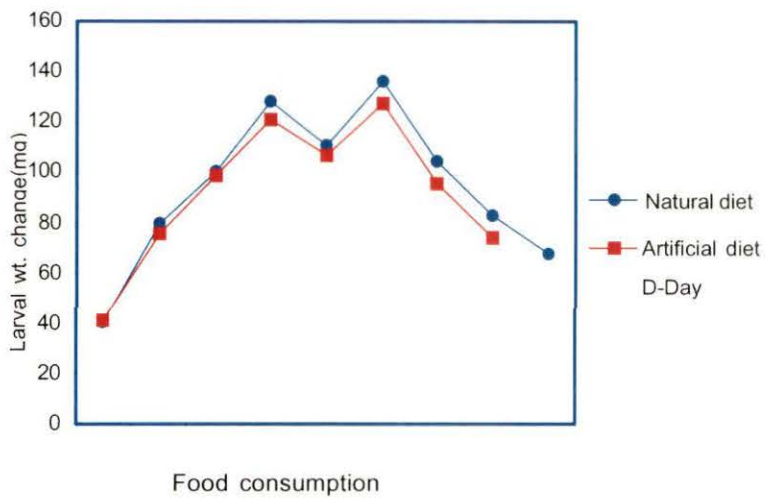


Fig.(b). VIth instar

Fig:18. Difference in Larval Dry wt. (mg) on **Natural & Artificial** Diets during Development at (a) **Vth** & (b) **VIth** instars of *Euproctis latifascia* recorded daywise.

Table 15 (a). Food Consumption and Larval Weight Change (Mean \pm SE) per Day on Natural and Artificial Diets of Vth Instar of *Euproctis latisfascia*

Natural Diet

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
Larval Weight	22.1 \pm 0.348	38.8 \pm 1.209	60.5 \pm 1.621	80.6 \pm 1.694	100.0 \pm 3.504	83.1 \pm 2.115	102.9 \pm 1.708	74.9 \pm 1.595	57.7 \pm 0.789
Food Consumption	12.3 \pm 0.879	22.4 \pm 1.257	43.7 \pm 1.350	65.6 \pm 1.967	88.2 \pm 4.718	69.2 \pm 2.528	89.1 \pm 2.818	48.7 \pm 2.620	16.4 \pm 1.076

Artificial Diet

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Larval Weight	21.9 \pm 0.406	47.8 \pm 2.559	82.8 \pm 3.189	77.3 \pm 4.297	96.8 \pm 3.431	73.1 \pm 2.071	60.5 \pm 0.636
Food Consumption	14.8 \pm 1.038	28.9 \pm 2.002	41.5 \pm 3.239	35.4 \pm 4.177	48.5 \pm 3.953	26.9 \pm 1.822	13.9 \pm 1.514

Table 15 (b). Food Consumption and Larval Weight Change (Mean \pm SE) per Day on Natural and Artificial Diets of VIth Instar of *Euproctis latisfascia*

Natural Diet

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
Larval Weight	40.8 ± 0.904	79.8 ± 2.772	100.3 ± 2.890	127.9 ± 2.262	110.4 ± 2.539	136.3 ± 2.662	104.6 ± 3.927	82.4 ± 2.463	67.8 ± 0.573
Food Consumption	25.6 ± 1.674	40.3 ± 2.944	56.4 ± 2.171	83.0 ± 2.236	68.9 ± 1.991	112.7 ± 3.467	74.9 ± 4.691	39.8 ± 2.153	18.8 ± 1.466

Artificial Diet

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
Larval Weight	41.33 ± 0.333	75.8 ± 1.466	98.7 ± 1.183	120.9 ± 2.349	106.7 ± 3.062	127.4 ± 1.557	95.6 ± 2.629	73.9 ± 1.873
Food Consumption	12.2 ± 1.028	28.4 ± 2.362	34.2 ± 1.919	50.3 ± 3.154	38.4 ± 2.828	67.2 ± 2.031	36.7 ± 1.825	10.9 ± 1.079

Pupal weight of *Buzura suppressaria* (for both male and female) was found to be significantly heavier on natural diet than on artificial diet. Such significantly heavier pupal weight on natural diet possibly resulted from a longer development period. Larvae reared on natural and artificial diets yielded about same number of males and females, the males showing no significant difference in weight when reared on the two different diets. Fecundity was also found to be close on both the diets. Eggs were laid in two or three batches per day for two or three days on both the diets (Table 16).

In a similar finding male and female pupae of *Et. magnifica* were significantly heavier on natural diet. The number of males and females emerging did not differ significantly on the two diets so also their longevity. However, a higher fecundity was noted on natural than on artificial diet. Similarly, eggs were laid in two or three batches per day for two or three days on both the diets (Table 17).

Performance of *E. latifascia* was almost similar on both the diets, but in a departure from the above two species, the female pupae and adults were heavier when reared on artificial diet than on natural diet. Emergence ratio of male and female adults were slightly different on both the diets. Longevity of adults were similar when developing on both the diets. Fecundity was also not affected by the difference of diet. Eggs were laid in two to three batches per day for one or two days on both the diets (Table 18).

Feeding and development in the larval stage may also influence performance of the adult through effects on adult size, nutrient reserves and

timing of oviposition (Barbosa et al., 1981; Moscardi et al., 1981a). A positive relationship between pupal or adult weight and fecundity in case of lepidopterans has been observed by Marshall (1990) and Kamata and Igarashi (1995).

In general female pupal weight was significantly higher than that of male on all diets. Feeding on artificial diet resulted in higher female pupal weight in *E. latifascia* as had also been observed in *Diatraea saccharalis* Fab. by Parra and Mithsfeldt (1992) and in *Platynota idaeusalis* (Walker) by Oscar and Bruce (1997). Pupal weight may be regarded as index of larval food consumption (Rafes, 1967). Body weight of male was significantly lower than the weight of females. This may presumably be due to greater nutrient accumulation associated with egg production and which is achieved through the increase in consumption of the female larval form (Scriber and Slansky, 1981). Moreover, the type of food consumed by larvae has a significant influence on pupal weight, adult weight, fecundity and hatchability.

Feeding can have biologically significant costs. This is most likely to occur in those species in which energy stored by a caterpillar is critical for pupal survival and / or adult performance (Slansky, 1993). The lepidopteran species studied fall in the category where the adults are non feeding and the only source of nutrition and energy is through the feeding activity during their larval stages.

The higher pupal and adult female weight of *B. suppressaria* and *Et. magnifica* on natural diet establishes the natural diet as more suitable diet as compared to artificial diet used in the present study. Irrespective of the diet used for rearing, no significant difference was found in the weight of males in

Table 16. Reproductive Performance of *Buzura suppressaria* on Natural (tea leaf) and Artificial Diets (Mean \pm SE).

Diet	Pupal Dry wt. (mg)		Adult Emergence		Longevity (days)		Adult Dry wt. (mg)		Fecundity
	Male	Female	Male	Female	Male	Female	Male	Female	
Natural Diet (TV₂₆)	33.000a \pm 0.447	38.000a \pm 0.730	25%	45%	5.167a \pm 0.307	6.667a \pm 0.333	23.333a \pm 0.667	28.667a \pm 0.667	422.500a \pm 21.611
Artificial Diet	31.000b \pm 0.719	34.000b \pm 0.730	20%	30%	4.833a \pm 0.401	6.167a \pm 0.401	21.333a \pm 1.430	26.332b \pm 0.615	360.500a \pm 23.086

Means followed by the same letter are not significantly different at 5% level.

Table 17. Reproductive Performance of *Eterusia magnifica* on Natural (tea leaf) and Artificial Diets (Mean \pm SE).

Diet	Pupal Dry wt. (mg)		Adult Emergence		Longevity (days)		Adult Dry wt. (mg)		Fecundity
	Male	Female	Male	Female	Male	Female	Male	Female	
Natural Diet (Tv ₂₆)	54.167a \pm 1.701	74.333a \pm 1.308	30%	40%	5.500a \pm 0.224	6.333a \pm 0.211	23.833a \pm 0.543	42.833a \pm 4.308	643.500a \pm 18.439
Artificial Diet	45.167b \pm 0.833	51.833b \pm 2.400	25%	25%	5.500a 0.245	6.667a 0.211	22.667a \pm 0.615	26.167b \pm 0.543	516.667b \pm 13.480

Means followed by the same letter are not significantly different at 5% level.

Table 18. Reproductive Performance of *Euproctis latisfascia* on Natural (tea leaf) and Artificial Diets (Mean \pm SE).

