Chapter II
REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1 Overview of Eri Culture

Ericulture is practiced in Assam, Meghalaya, Arunachal Pradesh, Nagaland and Manipur of North East India. In recent days, eri culture is being introduced in different non-traditional states like Andhra Pradesh, Gujarat, Madhya Pradesh, Chhattisgarh, Tamil Nadu, Karnataka, Maharashtra, Uttaranchal, Uttar Pradesh, Jharkhand, Bihar, West Bengal, Odisha and Sikkim. The largest share (above 90%) of eri silk production of India is contributed from North Eastern region of India and it shares 77% of the total non-mulberry raw silk produced in the country.

Indian's north eastern region harbours about a dozen wild silk producing insects which are important not only from biological point of view, but also from aesthetics. The valuable wealth is now fast declining and the world at large is likely to lose the precious germplasms (Chowdhury, 2004). Brahmaputra valley of Assam and its adjoining foot hills in the Sub-Himalayan belt is believed to be the native place of eri. The silkworm name 'Eri' derives from the Assamese word *'Era'* which means castor the main food plant of eri silkworm. The history of silk in Brahmaputra valley can be traced back to the vedic literature (around 1600 BC). Silk from Brahmaputra valley was marketed to Mugadh, Mithila and Brahmadesh during 1340 BC. During the period of great king Bhaskar Barman of Kamrup (600-650 AD.), silk trade from Assam to North India was at peak stage. Budhist visitor, Hieun Tsang mentioned Assam in his writing Suvarnkusi (Sualkuchi) as an important silk producing centre. King Harsha Vardhana of Kaunuj imported silk from Assam for making his royal dresses. Later during 1492-1520 AD, the great 'Ahom' King Sarna Narayan of Sivasagar patronized silk industry of Assam (Sarmah *et al.,* 2013a).

Piegler (1992) opined that *Samia ricini* is derived from *S. canningi*. The form has evolved due to artificial selection after century's selfing as a consequence of continuous stress on yield of silk. The species might have derived from the Japanese lepidopteran insect *S. pryeri* as both of them have equal number of chromosomes (i.e. 2n=14). Genes from other species might have been introduced in a gradual manner to *S. ricini* with the passing of time after several generations of inter-breeding (Chowdhury, 2004). Further, the structure of the genitalia, wing pattern and chromosome number demonstrates that *S. ricini* (Donovan) is derived from its wild form, *S. canningi* (Hutton). Several eco-races like Borduar, Titabar, Khanapara, Nongpoh, Mendipathar, Dhanubhanga, Sille, Kokrajhar, Diphu, Genung, etc. of eri silkworm are available in North Eastern region of India (Sarmah *et al*., 2002). Depending upon larval colours and markings, six pure line strains were isolated from Borduar and Titabar eco races like Yellow Plain, Yellow Spotted, Yellow Zebra, Greenish Blue Plain, Greenish Blue Spotted and Greenish Blue Zebra (Plate 6). Eri silk is unique among other silks for its typical quality of white soft yarn possessing thermal properties and branded as "Ahimsha or Non-Violent Silk" as pupa is not killed during yarn extraction process (Ahmed and Rajan, 2011).

The eri silk worm is the hardiest species among all commercially silk producing insects since it can be reared in indoor conditions successfully in different adverse climatic conditions and feeds on the diverse food plants which are either planted systematically in the farmers' field or available in the natural forests. However, the climate changes in the recent years has badly affected the industry which is contributed by manmade interventions like deforestation, rapid industrialization and urbanization, inorganic chemical based farming system and environment pollution, etc.

Eri-silkworm, *S. ricini* (Donovan) is fully domesticated, multivoltine and highly polyphagous in nature feeding on a number of host plants *viz*., Castor, (*Ricinus communis* L..), Kesseru (*Heteropanax fragrans* (Roxb.) Seem), Tapioca/Cassava (*Manihot esculanta* Crantz), Korha (*Sapium eugeniifolium* Buch-Ham), Payam (*Evodia flaxinifolia* Hook), Borpat (*Ailanthus grandis* Prain), Borkesseru (*Ailanthus excelsa* Roxb), Gulancha (*Plumeria acutifolia* (Poir)), Papaya (*Carica papaya)*, Jatropha (*Jetropa curcas* L.) and several others. Castor is the primary food plant of eri silkworm considering the shorter larval period, higher shell weight and fecundity compared to other food plants. Castor grows almost as a weed in desolate places, by the side of rivers, stream or as backyard crop. The leaf is more valued than the seed unlike in other states of India (Chowdhury, 1968). The non-mulberry (vanya) silk industry is depending primarily on the productivity of forest eco-system. The vanya silkworm germplasms have several idiotypes and wild counterparts in nature. Due to their strong endemism, the meta-population structures of these wild silkworms are highly sensitive to the present biodiversity crisis contributed deforestation, fragmentation of forests land, environmental pollution and climate changes (Ahmed, 2012; Ahmed *et al.*, 2012). Hence, though castor is considered as primary food plant in ericulture, the sector could not emerge as a commercially viable venture providing livelihood security to poor landless farmers and forest dwellers. In view of this, the host tree species of genus *Ailanthus* (i.e., *excelsa*, *grandisa*, *altissima* and *malabarica*) are very essential substitutes instead of castor shrub for increasing the production of cocoon (Chowdhury, 2004).

2.2 Types and distribution of *Ailanthus* species

Ailanthus is a perennial tree species. *Ailanthus* (derived from *ailanto*, an *Ambonese* word probably meaning "tree of the gods" or "tree of heaven") is a genus of trees belonging to the family Simaroubaceae, in the order Sapindales (formerly Rutales or Geraniales). The genus is native from East Asia south to northern Australasia. They are fast-growing deciduous trees growing up to 25-45 m tall, with spreading branches and large (40-100 cm) pinnate leaves with 15-41 long pointed leaflets, the terminal leaflet normally present, and the basal pairs of leaflets often lobed at their bases. The number of species is disputed, with some authorities accepting up to ten species, while others accept six or fewer. Four to five species are available in India, which are distributed throughout the country. Borpat, *A. grandis* Prain is widely distributed in the foothills of Himalayan range of North Eastern Region more specifically of Arunachal Pradesh and Nagaland states. During the period of investigation, it was recorded in the districts of Tinsukia, Sonitpur, North Lakhimpur, Bodo Territorial Council, Dibrugarh, Sivasagar and Jorhat district of Assam. Whereas in Arunachal Pradesh, the species is found in the Chessa forest of Papumpare district, West Siang, Lower Subansiri and West Kameng districts. *A. grandis* is a lofty tree (30-45 m in height), growing in India, Vietnam, Thailand and China (Nooteboom, 1962; Hegi, 1975; Basak, 1980).