Diet	Pupal Dry wt. (mg)		Adult Emergence		Longevity (days)		Adult Dry wt. (mg)		Fecundity
	Male	Female	Male	Female	Male	Female	Male	Female	
Natural Diet (TV₁₈)	24.303a \pm 0.615	31.833a \pm 0.615	30%	35%	3.833a \pm 0.307	4.667a \pm 0.374	20.000a \pm 1.555	26.167a \pm 0.543	248.833a \pm 7.485
Artificial Diet	25.667a \pm 0.955	33.667a \pm 0.615	25%	25%	3.833a \pm 0.401	4.833a \pm 0.374	22.333a \pm 0.955	29.333b \pm 0.843	230.333a \pm 9.160

Means followed by the same letter are not significantly different at 5% level.

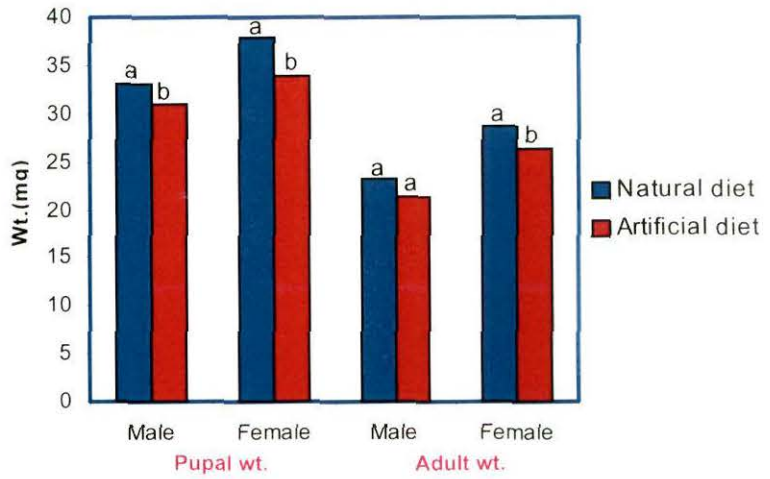


Fig.(a). *Buzura suppressaria*

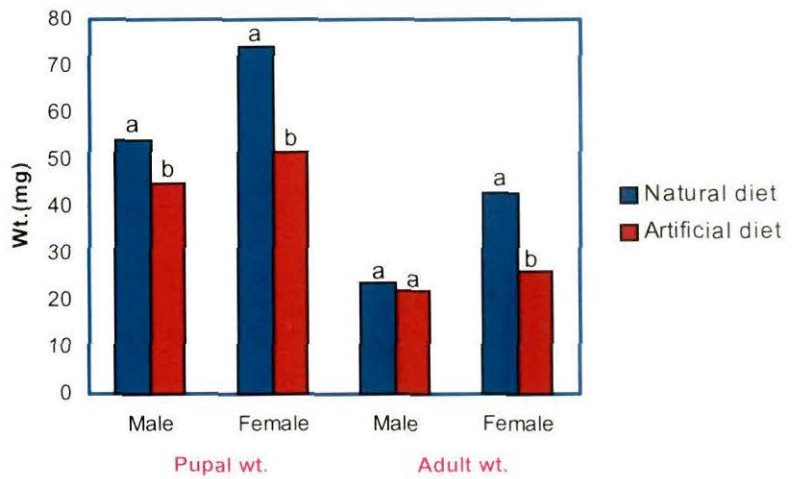


Fig.(b). *Eterusia magnifica*

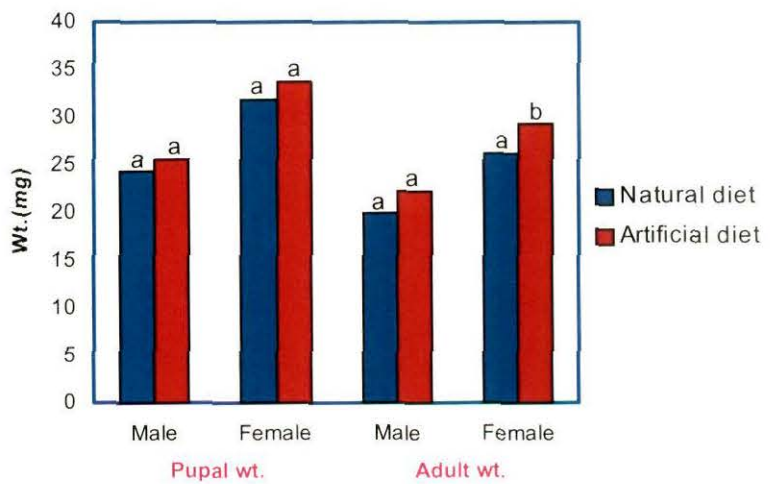


Fig.(c). *Euproctis latisfascia*

Figs.19. Comparison of Dry weights of various stages of : (a) *B. suppressaria*, (b) *Et. magnifica* and (c) *E. latisfascia* on Natural (Tea leaf) & Artificial Diets.

B. suppressaria, *Et. magnifica* and *E. latifascia* which indicates the adequacy of the artificial diets as far as male nutritional requirements are concerned. Longevity of adults (both sexes) were similar on both the diets in all three folivores. Number of eggs laid were also more or less similar on both the diets in *B. suppressaria* and *E. latifascia* but as an exception to this, fecundity of *Et. magnifica* was higher on natural diet. Fecundity of females is highly correlated with both pupal and adult weight (Roland and Myers, 1987; Tammaru, 1997) and is dependent on the quality of the host plant. However, similarity in male adult weight, longevity of male and female adults and fecundity on both the diets indicated the suitability of the artificial diet (Fig. 19).

5. 8. Dry mass budget

5. 8. 1. Relative Consumption Rate (RCR) & Relative Growth Rate (RGR)

Quantity of food consumed / ingested is influenced by a number of exogenous and endogenous factors. Among the host of factors (eg. nitrogen, water and energy content) food quality is an important one that affects consumption (Muthukrishnan and Pandian, 1987). In the present study food utilization efficiencies are discussed on the basis of quality of food consumed by these three lepidopteran tea pests.

Buzura suppressaria showed considerable changes of the quantity of food ingested, faecal matter egested and changes in body mass during development of fourth and fifth instars. This was found true both on natural and artificial diets. In fourth and fifth instars the Relative Consumption Rate (RCR) was found to be

higher on artificial diet as compared to that on natural (leaf) diet. However, Relative Growth Rate (RGR) showed variation, it being higher on natural diet in the fourth and just the reverse in the fifth i.e. higher on artificial diet (Table 19).

In *Eterusia magnifica* there was a general trend of decrease in RCR and RGR in last two instars on both the diets. In fourth instar the RCR values was significantly greater on natural diet when compared to that on artificial diet, although it was similar in the fifth instar. Interestingly, a greater RGR was recorded in fifth instar than that on fourth instar on artificial diet (Table 20).

The RCR in *Euproctis latisfascia* was higher on natural diet than that on artificial diet. It however, showed the decreasing trend in the subsequent stages (Vth to VIth) on both the diets and was found to be significantly lower in the sixth instar than that recorded in the fifth instar. RGR also showed a decrease of its values from fifth to sixth instar (Table 21). Similar findings have been reported by Chaterjee and Chaudhuri (1989) for *Diacrisia casignetum* Kollar (Lepidopter: Arctiidae) on different host plants.

Many factors affect a herbivores feeding rate which include not only environmental conditions but also attributes of food (especially its allelochemical and nutrient contents) and the conditions of the animal (eg. age, size, sex, reproductive state and activity level) (Slansky, 1992).

Relative consumption rate (RCR) may change both within and between instars presumably reflecting physiological changes during development. Late instars tend to have lower RCR values than earlier ones (Slansky and Scriber,

1985; Mohanty and Mitra 1991; Atluri et al., 2002) but only a few species have been studied and these must be interpreted with caution. The finding in the present study on *B. suppressaria*, *Et. magnifica* and *E. latisfascia* on both natural and artificial diets corroborated the above observation i.e. reduction in RCR values with advancement of instars. Similar results had also been reported by Bailey and Tara (1988) for *Diacrisia obliqua* Walk. on mulberry leaves and Bora and Dutta (1996) for *Nacoleia vulgaris* Guen.. A reduction in consumption rate may also be due to enhanced utilization of the energy required for development of body structure and spinning activity in the final instar larva (Muthukrishnan and Pandian, 1987).

The RCR value of *E. latisfascia* was recorded to be higher than the other two folivorous species (*B. suppressaria* and *Et. magnifica*). Such a difference may be accounted for by leaf quality. Tv₁₈ which was the preferred host was provided as natural diet to *E. latisfascia*. This variety as compared to Tv₂₆ is known to have more amount of non-digestible component (Bhuniaya, 1999) and less amount of moisture which possibly reduced the available nutrients, thus forcing *E. latisfascia* to eat more than the other two folivores in question.