Borkesseru, *A. excelsa* is found almost in all the states of the country namely, N.E. States, Odisha, West Bengal, Odisha, Tamil Nadu, Andhra Pradesh, Tamil Nadu, Gujarat, Rajasthan, Uttar Pradesh, Delhi UT, Bihar, Maharashtra, etc. *A. excelsa* is a lofty deciduous tree, indigenous to Indian peninsula and grows almost throughout the tropical and subtropical parts of the country especially in the dry tracts. It grows well in arid, semi arid and semi-moist regions (Chaturvedi, 1956).

Ailanthus is a genus of tall, leafy trees, widely distributed in Indo-Malay, Japan, China and Australia. The genus is noted for its antidysentric and antidiarrhial properties (Chopra *et al*., 1956). Different species of the genus are *A. glandulosa* in China and Malay Peninsula, (leaflets very coarsely toothed at the base and filaments several times exceeding the anther), *A. malbarica* in Indo-China (leaflets entire and filaments larger than anther) and *A. excelsa* in India (leaflets very coarsely toothed and filaments shorter than anther) (Lavhale and Mishra, 2007). *A excelsa* Roxb. belonging to family Simaroubaceae which is defined in Engler's Syllabus consists of six subfamilies with 32 genera and over 170 arboreous or shrubby species (Kumar, Dinesh *et al*., 2010).

Several species of lepidoptera utilize the leaves of *Ailanthus* as food, including the Indian moon moth (*Actias selene*) and the common grass yellow

(*Eurema hecabe*). In North America, the tree is the host plant for the *ailanthus* webworm (*Atteva aurea*), though this ermine moth is native to Central and South America and originally used other members of the mostly tropical Simaroubaceae as its hosts.-In its native range *A. altissima* is associated with at least 32 species of arthropods and 13 species of fungi (Zheng Hao *et al.*, 2004). The number of species of *Ailanthus* is disputed, with some authorities accepting up to ten species, while others accept six or fewer. Major species of *Ailanthus* are presented in the Table 3.

Table 3: Different *Ailanthus* species and its worldwide distribution

Ailanthus species	Distribution
Ailanthus altissima (Mill) Swingle [Syn. *Ailanthus glandulosa* (Desf)]	Northern and central mainland China, Taiwan, arguably the best known species
Ailanthus excelsa (Roxb.)	India and Sri Lanka
Ailanthus grandis Prain.	India
Ailanthus integrifolia Lamk. (ssp.) Calycina	New Guinea and Queensland, Australia
Ailanthus malabarica DC.	Southeast Asia
Ailanthus triphysa (Dennst.) Alston	Northern and eastern Australia
Ailanthus vilmoriniana Dode	Southwest China

2.3 Biology of eri silkworm

The life-cycle of eri silkworm has four stages- egg, larva, pupa embedded inside the cocoon and moth or adult. A complete life-cycle lasts about 44 days in summer and about 85 days in winter. The silkworm is multivoltine in nature having five to six generations in a year (Chowdhury, 1982). The eggs are oval in shape with a hard chitinous chorion of candid white colour with colourless glue and devoid of any markings (Plate I). The egg colour generally changed from candid white to bluish just before hatching. Micropyle placed in a slight depression at one extremity of the horizontal axis. The pattern of follicular imprints is very distinct. Cells are polygonal, inter-cellular space small and respiratory spines in between the cells (Jolly *et al.,* 1979; Sarmah, 1992).

The larva hatches out from the eggs generally in the morning hours after 9 to 10 days in summer and 14 to 15 days in winter at normal temperature. The larva is typically cruciform and has a hypognathus head with biting and chewing type mouth parts. The newly hatched larva is greenish yellow in colour, elongated and cylindrical in shape measuring about 5.0 x 1.0 mm and weighs about 1.5 mg. The body colour changes gradually to pure yellow by the end of the third day. From third instar onward the body colour changes depending upon races. The fully mature larva which measures about 7.0 x 1.5 cm is translucent and covered with white powdery substances (Dutta, 2000). The larva moults or shed off their skins four times and complete the larval period in five different instars. During moulting period they don't feed. Unlike other non-mulberry silkworm, eri silkworm does not eat the empty egg shell on hatching or the cast off skin after moulting (Jolly *et al.*, 1979). They have a very poor griping power. The mature larvae produce a rustling sound when rolled between the fingers and have tendency to move upward and away from the foliage.

The larvae are reared for production of silk which is the prime output of the culture. Silk is a secretion of a pair of large silk gland which corresponds to salivary glands of insects. The single gland is a long, tubular structure folded in a characteristic manner. The silk gland is the largest organ of the body and occupies almost the whole body of the mature larva (Dutta, 2000). There are large secretary cells and spinning apparatus with press and tube. Unlike mulberry silk gland, there is no "Lyonnet's" gland in eri larva and the cells secrete fibroin and sericin together whereas in mulberry silk glands, different layer of cells secrete fibroin and sericin (Chowdhury, 1982).

The larva attains maturity at the end of fifth instars. At this stage larva stops feeding and empties its alimentary canal by passing out the last excreta. The mature larva searches a suitable place on the mountage or dry leaves for spinning cocoon. The spinning starts with to and fro movement of the head. First the base of the cocoon is formed followed by the formation of sides and finally the upper part, but during these operations the head movement is irregular. The cocooning is completed in three to five days and the larva gets deeply embedded in the thick layers of silk. Eri cocoons are elongated, soft, flossy peduncleless, open mouthed and exhibit colour polymorphism being creamy white and brick red. The shape and size of cocoons vary according to host plant, season and type of cocoonage (mountage) used. The wild eri cocoons are compact, elongated, both end tapering, open mouthed, tight with a strong peduncle and dull chocolate in colour.

The larva metamorphoses inside the cocoon into pupa or chrysalid. The pupae are of obtect adectious type and brown in colour. The pupa is a prelude to moth stages with the appendages of future moth such as compound eyes, wings, antennae, legs, genitalia etc. The female pupae are heavier than the male. The colour of pupae turns black before emergence of moth and there is harp movement of posterior portion of the abdomen (Dutta, 2000).