Leaves of different plants / varieties differ in their suitability as insect food because of variations in nutrient content, water content, type and concentration of secondary plant compounds and degree of sclerophyll (toughness / fibre) (Gullan and Cranston, 1994). It has also been observed that an increase in leaf toughness (Fenny, 1968, 70 ; Hunter and Lechowicz, 1992) and lowering of water content of foliage (Scriber and Slansky, 1981 ; Martin and Van't Hof, 1988)

decreased the leaf quality resulting into a higher feeding rate or RCR (Farrar et al., 1989 ; Lindroth et al., 1997) but a lowering of RGR value was observed in the present case of *E. latifascia*. This situation may be compared with the nutritional indices of the other two folivores feeding on a nutritionally richer variety, Tv₂₆ and showing higher RGR values.

The two folivores, *B. suppressaria* and *Et. magnifica* that fed on the preferred host variety, Tv₂₆ showed a tendency to attack two different quality of leaves. While *B. suppressaria* consumed younger leaves of upper tier, the other folivore, *Et. magnifica* preferably fed more on mature leaves of middle tier of a tea bush (Fig. 3). The nutritional performance (RCR and RGR values) of *B. suppressaria* was in general, higher than that of *Et. magnifica* both in fourth and fifth instars. A better consumption and growth rate of *B. suppressaria* may be due to consumption of leaves of higher nutritional quality, in which the percentage of nitrogen and moisture is more than the leaves (mature) consumed by *Et. magnifica* (Table 22, 23). In a similar finding Scriber and Fenny (1979) showed that Swallow tails had a higher consumption rate on nitrogen and moisture rich forbs than when feeding on tree foliage having relatively less values of nitrogen and moisture.

As the growth rate is related to approximate digestibility (AD) and assimilation, an enhanced RGR value for *B. suppressaria* is matched here with a higher AD. A higher AD and assimilation are known to be influenced by quality, specially of nitrogen, water and toxin contents of the plant food (Muthukrishnan and Pandian, 1987). The role of moisture content (eg. Tabashnik, 1982) and

nitrogen content (Fox and Macauley, 1977; Slansky and Fenny, 1977) is significant in regulating insect growth rate.

Further, Panda and Khush (1995) found that total organic nitrogen (N), water content and allelochemicals of plant species exerted a strong influence on the 'bioavailability' of nutrients to phytophagous insects.

Food quality can be compared by measuring the body weight gained by insect. This parameter is an indication of the amount of food converted into body biomass. Foods on which insects gain greater body weight are always classified as a better source of energy (Ananthkrishnan, 1992). In the present study, the RGR values were higher for *B. suppressaria* and *Et. magnifica* on artificial diets clearly indicating a better adaptation of these folivores to artificial diets at the advanced stages.

In *E. latifascia* a comparatively higher RGR values of both the stages on artificial diet proved artificial to be superior to the natural diet (Tv₁₈). Though, comparatively RCR was lower in all the three folivores on artificial diet but a higher RGR indicated nutritional adequacy of the artificial diet. It is known that Relative growth rate of herbivorous insects is assumed to be nutrient-limited (Wiegert and Petersen, 1983) and dietary factors such as nitrogen, water, minerals and toxin contents of the food significantly influence the overall growth rate through feeding rate (Larsson and Tenow, 1979; Mattson, 1980). So a higher relative growth rate is an indication of higher utilization of ingested food for growth.

5. 8. 2 . Approximate Digestibility (AD), Efficiency of Ingested Food (ECI) & Efficiency of Digested Food (ECD).

Food quality, water and toxin contents of plant food of herbivores, are some of the factors responsible for influencing assimilation efficiency (Muthukrishnan and Pandian (1987).

A comparative study on approximate digestibility (AD) on natural (leaf) diet showed it to be highest for *B. suppressaria* followed by that on *Et. magnifica* and then *E. latifascia*. The value of approximate digestibility and efficiencies of food conversion, are generally higher among the larvae feeding on foliage having high nitrogen content (Barbosa and Greenblatt, 1979). Higher AD recorded for *B. suppressaria* which preferred nitrogen rich food with high percentage of water confirms the above finding. However, on artificial diet, the AD value of *Et. magnifica* was found to be the lowest in last two instars in reference to the values of the other two species. Increase in approximate digestibility may be compensating for reduced consumption of artificial diet in order to maintain good growth (Slansky and Scriber, 1985). This relation of AD and RCR values was found to hold good both in the fifth and sixth instars of *E. latifascia*. But in the other two species this relationship was observed to be variable.

In all the three species efficiencies of conversion of ingested (ECI) and digested food (ECD), in general, were higher for those on artificial diet than the ones on natural diet. The only exception was the fourth instar of *B. suppressaria*. Further, a comparison of ECD values of the three species showed that *B. suppressaria* and *E. latifascia* had lower values as compared to that of

Et. magnifica on both the diets, indicating a low efficiency of conversion of digested food to body tissues in the former two species. Such low values of ECD are not unusual (Waldbauer, 1968) (Table 19, 20 & 21).

A reduction in ECD associated with allelochemical ingestion is a common (although not universal) occurrence (Koul et al., 1990; Apple and Martin, 1992), which is evident in the two species, *B. suppressaria* and *E. latisfascia* when feeding on natural diet than on artificial one. This may be due to the direct interference of the allelochemical of the natural diet with some metabolic processes of caterpillars (Slansky, 1992) resulting in slowing of growth and due to diversion of a large part of the absorbed food to respiration (Apple and Martin, 1992).

The ECD values in the last two instars (IVth to Vth of *B. suppressaria* and *Et. magnifica* & Vth to VIth of *E. latisfascia*) showed a general reduction on natural as well as artificial diets (demonstrating some exceptions in the case of *B. suppressaria* on artificial diet, where it showed an enhancement from fourth to fifth instar) (Table 19). Such exceptions have also been reported by Mukerji and Guppy (1970) and Bailey (1976), wherein increase in ECD during larval development was found to be inconsistent. The decline in ECD and ECI may be due to internal changes and extra expenditure of energy prior to pupation as explained by Soo Hoo and Fraenkel (1966) for the last instar larva of the tree feeder southern armyworm, *Prodenia evidamia*.

Amongst the three lepidopteran tea pests ECI was found to be lowest for *E. latisfascia* on natural diet which may be due to low water in the food which has

a strong effect in the ECI of insects as inferred by Panda and Khush (1995). Low dietary water impairing the conversion efficiencies have also been reported in several lepidopteran larvae (Scriber, 1977; Martin and Von't hof, 1988 ; Deb et al. 2000).

5. 8. 3. Maintenance Cost and Production index.

In all the three folivores, in general, the assimilation (As) and production (P) values on natural diet by far exceeded the ones on artificial diet (with an exception of *E. latisfascia*) however, the cost of maintenance (R / P) was found higher on natural diet except for *B. suppressaria* in its fifth larval stage. In all the three species (in last two instars), *B. suppressaria*, *Et. magnifica* and *E. latisfascia*, the assimilation values on natural diets were 85, 127 ; 84.33, 129; 143, 167 mg., similarly, values on artificial diets were 78.86,114; 67.13, 112.8; 102.93,143.20 mg. respectively. The production values on natural diets were 22.20, 31.46; 26.64, 40.27; 35, 27.73 mg. and values on artificial diets were 17.00, 28.46; 26.01, 41.27; 37.8, 36.06 mg. respectively.

The dry mass budget of *Et. magnifica* indicated almost similar values of assimilation and production on both the diets. The higher maintenance cost on natural diet compared to artificial diet may be an indication that the utilization of the former is combined with expenditure of energy. Judging by the lower maintenance cost on artificial diet the same can be a good supporting diet for rearing *Et. magnifica* (Table 20). The facts that a higher nutritional quality involves lower maintenance cost has also been substantiated by the work of Karowe and Martin (1989).

Table 19. Comparison of Nutritional Indices of *Buzura suppressaria* (IVth and Vth instars) on Natural (tea leaf) and Artificial Diets (Mean \pm SE).