The eri silk moths are stout, brownish or blackish in colour and covered with white scales. The male moth is smaller than the female. Wings are of two pairs, buff coloured with white coloured strips in the marginal portion. Wings are covered with scales of different colour and shape. Veins are prominent and visible from both sides. Forewings are longer and narrower than hind wings. The forewings of both sexes are more or less similar in structure and colour pattern. The characteristics of anti median line are bright chocolate colour with a white border on either side and almost run through the centre. The postmedian line is black with a single dull grey border on either side. A conspicuous black spot, the plerostigma with a whitish tinge is present at the top of the wing apex. In addition the wing has a few white oblique lines (Jolly *et al.*, 1979; Sarmah, 1992). The emergence of moth takes place after about two weeks of pupal stage. The maximum emergence of moth is observed during early morning hours. The male moths emerge earlier than female moths. Soon after emergence the moth emit a creamy opaque liquid and within an hour they become fully active and prepare for mating. After coupling, each paired moths are tied in the Kharika for oviposition. The decoupling is done after 6 hours of mating and female moths start laying eggs after two to three hours of decoupling and continue for three to four days, but eggs laid during first two days are considered for rearing. The life cycle of the eri silk is presented in the Plate.1

2.4 Eri silkworm rearing on *Ailanthus* and other food plants

Lefroy and Ghosh (1912) reported that castor *Ricinus communis* L. as the main host plant of eri silkworm. Further, Arora and Gupta (1979) listed 30 plant species as host plants of Eri silkworm *viz*. castor (*Ricinus communis* L.), Kesseru (*Heteropanax fragrans* Seem), Tapioca (*Manihot utilissima* Phol.), Barkesseru (*Ailanthus excelsa* Roxb.), Physic nut (*Jatropha curcas* L.), Payam (*Evodia flaxinifolia* Hook.), Korha (*Sapium cugeniaefolium* Ham.), Barpat (*Ailanthus grandisprain* Rozb.), Godly tree (*Ailanthus altissima* Miller.), Papaya (*Carica papaya* Linn.), Jaunshar (*Xanthoxylum alatum* Roxb), Masuri (*Coriaria nepalensis* Wall.), Thebow-lata (*Hodgsonia heterochita* Hk.) China sumac (*Ailanthus triphysa* Alston.), Gulancha (*Plumeria acutifolia* Poir), Bajramoni (*Zanthoxylum rhesta* Roxb.), Chinese tallow tree (*Sapium sebiferum* Roxb.), Timur (*Zanthoxylum armatum* Roxb.), Jhari-udal (*Sterculia villosa* DC) and Catappa (*Terminalia catappa* L.). Among different host plants Castor was the principal food plant followed by Kesseru, Payam and Tapioca in order of choice of food plants (Sarkar, 1980).

The literature citing evaluation of *Ailanthus* tree in regards to rearing of eri silkworm is very much limited. Most of the studies have been conducted in utilization of *Ailanthus* plant extracts in medicine or in agro-forestry sectors. In Chinese literature, reports were available on the use of *Ailanthus* leaves for the silk industry in Shantung Province, and for medicine since the Tang Dynasty for the production of Shantung or pongee silk (Y. Chen, 1933). *Ailanthus* is cultivated for feeding the worms of a special kind of silk moth (*Attacus cynthia* Drury) for the production of "Shantung silk" in the Shantung Province of China (Y. Chen, 1933). This moth was later introduced to Eastern United States and feeding on *Ailanthus altissima* Mill (Peter P. Feret, 1985).

In national level, only reports on *Ailanthus* as host plant of eri silkworm are available, while no works have been conducted on proper germplasm maintenance and identifying the superior species of *Ailanthus* based on rearing performance and other economic traits. Phukan *et al.* (2006) reported *A. grandis* Prain (Simaroubaceae- Quassia family) as an alternate food plant of eri silkworm. Use of *excelsa* leaf at the last two stages save eri leaf requirement as the worm is a glutton (Chowdhury, 2006). Ministry of Forest & Environment, Govt. of India has permitted to utilize *A. altissima*, *A. grandis* and other *Ailanthus* species for rearing of eri silkworm. The genus *Ailanthus* is not only perennial but also a valuable asset for social forestry and plantation development programme (Chowdhury, 1982). Chowdhury (2006) reported that four species of *Ailanthus* exist in India, such as, *A. excelsa, A. grandis* (barpat), *A. altissima*, and *A. malabarica.* Sarmah *et al.* (2006) reported that *in situ* conservation of *Ailanthus grandis* has carried out in Kimin area of Arunachal Pradesh. Narayanswamy *et al.* (2006) studied the activity of amylase in digestive juice and hemolymph in eri silkworm and reported that the relationship was stronger for both castor and borkesseru than tapioca. Hence, Borkesseru could be exploited as suitable substitute for castor to rear eri silkworm. Kumari *et al.* (2009) also reported that the amylase activity of eri silkworm fed on borkesseru (*Ailanthus excelsa*) was at par with those fed on castor.

Joshi and Mishra (1979) analyzed the comparative live weight of larvae, cocoons, pupae and silk content of eri silkworms which were reared completely on castor leaves and on interchanged castor and tapioca leaves and recorded maximum weight of larval, pupal, cocoon and shell weights on CC (first to fifth instar on castor) diet than on CT (first to third on castor and fourth to fifth on tapioca), TC (first to third on tapioca and fourth to fifth on castor) and TT (first to fifth on tapioca) diet. Devaiah *et al.* (1988) also studied the effect of castor, tapioca and their combinations on the growth and development of larvae and cocoon characters of eri silkworm and reported that the larval weight, pupal weight and shell ratio percentage were superior when the larvae were fed with tapioca up to second instar and subsequently on castor. The larvae fed on castor alone showed higher cocoon, pupal and shell weight and shell ratio percentage compared to the larvae fed on tapioca alone.

2.5 Use of *Ailanthus* in medicine & other industries

The methanolic extract of *Ailanthus excelsa* (Roxb) leaves, a plant used in Egyptian traditional medicine was investigated for phyto-chemical constituents and some biological activities (Ataa Said *et. al*, 2010). Gülriz Bayçu *et.al* (2008) studied the biochemical constituents and protein presence pattern in *A. excelsa* and *A. grandis*.

A. excelsa plant is used in the Indian school/system of medicine for variety of purposes (Kirtikar and Basu, 1995). *A. excelsa* is used to cure wounds and skin eruption and also in the indigenous system of medicine in febrifuge, bronchitis, asthma, diarrhea and dysentery (British Pharmacopoeia 1988). Previous studies on phyto-chemical of *A. excelsa* have demonstrated the presence of quassinoids, flavonoids, alkaloid, terpenoids, and proteins (Ogura *et al.* 1977; Loizzo *et al.* 2007; Joshi *et al.* 2003a; Sherman *et al.* 1980; Nag and Matai 1994). *A. excelsa* extracts and some isolated compounds have demonstrated medicinal properties such as significant antileukemic, antibacterial, antifungal and antifertility activities (Ogura *et al.* 1977; Dhanasekaran *et al.* 1993; Shrimali *et al.* 2001; Joshi *et al.* 2003b). The male tree of *A. excelsa* possesses a glucoside that cures malaria (Chowdhury, 2006). Methanolic extract from stem bark of *A. excelsa* possesses significant properties of bronchodilating, mast cell stabilizing, and adaptogenic activity, suggestive of its potential in prophylaxis and management of asthma

(Kumar, D. *et al.* 2010). The leaves of *A. excelsa* are used for the preparation of lotion for scabies and the root bark is used for epilepsy and asthma (Jat *et al*, 2011).