IVth instar:

	RCR	RGR	ECI	ECD	AD	Main.cost	Prod.index
Natural diet	0.871a ± 0.013	0.110a ± 0.173	12.602a ± 0.518	25.799a ± 0.834	48.709a ± 0.725	2.948a ± 0.164	0.257a ± 0.008
Artificial diet	0.933b ± 0.011	0.093b ± 0.007	10.034b ± 0.178	21.810b ± 0.394	46.650b ± 0.520	3.664b ± 0.076	0.215b ± 0.004

Vth instar:

	RCR	RGR	ECI	ECD	AD	Main.cost	Prod.index
Natural diet	0.630a ± 0.008	0.078a ± 0.002	12.355a ± 0.246	24.761a ± 0.453	49.904a ± 0.441	3.056a ± 0.070	0.247a ± 0.005
Artificial diet	0.680b ± 0.006	0.089b ± 0.002	13.162a ± 0.373	24.996a ± 0.602	52.809b ± 0.579	3.047b ± 0.095	0.249a ± 0.006

Means followed by the same letter are not significantly different at 5% level.

Table 20. Comparison of Nutritional Indices of *Eterusia magnifica* (IVth and Vth instars) on Natural (tea leaf) and Artificial Diets (Mean \pm SE).

IVth instar:

	RCR	RGR	ECI	ECD	AD	Main.cost	Prod.index
Natural diet	0.718a \pm 0.009	0.098a \pm 0.002	13.611a \pm 0.210	31.724a \pm 0.802	43.092a \pm 0.606	2.177a \pm 0.080	0.317a \pm 0.008
Artificial diet	0.688b \pm 0.011	0.097a \pm 0.001	14.223a \pm 0.258	38.957b \pm 0.862	36.814b \pm 1.030	1.579b \pm 0.051	0.389b \pm 0.008

Vth instar:

	RCR	RGR	ECI	ECD	AD	Main. cost	Prod.Index
Natural diet	0.574a \pm 0.004	0.080a \pm 0.001	13.879a \pm 0.212	31.241a \pm 0.509	44.453a \pm 0.243	2.212a \pm 0.051	0.312a \pm 0.005
Artificial diet	0.585a \pm 0.009	0.090b \pm 0.002	15.509b \pm 0.500	36.648b \pm 1.066	42.326b \pm 0.668	1.759b \pm 0.076	0.366b \pm 0.010

Means followed by the same letter are not significantly different at 5% level.

Table 21. Comparison of Nutritional Indices of *Euproctis latisfascia* (Vth and VIth instars) on Natural (tea leaf) and Artificial Diets (Mean \pm SE).

Vth instar:

	RCR	RGR	ECI	ECD	AD	Main.cost	Prod.index
Natural diet	1.244a ± 0.013	0.098a ± 0.002	7.860a ± 0.142	24.506a ± 0.627	32.303a ± 0.369	3.111a ± 0.099	0.245a ± 0.005
Artificial diet	0.681b ± 0.010	0.132b ± 0.002	19.417b ± 0.335	36.799b ± 0.733	52.843b ± 0.578	1.728b ± 0.051	0.367b ± 0.007

VIth instar:

	RCR	RGR	ECI	ECD	AD	Main.cost	Prod.index
Natural diet	0.885a ± 0.083	0.056a ± 0.002	5.637a ± 0.216	16.486a ± 0.572	34.084a ± 0.624	5.136a ± 0.200	0.165a ± 0.005
Artificial diet	0.616b ± 0.105	0.076b ± 0.000	12.451b ± 0.191	25.224b ± 0.315	49.340b ± 0.320	2.971b ± 0.050	0.251b ± 0.002

Means followed by the same letter are not significantly different at 5% level.



(a)



(b)



(c)

Plate 6. Rearing of Adults .

- (a). *Buzura suppressaria* ;
- (b). *Eterusia magnifica* ; and
- (c). *Euproctis latisfascia*.



(a)



(b)



(c)

Plate 7. Rearing on Artificial Diet.

- (a) *Buzura suppressaria* ;
- (b) *Eterusia magnifica* ; and
- (c) *Euproctis latifascia* .

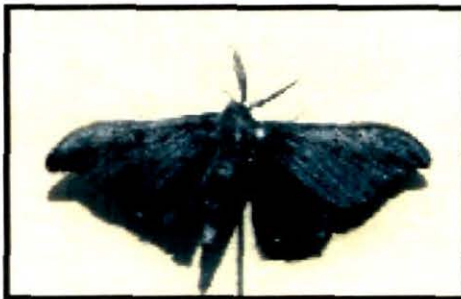
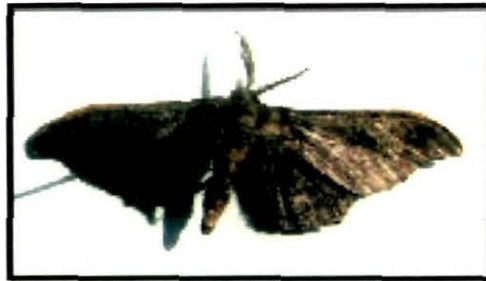


Plate 8. Melanism in Adults of *Buzura suppressaria*.

The increase in food consumption which enhanced the cost of maintenance of *E. latifascia* on natural diet, may be due to its food quality (Table 21). Higher expenditure of energy may result from higher quantity of consumption through a longer time (Slansky, 1992, 1993). In *E. latifascia* presumably most part of the ingested food has been utilized in basal metabolism, resulting in low conversion for growth. Mukerji and Guppy (1970) observed a similar phenomenon in the lepidoptera, *Pseudaletia unipuncta* (Haw.). The suboptimal availability of nutrient often nitrogen or water reduces growth rate, increases maintenance costs and causes a lower metabolic efficiency (Shoonhoven et al., 1998).

In the last two stages of all the three species in question, production index was found to be higher on artificial diet than on natural diet except for the fourth instar of *B. suppressaria* (Table 19). The higher production index can be considered as an indicator of better suitability of the artificial diet in supporting the advanced life stages of all the three species. Based on these findings, the artificial diets can be considered as an alternative food for supporting partial or complete rearing of the three lepidopteran pests of tea in concern.

5. 9. Biochemical analysis

In an estimation done for the three lepidopteran tea pests, *Buzura suppressaria*, *Eterusia magnifica* and *Euproctis latifascia* with regard to their biochemical profile specially basic nutrients along with moisture and ash content, clear reflections of the plant nutrients and the corresponding body mass chemistry of the larvae were evident.

5. 9. 1. Nitrogen

The analysis also gives us an insight into the efficiency by which the nutritional components present in the natural and artificial food have been utilized by the above lepidopteran larvae to support their development and activity. Since we know herbivores are likely to be nitrogen limited, seeking to concentrate it as rapidly as possible (McNeil and Southwood , 1978; Slansky & Scriber, 1985), the present data (Table 22, 23, 24) on nitrogen shows that a conversion from natural / artificial diet to body mass of the larva may take place in the proportion of 2 - 4 times, while from the natural diet the concentration of nitrogen in the final instar of the above species are in the proportion of 2.60, 2.68 and 2.35, whereas the proportion of conversion was much higher from artificial diet which were in the range of 3.15, 3.13 and 3.82 for *B. suppresssaria*, *Et. magnifica* and *E. latisfascia* respectively (Figs. 20, 21, 22). Such increase in the proportion of nitrogen has been documented by Muthukrishnan and Pandian (1987).

It is not a surprise that a conversion of the nitrogen present in tea leaves (natural diet) to the nitrogen of the larval body mass is at a reduced proportion as compared to that on the artificial diet. Phenolic compounds are ubiquitous in plants. Many colourless representatives of these groups are often considered significant as insect toxicants. Besides this, the phenolic compounds like tannins that are found in fair proportion in the tea leaves bind to almost all soluble proteins, producing insoluble polymers. Enzymes complexed in this way show a marked reduction in activity. Also proteins bound to tannins cannot be degraded

by enzymes in the digestive tract and tannins are therefore generally thought to decrease the nutritional value of plant tissues (Shoonhoven et al., 1998).

Hence, it can be inferred that artificial diet, despite having a lower nitrogen content than tea leaves has a higher proportion of conversion to the larval body mass due to the absence of any such polyphenolic compound interfering with the available nitrogen in the diet (Fig. 20, 21 & 22).

5. 9. 2. Lipid

An analysis of the lipid content of the natural and artificial diets alongwith larval body mass of the three lepidopteran species showed that there is an increase in the conversion of the quantum of lipid ranging from about 2 - 7 times. Such higher proportion of conversion of lipid suggests that the lipid was selectively accumulated by the artificial diet reared larvae, which was also found true in *Anticarsia gemmatalis* and *Heliothis virescens* (F) by (Cookman et al., 1983 ; Dikeman et al. (1981) mediated through fatty acids. The enrichment of the proportion of lipid in the body mass apparently is necessary for maintenance of certain physiological processes like the ecdysis, specially that of pupa as has been established in several lepidopterans like *Ephestia*, *Spodoptera littoralis* (Levinson and Navon, 1969). Hence a high proportion, ranging from 14.32 to 19.7 %, of lipid in the body mass of the three lepidopterans was found to be present. This was always found to be, in most cases, several times higher than the percentage in which they occur in the diets (Table 22, 23, 24).