Ardu (*Ailanthus* sp.) play a pivotal role in management of land resources and securing livelihoods of economically poor people through agroforestry system. Ardu used for many purposes including timber, fuel, fodder, ethno-medicine, etc. make it a multipurpose species. The species found to be very much compatible and adapted to harsh arid ecosystem is one of the main species which act as an integrated component in farming systems of farmers, and especially during the drought. *Ardu* could be one of the important tree species for the drought period and in arid ecosystem to sustain the productivity sheep, goats and other animals, and secure livelihoods pastoralists and farmers. The timber of the tree is considered good for manufacturing plywood. The pulp is obtained from debarked wood and used in paper industry as a substitute for aspen and for printing papers. It improves the surface quality of paper (Jat *et al.,* 2011).

In traditional medicine in Nepal and Northern India, the gum-resin from the trunk of *A. grandis* (known as 'Gokuldhup') has been used for the treatment of boils and pimples (M. P. Manandhar, personal communication). Wood of *A. altissima* and *A. grandis* is used for general construction purposes and in the production of tea chests, matches, laminated board and fancy items (Dastur, 1951). Stem bark of *A. excelsa* is traditionally useful as anti-fertility in tribals of Nilgiri region (Abraham, 1981). In Africa, *A. excelsa* plant is used to treat cramps, gonorrhea, epilepsy, tape worm infestation and high blood pressure (Medical Economics Company, 1998; Sharma, 1996). In Konkan, the juice of the leaves is usually administered in khir, or the juice of the fresh bark is given with coconut juice and treacle or with aromatics or honey to stop after pains (Nadkarni, 1976). The bark of *A. triphysa* and *A. malabarica* is considered as a valuable tonic, febrifuge and carminative (Kirtikar and Basu, 1933). Decoction of the bark is reported to be given in typhoid and constipation (Kirtikar and Basu, 1933; Chopra *et al.* 1956). Root bark of *A. malabarica* DC is also used in the case of snake bite; it is bruised and kept in gingelly oil and is given internally as an antidote especially in case of cobra bite (Dastur, 1951). Enormous works have been carried by researchers for utilization of the plant in traditional medicine. The biochemical components extracted and tested have also evidenced the authenticity of the claims and ITKs documented in global arena. In nutshell, the plant is a really a Tree of Heaven which is having anti-fungal, anti-bacterial, anti-protozoan and anti-viral properties with excellent nutritive status useful for human as well as animals.

2.6 Primary and secondary metabolites in the food plants of eri silkworm

2.6.1. Basic feature of primary and secondary metabolites of plants

Metabolites are compounds synthesized by plants for both essential functions such as, growth and development (primary metabolites), and specific functions, such as pollinator attraction or defense against herbivore (secondary metabolites). Metabolites are organic compounds synthesized by organisms using enzyme-mediated chemical reactions called metabolic pathways. Primary metabolites have functions that are essential to growth and development and are therefore present in all plants. In contrast, secondary metabolites are variously distributed in the plant kingdom, and their functions are specific to the plants in which they are found.

Secondary metabolites are often colored, fragrant, or flavorful compounds and they typically mediate the interaction of plants with other organisms. Such interactions include those of plant-pollinator, plant-pathogen, and plant-herbivore.

Primary Metabolites:

Primary metabolites comprise many different types of organic compounds, including, but not limited to, carbohydrates, lipids, proteins, and nucleic acids. They are found universally in the plant kingdom because they are the components or products of fundamental metabolic pathways or cycles such as glycolysis, the Krebs cycle, and the Calvin cycle. Because of the importance of these and other primary pathways in enabling a plant to synthesize, assimilate, and degrade organic compounds, primary metabolites are essential. Examples of primary metabolites include energy rich fuel molecules, such as sucrose and starch, structural components such as cellulose, informational molecules such as DNA (deoxyribonucleic acid) and RNA (ribonucleic acid), and pigments, such as chlorophyll. In addition to having fundamental roles in plant growth and development, some primary metabolites are precursors (starting materials) for the synthesis of secondary metabolites.

Secondary Metabolites

Secondary metabolites largely fall into three classes of compounds: alkaloids, terpenoids and phenolics. However, these classes of compounds also include primary metabolites, so whether a compound is a primary or secondary metabolite is a distinction based not only on its chemical structure but also on its function and distribution within the plant kingdom. Many thousands of secondary metabolites have been isolated from plants, and many of them have powerful physiological effects in humans and are used as medicines. It is only since the late twentieth century that secondary metabolites have been clearly recognized as having important functions in plants. Research has focused on the role of secondary metabolites in plant defense. This is discussed below with reference to alkaloids, though it is relevant to many types of secondary metabolites.

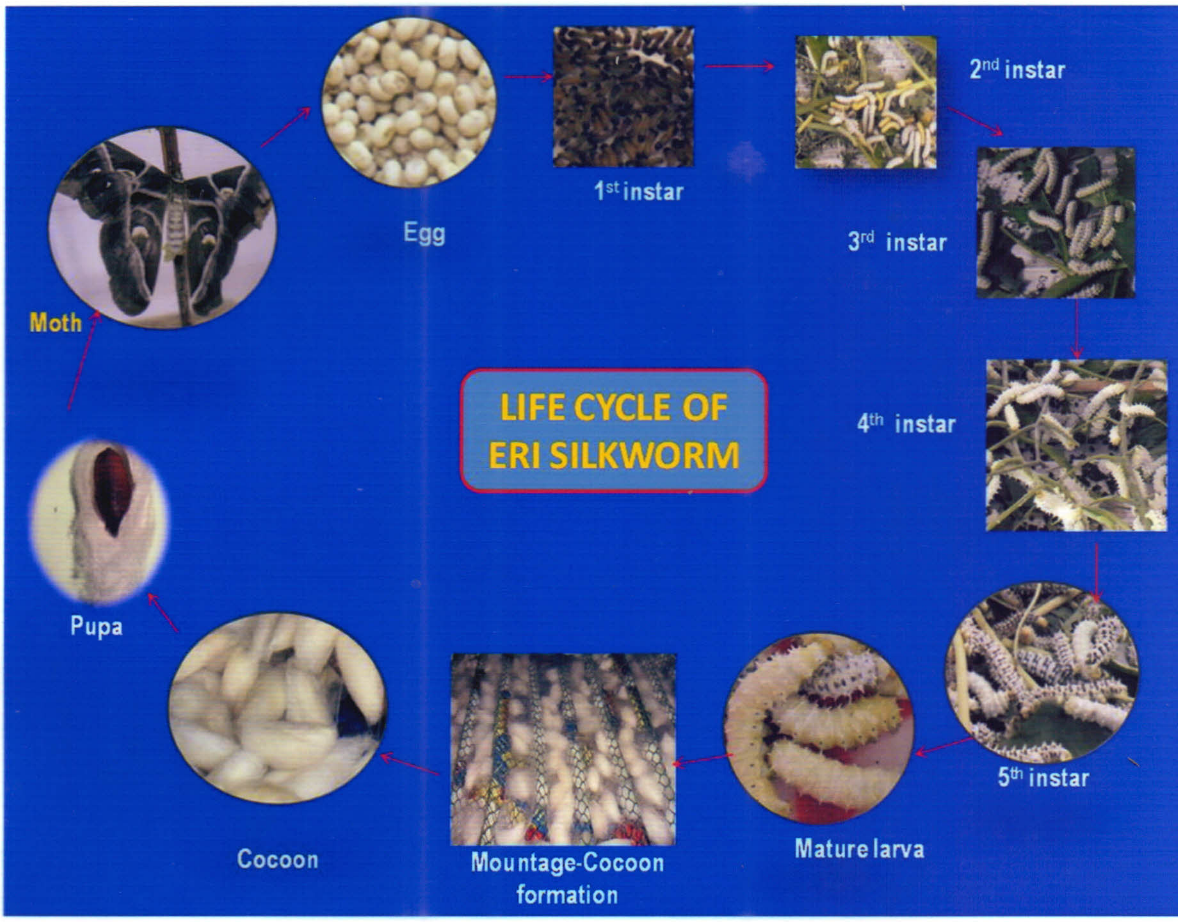


Plate. 1 Life cycle of eri silkworm

2(A)

2(B)

Plate . 2 (A& B.) Borkesseru (*Ailanthus excelsa* Roxb.) plant

3(A)

3(B)

Plate . 3 (A&B). Borpat (*Ailanthus grandis* Prain.) plant and leaves

Plate . 4. Kesseru , *Heterpanax fragrans* (Roxb.) plant

Plate . 5. Castor (*Ricinus communis L.*) plant

Alkaloids

Alkaloids are a large group of nitrogen-containing compounds, examples of which are known to occur in approximately 20 percent of all flowering plants. Closely related plant species often contain alkaloids of related chemical structure. The primary metabolites from which they are derived include amino acids such as tryptophan, tyrosine, and lysine. Alkaloid biosynthetic pathways can be long, and many alkaloids have correspondingly complex chemical structures. Alkaloids accumulate in plant organs such as leaves or fruits and are ingested by animals that consume those plant parts. Many alkaloids are extremely toxic, especially to mammals, and act as potent nerve poisons, enzyme inhibitors, or membrane transport inhibitors. In addition to being toxic, many alkaloids are also bitter or otherwise bad-tasting. Therefore, the presence of alkaloids and other toxic secondary metabolites can serve as a deterrent to animals, which learn to avoid eating such plants. Sometimes domesticated animals that have not previously been exposed to alkaloid-containing plants do not have acquired avoidance mechanisms, and they become poisoned.

For example, groundsel contains the alkaloid senecionine, which has resulted in many recorded cases of livestock fatalities due to liver failure. More frequently, over time, natural selection has resulted in animals developing biochemical mechanisms or behavioral traits that lead to avoidance of alkaloid-containing plants. In other, more unusual cases, animals may evolve a mechanism for sequestering (storing) or breaking down a potentially toxic compound, thus "disarming" the plant.

For instance, caterpillars of the cinnabar moth can devour groundsel plants and sequester senecionine without suffering any ill effects. Moreover, the caterpillars thereby acquire their own weapon against predators: the plant-derived alkaloid stored within their bodies. Over time, plants acquire new capabilities to synthesize additional defense compounds to combat animals that have developed "resistance" to the original chemicals. This type of an "arms race" is a form of co evolution and may help to account for the incredible abundance of secondary metabolites in flowering plants.

Medicinal Alkaloids

Many potentially toxic plant-derived alkaloids have medicinal properties, as long as they are administered in carefully regulated doses. Alkaloids with important medicinal uses include morphine and codeine from the opium poppy and cocaine from the coca plant. These alkaloids act on the nervous system and are used as painkillers. Atropine, from the deadly nightshade plant, also acts on the nervous system and is used in anesthesia and ophthalmology. Vincristine and vinblastine from the periwinkle plant are inhibitors of cell division and are used to treat cancers of the blood and lymphatic systems. Quinine from the bark of the cinchona tree is toxic to the Plasmodium parasite, which causes malaria, and has long been used in tropical and subtropical regions of the world. Other alkaloids are used as stimulants, including caffeine, present in coffee, tea, and cola plants (and the drinks derived from these plants), and nicotine, which is present in tobacco. Nicotine preparations are, paradoxically, also used as an aid in smoking cessation. Nicotine is also a very potent insecticide. For many years ground-up tobacco leaves were used for insect control, but this practice was superseded by the use of special formulations of nicotine. More recently the use of nicotine as an insecticide has been discouraged because of its toxicity to human.

Terpenoids

Terpenoids are derived from acetyl coenzyme A or from intermediates in glycolysis. They are classified by the number of five-carbon isoprenoid units they contain. Monoterpenes (containing two C5- units) are exemplified by the aromatic oils (such as menthol) contained in the leaves of members of the mint family. In addition of giving these plants their characteristic taste and fragrance, these aromatic oils have insect-repellent qualities. The pyrethroids, which are monoterpene esters from the flowers of chrysanthemum and related species, are used commercially as insecticides. They fatally affect the nervous systems of insects while being biodegradable and nontoxic to mammals, including human.

Diterpenes are formed from four C5-units. Paclitaxel (commonly known by the brand name Taxol), a diterpene found in bark of the Pacific yew tree, is a potent inhibitor of cell division in animals. At the end of the twentieth century, paclitaxel was developed as a powerful new chemotherapeutic treatment for people with solid tumors, such as ovarian cancer patients. Triterpenoids (formed from six C_5^- units) comprise the plant steroids, some of which act as plant hormones. These also can protect plants from insect attack, though their mode of action is quite different from that of the pyrethroids. For example, the phytoecdysones are a group of plant sterols that resemble insect molting hormones. When ingested in excess, phytoecdysones can disrupt the normal molting cycle with often lethal consequences to the insect. Tetraterpenoids (eight C_5^- units) include important pigments such as beta-carotene, which is a precursor of vitamin A, and lycopene, which gives tomatoes their red color. Rather than functioning in plant defense, the colored pigments that accumulate in ripening fruits can serve as attractants to animals, which actually aid the plant in seed dispersal. The polyterpenes are polymers that may contain several thousand isoprenoid units. Rubber, a polyterpene in the latex of rubber trees that probably aids in wound healing in the plant, is also very important for the manufacture of tires and other products.