Carbohydrate

Carbohydrates are the common source of energy and although not always essential, are usually necessary for normal growth (Berlinger, 1992). In the three species the percentage of carbohydrate found in the larval body mass (5 to 6%) were lower than that found in their diets (both natural and artificial) which has been reported in the tune of 30 % in natural diet (Mulky, 1993) and found to be in the tune of 12 to 16 % as evident from the formulation of the artificial diets (Table I & Table II). This phenomenon appears to be a general rule for insects (Clercq, 1993). A plausible explanation for this may be the interference of the allelochemicals specially polyphenols and tannins that are present in the leaves influencing the uptake of carbohydrate. Such an interpretation has also been furnished by Schoonhoven et al., (1998) where cross finding of tannins with polysaccharides and the consequent lowering of their physiological function and nutritional value has been hypothesized.

5. 9. 3. Moisture

Water is the cradle of life. Amount of water in the food of lepidopterous larvae provides a surprisingly useful index of its nutritional value and thus growth performance. Significantly better growth occurred on plants with higher water content. The relevance of dietary water was confirmed in experiments with artificial diets varying in water content (Scriber, 1984). The percentage of moisture present both in natural (leaf) and the artificial diets offered to the lepidopteran species in question were quite high ranging between 50 - 70 %, while it is reported that the water content in the foliage usually varies between

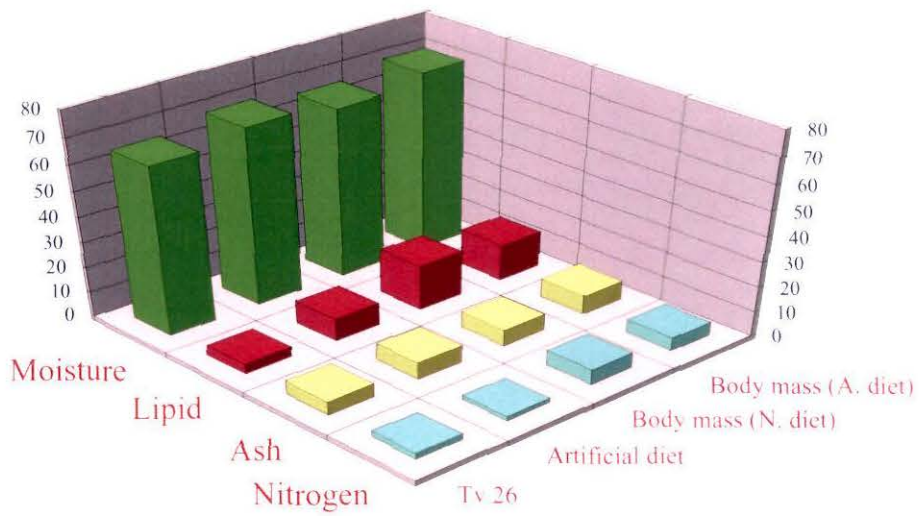


Fig. 20. Comparison of Biochemical components present (Mean Dry wt. % Value) in Natural & Artificial Diets and Larval Body Mass of *B. Suppressaria* and Moisture (Mean Fresh wt. %)

Table 22. Comparison of Biochemical Components present (Mean Dry wt. % value) in : Natural (tea leaf) and Artificial Diets and Larval Body mass of *Buzura suppressaria* and Moisture (Mean Fresh wt. % value).

<i>B.suppressaria</i>	TV ₂₆	Artificial diet	Body mass (Natural diet)	Body mass (Artificial diet)
Nitrogen	2.281	1.650	5.954	5.199
Lipid	3.880	8.880	17.960	14.380
Ash	5.350	6.780	6.420	7.480
Moisture	66.20	70.000	66.980	70.795

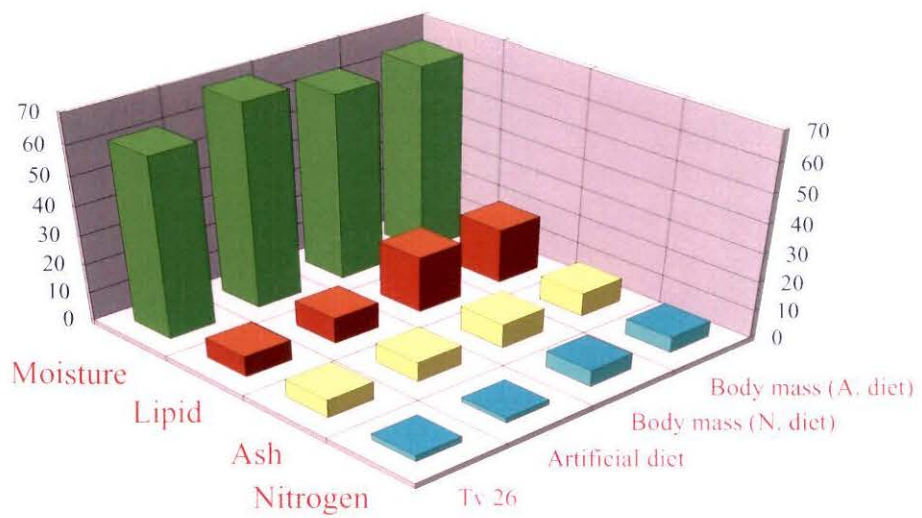


Fig. 21. Comparison of Biochemical components present (Mean Dry wt. % Value) in Natural & Artificial Diets and Larval Body Mass of *Et. magnifica* and Moisture (Mean Fresh wt. %)

Table 23. Comparison of Biochemical Components present (Mean Dry wt. % value) in : Natural (tea leaf) and Artificial Diets and Larval Body mass of *Eterusia magnifica* and Moisture (Mean Fresh wt. % value).

<i>Et. magnifica</i>	TV ₂₆	Artificial diet	Body mass (Natural diet)	Body mass (Artificial diet)
Nitrogen	2.111	1.650	5.642	5.471
Lipid	7.050	8.880	19.550	18.950
Ash	6.300	6.780	8.430	8.250
Moisture	62.000	70.000	64.177	65.249

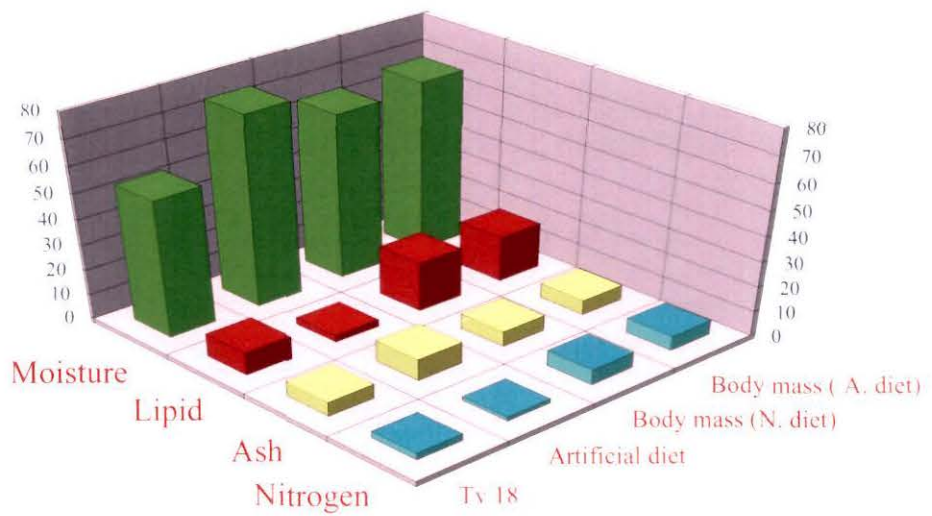


Fig. 22. Comparison of Biochemical components present (Mean Dry wt. % Value) in Natural & Artificial Diets and Larval Body Mass of *E.latifascia* and Moisture (Mean Fresh wt. %)

Table 24. Comparison of Biochemical Components present (Mean Dry wt. % value) in: Natural (tea leaf) and Artificial Diets and Larval Body mass of *Euproctis latisfascia* and Moisture (Mean Fresh wt. % value).