Phenolic Compounds

Phenolic compounds are defined by the presence of one or more aromatic rings bearing a hydroxyl functional group. Many are synthesized from the amino acid phenylalanine. Simple phenolic compounds, such as salicylic acid, can be important in defense against fungal pathogens. Salicylic acid concentration increases in the leaves of certain plants in response to fungal attack and enables the plant to mount a complex defense response. Interestingly, aspirin, a derivative of salicylic acid, is routinely used in humans to reduce inflammation, pain, and fever. Other phenolic compounds, called isoflavones, are synthesized rapidly in plants of the legume family when they are attacked by bacterial or fungal pathogens, and they have strong antimicrobial activity.

Lignin, a complex phenolic macromolecule, is laid down in plant secondary cell walls and is the main component of wood. It is a very important structural molecule in all woody plants, allowing them to achieve height, girth, and longevity. Lignin is also valuable for plant defense: Plant parts containing cells with lignified walls are much less palatable to insects and other animals than are nonwoody plants and are much less easily digested by fungal enzymes than plant parts that contain only cells with primary cellulose walls.

Other phenolics function as attractants. Anthocyanins and anthocyanidins are phenolic pigments that impart pink and purple colors to flowers and fruits. This pigmentation attracts insects and other animals that move between individual plants and accomplish pollination and fruit dispersal. Often the plant pigment and the pollinator's visual systems are well matched. Plants with red flowers attract birds and mammals because these animals possess the correct photoreceptors to see red pigments.

2.6.2 Role of primary and secondary metabolites of eri silkworm food plants

The quality of leaves provided to the worms for feeding has been considered as the prime factor influencing the production of good cocoon crop. It has been observed that growth, development and cocoon yield are influenced by the castor genotype and quality of leaves fed to the worms. Nutritional status of leaves has been considered as a major factor in the survival of non-mulberry silkworms (Pandey, 1995). Better the quality of leaves, greater would be the chances of getting the good cocoon harvest (Ravikumar, 1988). It has also been noticed that the silk ratio varies with the type of host and eri silkworm breed used for rearing (Dookia, 1980).

Moisture content of leaf plays a very important role in silkworm metabolism as it regulates the rate of ingestion by eri silkworm. It acts as diluents of nutrients, but not as a phagostimulant. Hazarika *et al.* (1994) found that, higher the moisture content of leaves, higher the blood volume in different instars of muga silkworm body, but lower the total haemocyte count and *vice versa*. Importance of moisture content and moisture retention capacity in relation to performance of mulberry silkworm was reported by Narayanaprakash *et al.* (1985) and Paul *et al.* (1992). This character again varies among genotypes of different plants as well as environment (Clarke & Townby, 1986; Roark & Quisenberry, 1977).

Sarmah *et al.* (2011) evaluated the promising castor genotype in terms of agronomical and yield attributing traits, biochemical properties and rearing performance of eri silkworm, *Samia ricini* (Donovan). Effective rate of rearing (ERR) of eri silkworm was influenced by biochemical compositions of leaves of different castor accessions. The weight of larvae and cocoons were significantly influenced by nitrogen and crude protein content of the foliages.

Significant variations were noticed for total carbohydrate content among the leaves of castor genotypes. Local genotype recorded highest carbohydrate content of 53.61 per cent. The genotypes DCS-85 (47.49%) and DCH-32 (45.16%), DCH-177 (44.60%) and Kranti (44.19%) were found next best with no statistical variations among themselves (Chandrashekhar *et al.* 2013). Similarly, the highest crude protein was recorded with local genotype (34.56%) and less with GCH-4 (13.48%).

The foliar constituents of castor, tapioca, papaya and borkesseru of eri silkworm were analyzed and significant variation observed between these food plants in their moisture, ash, total carbohydrate, total protein, calcium and magnesium contents. Tapioca has the highest protein content (27.60%) and lowest carbohydrate content (18.41%) among these food plants (Kaleemurrahman and

Gowri, 1982). Sarkar (1980) gave priority to castor among other food plants. This might be due to the higher carbohydrate (40.63%) and calcium (1.14%) contents of castor are supported by the reports of Hatano, Torri and Nakane (quoted by Tanaka, 1964).

Jayaramaiah and Sanappa (1998) revealed that in eri silkworm, *S. cynthia ricini* the larval duration, weight, survivability and effective rate of rearing have significant positive relationship with moisture, total carbohydrates, total amino acids, phosphorus, potassium, calcium and magnesium content of castor leaves. There also existed positive significant relationship between above foliar constituents and weight of cocoons, pupae, shell weight and shell ratio.

Govindan *et al.* (1992) studied the economic traits and growth indices of eri silkworm, S. *cynthia ricini* Boisd., as influenced by substitution of castor with three other food plants. The study revealed that eri silkworm reared exclusively on castor exhibited superiority in larval, cocoon and seed technological traits followed by the worms reared up to the end of the fourth instar on castor and in the fifth instar on tapioca leaves. They also worked out the growth indices of the silkworm such as growth, larval weight, larval duration, cocoon spinning, cocoon weight, silk, pupal and oviposition for different food regimens involving the combination of castor with tapioca *(Manihot utilissima), Plumeria alba* and *Ailanthus excelsa.*

Nag and Matai (1994) have reported *Ailanthus* species as good sources of protein. Gülriz Bayçu, *et al.* (2008) reported that carbohydrates and/or glycosides, condensed tannins, sterols and/or triterpenes, coumarins were present in all of the *Ailanthus* extracts, but hydrolysable tannins and saponins were absent. Alkaloids and/or nitrogenous bases were present in *A. excelsa* and *A. altissima* stem bark extracts and also in the leaf extracts of *A. altissima,* but interestingly no alkaloids and/or nitrogenous bases were observed in *A. excelsa* leaf extracts.

Type, quantity and quality of proteins, essential oils and phenolic compounds found to have effect on the feeding behaviour of silkworm on different food plants. Concentrations of major essential oils like dodecanal, decanal, caryophyllene and borneol were found to be much higher in the most preferred idiotypes of Som than in the less preferred. Phenolic compounds like 7,2',4'-trimethoxy 3,5 dihydroxyflavone and myrcetin were found to be in much higher concentrations in the most preferred types while 3',4'-dimethylquercetin, quercetin, 2'4'-dimethylmorin and morin were in much higher concentrations in the least preferred idiotypes. Fatty acids are known to be feeding stimulants for certain insects, for example, linolenic acid for *Bombyx mori*, linoleic acid for the fire ant and laurate for many insects. Kataky and Hazarika (1997) identified fifteen C_8-C_{22} fatty acids in three host plants (Som, Soalu and Mezankari) and the insect; palmitate and stearate being the most predominant. They also concluded that, the presence of laurate in higher quantity in som leaves than in those of soalu and Mejankari may determine the feeding preference of *A. assama* on the leaves of som.

Chakravorty *et al.* (2004) studied the preferential feeding and moulting behaviour of muga silkworm in three host plants (Som, Soalu and Digloti) and correlated with the biochemical parameters like moisture, crude fibre, crude protein, total soluble sugars, reducing sugars, starch, crude fat and ß-sitosterol. Their study concluded superiority of som over other host plants in terms of feeding and biochemical composition. The lipid soluble factor ß-sitosterol, which has been established as the biting factor for mulberry silkworm was also present in the food plants of muga silkworm (0.92% in Som, 0.58% in Soalu and 0.47% in Digloti) showing highly significant positive correlation which may have profound effect on the preferential feeding by this insect.

Choudhury *et al.*, (2006) reported the effect of leaf chemical constituents in producing quality cocoons and seed. They concluded that higher leaf sugar improves pre and post harvest cocoon characters and decreases the mortality, higher ascorbic acid decreases the mortality during moulting, more crude fibre adversely affect yield attributing characters and low viscous leavers are more palatable and produces healthy worms. They reported "azaindole" as a growth inhibitory substance in the som leaves for muga silkworm rearing. Mortality of silkworm was very high with higher concentration of azaindole (above 0.3 to 0.5%) in leaf. Silkworm fed with such leaves produced flimsy cocoons, less number of eggs per laying and duration of hatching were uneven. Estimation of essential oil content in the som leaf and its effect on palatability of muga silkworm indicated that Aldehyde, mostly dodecanal (1.3 – 25.8%), 11-dodecanal (1.5-16.3%), undecanal (1.3-9.5%) and decanal (2.4-25.8%) have strong positive effect on the growth and cocoon quality.

Secondary metabolites are organic compounds that are not directly involved in the normal growth, development, or reproduction of organisms. Unlike primary metabolites, absence of secondary metabolites does not result in immediate death, but rather in long term impairment of the organism's survivability, fecundity, or aesthetics, or perhaps in no significant change at all. Secondary metabolites are often restricted to a narrow set of species within a phylogenetic group. Secondary metabolites often play an important role in plant defense against herbivores and other interspecies defenses. Secondary metabolites are chemicals produced by plants for which no role has yet been found in growth, photosynthesis, reproduction, or other "primary" functions. These chemicals are extremely diverse; many thousands have been identified in several major classes (Neog *et al.* ,2011a).

Secondary metabolites play a major role in the adaptation of plants to the changing environment and in overcoming stress constraints and secondary metabolites through their diversity of functions can be involved in the nonenzymatic plant defense strategy (Edreva A. *et al.,* 2008). The apparent lack of primary function in the plant, combined with the observation that many secondary metabolites have specific negative impacts on other organisms such as herbivores and pathogens, leads to the hypothesis that they have evolved because of their protective value.

Estimation, importance and biological relevance of Secondary metabolites on the cocoon production of mulberry silkworm, *Bombyx mori* is well documented. Sterol compound, β-sitosterol and β -d-glycoside of β - sitosterol present in mulberry leaf plays the role of a biting factor (Goto *et al.*, 1965; Hamamura *et al.,* 1962). Attraction and feeding tests with detached leaves and artificial diet with different chemical stimulants revealed that a mixture of the flavonoids, myrcetin, and 7, 2', 4' trimethoxy dihydroxy flavone with sterol compound β-sitosterol elicited the most biting behavior by *A. assamensis* larvae (Neog *et al.*, 2011b). Terpene compounds, terpinyl acetate, linalyl acetate, linalool and citral act as attractants for *Bombyx mori*. Phenolic acid and cholrogenic acid is reported to have strong growth promoting action and a role in moulting of *B. mori* larvae. This acid is indispensable for normal growth of the silkworm on a synthetic diet. This acid could not be replaced by phenyl alanine, tyrosine or digydroxy – phyl-alanine, which has commonly been proposed as preserver of poly phenols. The β-sitosterol in *Moringa oleifera* may be responsible for hypolipidemic, and as well as antioxidant properties (Rajanandh *et al.,* 2010). Phenols comprise the largest group of plant secondary metabolites found in both edible and non-edible plants. These compounds have been represented to have multiple biological effects including antioxidant property.

Phytophagous insects show varying degree of association with a particular plant species or group of plants, on which they feed and these plants are referred to as host plants (food plant range) (Unni *et al.*,1996). The host plant selection behaviour or feeding preferences of the insects are largely mediated by the presence and distribution of secondary metabolites in plant is largely accepted (Fraenkel, 1959; Linn S. *et al.*, 1998). Flavonoids and related phenolic compounds act as strong feeding deterrents to many insects, they may sometimes be stimulatory to others (Neilson *et al.,* 1979; Farlane and Distler, 1982; Simmonds, 2001; Green *et al*., 2003).

The phyto-chemical investigation into the genus *Ailanthus* has afforded nearly 200 compounds with varying structural patterns such as alkaloids, terpenoids, steroids, flavonoids together with some other compounds. Among these compounds, alkaloids and terpenoids are common major constituents of the genus *Ailanthus* (Kundu and Laskar, 2010).

The role of inorganic elements in the maintenance of healthy growth of host plants as well as of silkworm is essentially an accepted phenomenon. Elucidation of quantitative role of such elements in the maintenance of growth of silkworm is also an important future area of research.

A tannin (also known as vegetable tannin, natural organic tannins or sometimes *tannoid*, i.e. a type of biomolecule, as opposed to modern synthetic tannin) is an astringent, bitter plant polyphenolic compound that binds to and precipitates proteins and various other organic compounds including amino acids and alkaloids. Condensed tannins, polymers composed of 2 to 50 (or more) flavonoid molecules, inhibit herbivore digestion by binding to consumed plant proteins and making them more difficult for animals to digest, and by interfering with protein absorption and digestive enzymes (Van Soest, Peter J., 1982).