<i>E. latisfascia</i>	Tv ₂₆	Artificial diet	Body mass (Natural diet)	Body mass (Artificial diet)
Nitrogen	2.607	1.537	6.142	5.823
Lipid	9.030	2.680	19.700	18.040
Ash	5.820	8.560	6.130	5.830
Moisture	54.060	75.000	65.244	67.877

45 - 95 % of the fresh weight (Shoonhoven et al., 1998). So, the presence of adequate moisture had a definite influence on the nutritional value and vis-à-vis of the performance of the three concerned lepidopteran species.

In an experiment with 16 species, when fed upon exercised leaves without water supplementation via petioles, their relative growth rates (RGR) showed reduction upto 40 % even when the food did not show any indication of desiccation. Such effects were more pronounced on tree leaf feeders (Shoonhoven et al., 1998). In the present study, RGR values of the penultimate larval instars were found to be at par (with an exception of *E. latifascia*) on both the diets which indicates that the moisture provided through their diets had been adequate in supporting their development and growth activity. (Table 22, 23, 24 & Fig. 20, 21, 22).



(a)



(b)



(c)



(d)



(e)

Plate 9. Various studies on feeding.

- (a) Host Preference with Leaf Discs ;
- (b) Darjeeling Black Hairy Caterpillar feeding on Tea Leaf ;
- (c) Red Slug Caterpillar feeding on Epidermal Surface of Tea Leaf ;
- (d) Skeletonised Tea Leaf ; and
- (e) Rearing on Artificial Diet.

SUMMARY

6. Summary

1. Three lepidopteran tea pests, *Buzura suppressaria*, *Eterusia magnifica* and *Euproctis latisfascia* commonly occurred in tea plantations of Darjeeling Terai (foothills and plains). While *B. suppressaria* mostly attacked the younger leaves of full grown tea bushes, *Et. magnifica* was largely confined to the mature leaves of middle tier and *E. latisfascia* frequented the lower tier on old and senescent leaves.
2. Host preference tests conducted with the above three folivores on three common clonal varieties (Tv₁, Tv₁₈ and Tv₂₆) revealed that all the three varieties were consumed by the three folivores. However, early and late instars of *B. suppressaria* and *Et. magnifica* showed a clear preference for Tv₂₆ and *E. latisfascia* (early and late instars) had a preference for Tv₁₈.
3. Allometric growth study indicated the different patterns of growth among the three lepidopteran tea pests. Such a study can help in distinguishing the developing instars of the above three folivorous species based on the measurement of different parts of the body. Further, the difference in the slope (k) and intercept (b) values also reflected the differential growth patterns of the three species. The morphometric study also indicated a gradual increase of the different parts of the body along with the age.

4. In the present study, artificial diets for the rearing of *B. suppressaria*, *Et. magnifica* and *E. latisfascia* under the laboratory condition was established for the first time.
5. Comparative study on performance of the three lepidopteran tea pests on natural (tea leaf) and artificial diets were done. Artificial diets were found to be almost equally capable of supporting growth and development of the three folivores like that of their natural diets.
6. Regression values based on daily food consumption and larval body weight change showed that these two variables were closely related on both the diets irrespective of the stages in *B. suppressaria* and *E. latisfascia*. However, *Et. magnifica* showed a less relationship between the two variables.
7. Survivorship study of each species on natural (tea leaf) and artificial diets indicated similar pattern of curves on both the diets. Percentage of mortality shows parallel trends on both the diets. The number of survivors (emerging adults) were almost equal (20%) for *B. suppressaria* and *E. magnifica* but number was somewhat less (10%) in *E. latisfascia*, possibly for its complete rearing from egg to egg on artificial diet.
8. The nutritional quality of the artificial diet could be judged by stable growth and development of all the three species. In general the duration of different developmental stages (stadium) and life cycles were found to be shortened on artificial diet than on natural diet. In *B. suppressaria* third,

fifth and pupal durations were shorter on artificial than on natural diet. *Et. magnifica* showed almost similar result where the third and fourth larval durations were shorter on artificial diet than on natural diet. In *E. latisfascia*, second, fourth, fifth instar and pupal stadia durations were shorter on artificial diet.

9. Under reproductive performance the study on changes in body mass for the pupa and adults on both the diets indicated that the natural diet influenced formation of heavier females in *B. suppressaria* and *Et. magnifica* than on artificial diet, while the situation was reverse in case of *E. latisfascia*. No differential influence of the diets could be noted on adult emergence and longevity.
10. In general higher relative consumption rate (RCR) and relative growth rate (RGR) were recorded in all the three species on natural diet despite higher maintenance cost as compared to that on artificial diets. Such higher maintenance cost on natural diet indicated a greater utilization of energy for keeping up the metabolic functions of the body.
11. The RCR and RGR values of *B. suppressaria* were found to be higher than that of *Et. magnifica* both in fourth and fifth instars on natural diet which can be related with higher nutritional quality of its food (tea leaf). An enhanced RGR value for *B. suppressaria* was matched with a higher AD (Approximate digestibility).

12. The RCR value of *E. latisfascia* was recorded to be higher than the other two folivorous species (*B. suppressaria* and *Et. magnifica*) on natural diet. Higher RCR was matched with lower RGR value indicating compensatory feeding to mitigate the less amount of nutrients from food.
13. In general, the RCR was lower in all the three folivores on artificial diet but a higher RGR indicated nutritional adequacy of the artificial diet. RCR of *B. suppressaria* and *Et. magnifica* were higher on artificial diet at the penultimate stage showing a better adaptation of these folivores at the advanced stages on artificial diet. In spite of lower RCR on artificial diet in *E. latisfascia*, RGR was higher on both the stages on artificial diet showing a better performance on artificial diet.
14. Approximate digestibility (AD) on natural diet showed to be higher for *B. suppressaria* followed by *Et. magnifica* and then *E. latisfascia*. On artificial diet AD value of *Et. magnifica* was found to be lowest compared to the other two species. The higher AD indicated better quality of the food consumed by three lepidopteran tea pests.
15. In all the three species, efficiencies of conversion of ingested (ECI) and digested (ECD) food, in general were higher on artificial diet than on the natural diet. The only exception was the fourth instar of *B. suppressaria*.
16. Higher the maintenance cost, lower is the accumulation of energy indicated by a lower production index. This was found to be true for *E. latisfascia* on natural diet. However, high production index on artificial diet

in all the three species in advanced stages indicated that the utilization of the nutrients (present in the diet) took place.

17. Biochemical analysis of the plant nutrients and the corresponding body mass of the larvae reflected an efficient system of conversion of the nutritional components present in the natural and artificial diets by all the advanced larvae of the three lepidopteran tea pests.

18. The proportion of conversion of nitrogen from artificial diet to body mass was found to be much higher on artificial diet than on natural diet. This may be due to the absence of polyphenolic compounds in artificial diet interfering with the available nitrogen in the diet.

19. The accumulation of lipid in the artificial diet-reared larvae showed concentration of lipid (despite a lipid poor diet) supporting their normal growth and development.

20. The significant role of moisture was evident by the better performance of the folivores on the natural diet having higher amount of moisture.

21. Judging by the overall performance of the three lepidopteran species, artificial diet could be evaluated as a viable alternative resource for rearing of these tea pests. Such a maiden attempt, hopefully, would serve several purposes connected with basic and applied researches on tea pests. Nevertheless, there is still room for improvement of the diets for developing rearing facilities of these lepidopteran pests.

HIGHLIGHTS

Highlights

1. Establishment of artificial diets for rearing three species (*Buzura suppressaria*, *Eterusia magnifica* and *Euproctis latisfascia*) of lepidopteran tea pests for the first time.
2. Detailed accounts of post-embryonic developmental stages along with morphometric study on natural hosts under laboratory condition.
3. Maiden study was made on performance of the three lepidopteran pest species based on their growth and development and survivorship parameters on natural (tea leaf) and artificial diets.
4. Host choice study was conducted to find out degree of preference and acceptance of the clonal varieties (out of Tv₁, Tv₁₈, Tv₂₆) as food by three species.
5. Higher consumption and compensatory feeding could be related with less amount of moisture and quality of food present in natural diet as compared to that of artificial diet.
6. Maintenance cost, in general, was higher on natural diet than on artificial diet.
7. As a rule, production index was higher in advanced larvae, reared on artificial diet with exception of fourth instar of *B. suppressaria*.

8. Comparison of quantity of biochemical components (of basic nutritional value) of natural and artificial diets and larval body mass along with their moisture content reflected variable efficiencies of conversion (food to body mass) by the penultimate larval instars of the three lepidopteran pests.

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Diversity of ground arthropod community at organic and chemically intensive tea plantation of Darjeeling terai

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Abstract : Tea in Darjeeling foothills and terai is grown conventionally, with application of chemical fertilizers and pesticides, as well as organically without these inputs. Ground level arthropod community was collected from the above two types of tea plots using pitfall traps. Catches from these environments showed variation in the arthropod faunal structure with numerically and taxonomically greater abundance in the organic than that of the conventional plot. Coleopterans were more diverse with largest number of families and Recognizable Taxonomic Units (or morphospecies) in the organic tea plot. The diversity and similarity indices for coleopterans were comparable, in organic and conventional tea plots at species and family levels. The close relationship of the indices suggested that diversity study at family level could be used as surrogate for species level diversity; thus alleviating the laborious and expertise job of taxonomic identification of arthropod species. Faunal diversity study at ground level gave the clue that soil of the organic plantation was healthier than that of the conventional tea plot.

Key words : Arthropod community, Ground level, Tea plots, Faunal diversity.

Introduction

Tea being a perennial crop is grown in monocultures, interrupted only by shade trees. The monoculture provides a stable environment, food, and a breeding place for insects, mites and worms. Most of the dead plant tissues fall on the ground, making the surface and the sub-surface of soil an abode of great biological activity. A diverse array of soil arthropods is active in tea areas (Banerjee, 1993). Besides, these organisms also serve as pedobiological monitors, indicating the quality of habitat and/or its degradation (Luff *et al.*, 1989). The soils rich in biodiversity support healthy growth of plantation crops, and are termed as living soils, and form the basis for organic farming (Nampoothiri, 2001). To quantify the quality of habitats at ground level of the plantation, the study of the incidence and diversity of soil-surface arthropod fauna is important.

Pitfall traps are most commonly used for sampling ground-dwelling insects such as carabids and staphylinid beetles, spiders and predatory mites. The containers that can be used as pitfall traps are many and varied, but round plated pots and glass jars are the most popular (Jervis and Kidd, 1996). A liquid preservative is often placed in the trap to kill

and to preserve the catch, thereby reducing the risk of escape and predation within the trap, particularly of small individuals by the larger ones. Gist and Crossley (1973) have found that catches in pitfall traps might yield meaningful data and understanding of faunal diversity, provided proper attention is paid to potential sources of variation.

Since identification of a large variety of arthropods is very difficult, Gullan and Cranston (1994) have suggested that studies at community level in a particular area could yield more valuable information than any single species study. In order to alleviate taxonomic difficulties, they suggested selection of one or higher taxonomic groups instead of species level identification from amongst the organisms collected. As a second approach, Speight *et al.* (1999) recommended the use of morphospecies, 'recognizable taxonomic units' (RTUs) or 'operational taxonomic units' (OTUs) to overcome the taxonomic problem of determination.

The present study was an attempt to analyze taxonomically the pitfall trap catch upto the morphospecies level, and to determine the dynamics of incidence of the coleopterans on the ground, through six productive months of tea. The study further contemplated to compare the environmental

conditions occurring at the ground in organic and conventional tea-growing plots through careful analysis of the arthropod fauna caught in the pitfall traps.

The family is the most conspicuous and easily identifiable category. Each family usually presents a general facet that is recognizable at a glance and most of its entire species occupy a similar niche in their particular communities (Mayr and Ashlock, 1991). An attempt was also made to find whether higher taxonomic categories such as family diversity could be used as a substitute/surrogate for species level diversity, thus helping in circumventing the species identification problem by the ecologists or non-specialists.

Materials and Methods

Sampling was carried out at weekly intervals using pitfall traps, deployed in a randomized complete block design. A set of five traps was laid out in an organic tea plot as well as in a tea plot treated conventionally with mineral fertilizers and Tea Research Association approved pesticides (Anonymous, 1997). This deployment of the pitfall traps gave an opportunity for comparative study of the catches from the two differentially treated tea plots. The plots selected for the present study were located in a typical terai belt.

The traps used were made of glass, 11cm long and 6 cm in diameter with formaldehyde (4%) as a preservative (Vennila and Rajagopal, 2000). The traps were set in the soil with their brim flushed with the soil surface. The preservative added in each trap was one-third its volume. Polythene sheets cut into square shapes were used as covers to protect the traps, especially from rain.

Sampling was carried out during a period of six summer and monsoon months (April to September) with twenty-four weekly catches when the tea leaf yield in North-eastern region of India is the highest (Banerjee, 1993). The trapped insects were collected by straining the preservative. The traps were replaced in the same position. The collections from both the plots were then brought to the laboratory and sorted taxonomically. Coleopterans, which were recorded as the major

catch, were analysed upto 'recognizable taxonomic unit' (RTU) or 'operational taxonomic unit' (OTU) levels, deemed equivalent to morphospecies. According to the concept of RTU/OTU, the classification of the specimens was done by considering their morphological features, which were then grouped to comprise morphospecies. Oliver and Beattie (1993, 1996 a, b) has described this method in detail and tested with case studies. Diversity (Shannon and Weaver, 1963) and similarity (Sorensen, 1948) indices were calculated at morphospecies and family levels, in both the habitats.

Results and Discussion

An overall analysis of the arthropod fauna collected in the pitfall traps in organic tea plot showed a greater abundance of the representatives of Coleoptera, Hymenoptera, Lepidoptera, Acari, Collembola and terrestrial crustacean order, Isopoda, along with the orders Neuroptera and Scolopendromorpha that constituted the exclusive predatory groups. The conventional tea plot catch in general indicated a fair number of orthopterans, dermapterans, isopterans, hemipterans, dictyopterans, diplopodans, and spiders. Greater occurrence of the major players of the detritus food chain such as isopodan crustaceans, springtails (collembolan), diplopodans, and a large number of coleopteran species was recorded in the organic tea plot. It was clearly evident that the coleopterans were consistently more abundant in the organic tea plot than in the conventional one, although there were periodic surges in population abundance in both the plots (Fig. 1). Detailed analysis of coleopteran families and morphospecies of six samples spread through five months of the study clearly indicated that the number of individuals and families were, in general, greater in organic tea plots compared to the conventional ones (Table-1). Further, the increase in the number of morphospecies or RTU of coleopterans had a corresponding increase in the number of its families. The positive relationship between these two variables was evident from the trend line diagrams, both for the samples taken in organic and in the conventional tea plots (Fig.2).

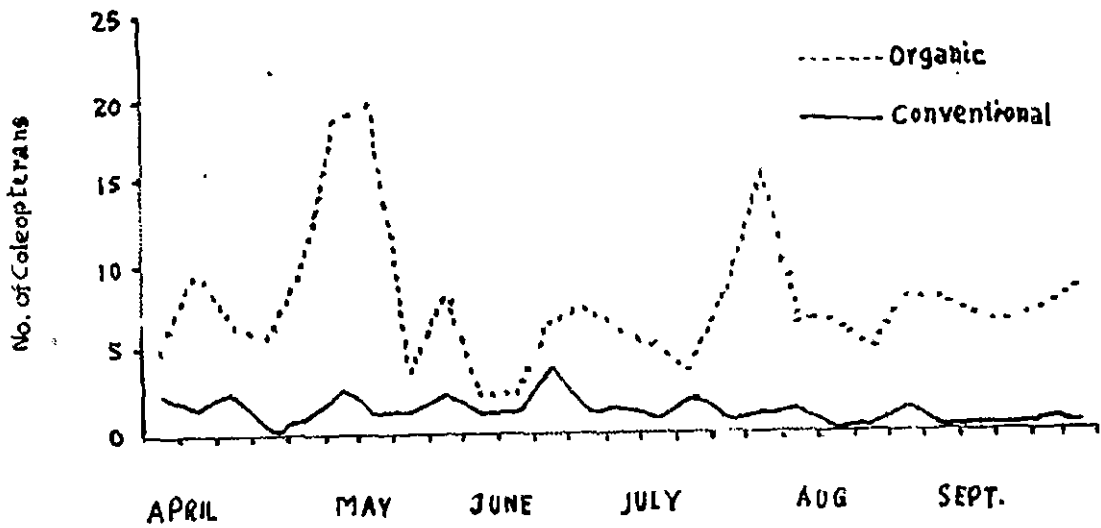


Fig. 1 : Weekly occurrence of coleopterans in organic and conventional tea plots.

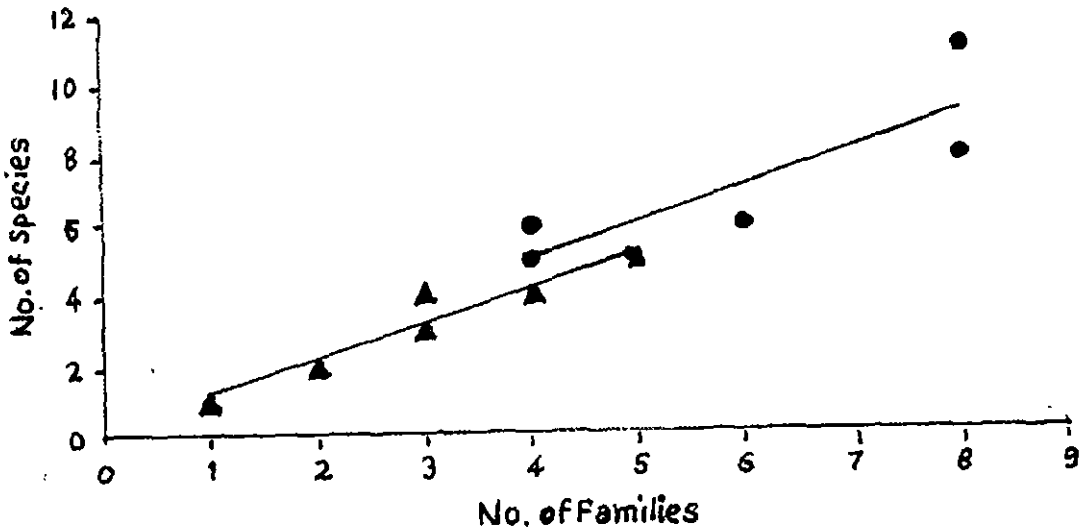


Fig. 2 : Relationship of coleopteran families and species occurring at organic (●) and conventional (▲) tea plots as observed from six pitfall trap catches (April to September, 2001).

With the application of Shannon's General Diversity Index, it was evident that diversity at the morphospecies (RTUs) level was almost similar to the diversity at the family level (Table-2). Further, similarity index values were also found closely comparable at both the taxonomic categories, based on the samples collected from the two different habitats (organic and conventional).

Soil supports a vast diversity of organisms. From the ecological point of view, the functional significance of soil biota are those associated with organic matter decomposition, mineralization of nutrients and synthesis of humic compounds. The synergistic relationship of soil animals with free living and symbiotic microorganisms is responsible for rapid cycling of essential nutrients (Lee, 1991).

Table - 1 : Families of Coleoptera with mean number of individuals in the samples collected from organic and conventional tea plots.

Date of collection	28.5.2001		18.6.2001		02.7.2001		27.8.2001		03.9.2001		30.10.2001	
	Organic	Convnl.	Organic	Convnl.	Organic	Convnl.	Organic	Convnl.	Organic	Convnl.	Organic	Convnl.
Histeridae	1	0.4	0.4	1.2	0.4	0.4	0.4	1	---	0.25	---	---
Staphylinidae	0.6	1	3	1.6	0.8	0.6	2.4	---	1.6	---	1.4	---
Psephenidae	2.4	---	0.2	0.2	0.8	---	---	0.25	0.6	0.2	---	---
Elateridae	0.6	---	1.8	---	0.8	---	0.4	---	0.8	---	2.6	0.2
Carabidae	0.6	---	---	0.4	0.2	---	0.2	---	3	---	---	---
Cucujidae	2.8	---	1.2	---	1.8	0.2	3.4	---	---	---	4.2	---
Tenebrionidae	---	0.4	---	---	1	0.2	---	---	---	---	---	---
Silphidae	---	---	---	0.8	---	---	0.6	---	---	---	0.4	0.2
Coccinellidae	---	---	---	---	0.2	---	---	---	---	---	---	---
Scarabidae	---	---	---	---	---	---	0.2	---	---	---	---	---
Dermestidae	---	---	---	---	---	---	0.2	0.25	---	---	---	---

Table - 2 : Indices of diversity and similarity of coleopterans at species and family levels in organic and conventional tea plots for six observation (May-September, 2001).

Date	Shannon's general diversity index			
	Species level		Family level	
	Organic	Conventional	Organic	Conventional
28.5.2001	0.68	0.43	0.68	0.43
18.6.2001	1.18	0.61	1.18	0.61
2.7.2001	0.59	0.59	0.59	0.56
27.8.2001	0.79	0.39	0.79	0.39
3.9.2001	0.58	0.29	0.51	0.29
30.9.2001	0.58	0.3	0.49	0.3

Date	Sorenson's index of similarity	
	Organic vs conventional	Organic vs conventional
	Species level	Family level
28.5.2001	0.44	0.44
18.6.2001	0.6	0.6
2.7.2001	0.67	0.67
27.8.2001	0.27	0.36
3.9.2001	0.28	0.33
30.9.2001	0.5	0.67

The pitfall trap sampling method used in the present study was found to be a useful tool in assessing biodiversity and the population changes of different guilds of ground-dwelling arthropod fauna inhabiting the tea-growing plots. Such a method has also been found to be very helpful in knowing the occurrence of certain species, in providing an idea of the species composition of a particular locality, and in classifying different habitats and their health, based on the arthropod communities (Eyre and Luff, 1990; Eyre *et al.*, 1990).

The ecological roles of the arthropods trapped require an understanding of their collective contribution to the ground-level ecology in two different situations, organic and conventional tea plots. Coleopterans predominates the arthropod community at ground level either as predators or as scavengers of decaying animals and/or vegetable matter (Raw, 1967). The members of other arthropod orders collected in the pitfall traps could broadly be classified under four feeding guilds. Herbivores were mainly from Orthoptera,

Homoptera, Lepidoptera and Diptera. Saprophages by and large belonged to Isoptera, Collembola and non-insects such as mites, diplopods and isopods. A good number of omnivores known for their phytophagic as well as predatory/parasitic habit belonged to Hymenoptera, Dermaptera and Heteroptera. Predominantly predatory or carnivorous members belonged to Neuroptera, Scolopendromorpha and Araneae (Arachnida), besides families of ground beetles (Carabidae) and rove beetles (Staphylinidae).

The functional significance of soil animals in fragmentation of litter is well established (Weiser, 1984). However, it may be hampered due to various anthropogenic factors and pesticide pollution in agricultural soil. In the present study, by and large, the diversity and numerical abundance of soil-fauna was found to be more in the organic tea plot than in the conventionally maintained one.

The natural environmental conditions occurring at the ground level of organic plot might be favorable for maintenance of diversity and population increase, while the same were less abundant due to the detrimental effects of the inorganic inputs (fertilizers and pesticides) applied in the conventionally maintained tea plot. It was also observed that the neuropteran predators occurred exclusively in the organic tea plot. Their absence in the conventional plots was not only due to killing effects of the pesticides on the non-target organism, but also due to uncertainty of prey (pest) availability.

The idea of using some higher taxa as a surrogate system for analyzing biodiversity as a substitute for studying species diversity had earlier been proposed by Gullan and Cranston (1994); that indicated that surrogacy-based method of estimating species richness was founded in the relationship between the numbers of species and the numbers of supra-specific taxa, such as family. Positive relationships between the number of species and higher taxa in different areas have been documented for a variety of extant groups (Williams and Gaston, 1994), which have also been found to be true in the present study of coleopteran fauna, as was evident from the analysis of the pitfall-trap catch.

The principal advantage of an approach of estimating species richness based on higher taxon richness is that, once an overall relationship between species richness and higher taxon richness has been established, it is only necessary to directly determine the numbers of higher taxa in other areas. The number of higher taxa in areas can be documented more rapidly than the number of species simply because there are fewer of them and they can be enumerated more readily (Gaston, 1996).

Speight *et al.* (1999) and Gadagkar *et al.* (1990) had recommended the use of morphospecies, 'recognizable taxonomic units' (RTUs) or 'operational taxonomic units' (OTUs) to overcome the taxonomic difficulties of identification at species level. Using graphical analysis as well as diversity/similarity indices of the present data on order Coleoptera, it was observed that the biodiversity/similarity at the morphospecies level was also reflected at the family level. Thus, it was inferred that family level diversity study could be helpful in understanding diversity even at species level. Moreover the family category is especially useful since each family usually presents a general facet that is recognizable at a glance and most of its species occupy a similar niche in particular communities (Mayr and Ashlock, 1991). The surrogate system is of advantage, in that it can be used as an alternative to the more time consuming and expert-dependent system of classifying and identifying the arthropod fauna.

There are significant levels of biological organization above the level of species and that the dynamics which occur at these levels as well as the processes responsible for the existence of these levels are fundamental to the expression of biodiversity. An ecological community is clearly a higher level organization, and the mechanics responsible for production of these levels are variously capable of influencing it if not regulating the biodiversity (Drake *et al.*, 1996).

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