2.7 Determination of chemical composition of silk gland and silk in relation to host plant

On the average, shell weight, length of cocoon filament, fineness of muga fibre and floss percent of muga cocoon were found to be 0.428g, 425.25m, 5.3 denier and 12.8%, respectively. Sixteen amino acids were detected in the fibroin of muga silk protein (glycine, alanine, valine, leucine, isoleucine, serine, threonine, aspartic acid, glutamine, phenylealanine, tyrosine, lysine, histidine, arginine, proline and tryptophan, of which concentration of alanine was the highest. In sericin of muga silk protein, it has also been reported to contain sixteen amino acids (instead of phenylealanine, cysteine was found, others were the same as observed for fibroin) of which concentration of lysine was the highest (Neog, K. 2011). Prasong *et al.* (2009) reported that silk cocoon composed of 31.60% sericin and 68.40% fibroin for *B. mori*, while in case of Eri it was 15.74 % sericin and 84.26% fibroin. With Lowry method, the protein content of sericin was 0.2705 mg mL^{-1} and fibroin was 0.3581 mg mL^{-1} for *B. mori* whereas Eri composed of 0.0561 mg mL^{-1} sericin and 0.0830 mg mL^{-1} of fibroin content.

However, silk fibre from 'Som' fed insects revealed higher concentration of aspartic acid, serine, glycine, phenylealanine, histidine and arginine and silk from 'Soalu' fed insects recorded a higher level of only two amino acids, namely as threonine and alanine.

Hazarika *et al.* (1998) reported that the contents of the predominant amino-acids; glycine (10.55 μg), aspartic (5.43 μg) and serine (7.15 μg) were higher in fibres obtained from cocoons of *A. assamensis* fed on 'Som', while alanine (9.46 μg) was higher in the fibres obtained from 'Soalu' and 'Mezankari'. The X-ray diffraction pattern showed the amorphous nature of the fibres obtained from the cocoons of *A. assamensis* fed on 'Soalu' and 'Mezankari', while fibres obtained from 'Som' showed amorphous bands with little tendency to two-dimensional order. Above all, the natural golden yellow hue of the fibre, which is one of the most important and commercially valuable added properties of this particular silk variety, was better retained in the fibres extracted from cocoons produced by 'Som' reared larvae.

2.8 Quantitative consumption and utilization of food by eri silkworm

In food consumption and utilization studies, the accurate quantitative and qualitative measurement of food ingestion, faeces egestion, assimilation and utilization of food and finding its relation to body substance produced (conversion efficiency) and the metabolic energy it gives are difficult to ascertain. The procedures for such studies are not only time consuming exercises but also very difficult to compute accurately.

Almost all insects are host specific and select their most preferred food in order to extract the maximum benefit out of it, although most of them eat a great many varieties (Brues, 1946). Different food plants may influence differently on food intake, efficiency of digestion and conversion of food to body biomass and finally on growth and development of insect (Waldbauer, 1968; Bhattacharya and Pant, 1976). Scriber and Slansky (1981) and Slansky and Scriber (1985) critically reviewed these aspects of nutrition ecology of insect and concluded that nutritional indices as well as growth and development of insect varied on different host plants. Generally varieties of some species may exert variable effect on the relative survival of an herbivore insect.

The quality of food which the silkworm feed directly influences the growth and development of the insect and ultimately the quantity and quality of product produced by them. Dietary efficiency of the food plants from which the silkworm derives their nutritional requirement depends upon their chemical makeup. Most of the food plants may contain all the nutritional requirements but the quantity of each nutrient may not be well balanced for proper growth and development of silkworm. Quantitative requirements for each nutrient and the required balance of nutrients for optimum nutrition may vary within and between species owing to many factors including synthetic ability of the insect and metabolic activities involving specific interrelations between certain nutrients (House, 1974). Thus, studies on quantitative and qualitative aspects of insect nutrition is much essential for better understanding of the insect-plant relationship and is of great importance for improvement of diet of the silkworm through selection of food plants. Besides, the major ecological factors also have great influence in determining the quality of the host leaves as well as nutrition, growth and development of silkworm. Literature contains a few studies on effect of different food plants in nutritional ecology and economic aspects of eri silkworm (Joshi and Mishra, 1979; Joshi, 1986; Pathak, 1988; Joshi, 1992; Dutta and Kalita, 1997).

Dutta and Kalita (1997) worked on food consumption and utilization by the larvae of eri silkworm, *Philosamia ricini* on different food plants revealed that with lower rate of food consumption, higher percentage of approximate digestibility and higher efficiency of conversion of ingested and digested food to body biomass. Castor *(R. communis)* was utilized best for better growth of the larvae. Kesseru *(H. fragrans)* was next to Castor followed by Tapioca *(M. utilissima)* and Borpat *(A. grandis)* rated as inferior food plant in terms of nutrition to the eri silkworm.

Studies on quantitative consumption and utilization of food in relation to development of silk protein biosynthesis are very inadequate. Barah *et al.*, (1989) for the first time reported consumption and utilization of food in different instars of muga silkworm by rearing it in indoor on som twigs. Their study revealed that, during 32 days of its larval life, total consumption per larva was 33.925 g of which around 63% was assimilated to the insect body. More than 80% of the total consumption took place in the fifth instar alone. The assimilation and tissue growth were positively correlated with the amount of food consumed whereas approximate digestibility was negatively correlated. Efficiency of conversion of ingested and digested food increased in the first four instars and declined in the fifth instar. In food consumption and utilization studies, the accurate quantitative and qualitative measurement of food ingestion, feces egestion, assimilation and utilization of food and finding its relation to body substance produced (conversion efficiency) and the metabolic energy it gives are difficult to ascertain. The procedures for such studies are not only time consuming exercises but also very difficult to compute accurately, especially in case of muga silkworm which are reared successfully on host plants grown outdoor.

2.9 Studies on attracting/biting/swallowing/repellents in silkworms' nutrition

When an insect is selecting a host-plant, it may use a variety of senses, including smell, vision, touch and taste (Bernays and Chapman, 1994). In the first stages, smell and vision are the most important ones because they normally operate at long distances. After the insect lands on a possibly suitable host-plant, touch and taste become more important.

The involved chemicals are classified according to host-plant selection by insects and to their effect on insect behavior. Definitions given in 1960 by Dethier *et al.* (1960) still in use, are: attractant, a chemical (volatile) that causes an insect to make orientated movements towards the source of stimulus (plant); repellent, a chemical (volatile) that causes an insect to make orientated movements away from the source (plant) feeding or oviposition stimulant, a chemical that elicits feeding or oviposition (plant surface compounds); deterrent, a chemical that inhibits feeding or oviposition (plant surface compounds and plant tissues). In the field, the rate of production and release of volatile compounds by a plant is closely dependent on the air temperature and UV radiation (Williams, 1981). Despite this problem, headspace volatile compounds are the best indicators of the chemicals that play a dominant role in insect host-plant searching in nature, because they represent the compounds normally and naturally released by plants into the air (Urzua, 2002). Volatile compounds liberated by plants can elicit different behaviors in different insect species. For example, camphor acts as a repellent to *Harmonia axyridis,* the multicolored ladybeetle (Coleoptera: Coccinellidae), and is an attractant for *Cicloneda sanguinea* and *Eriopis connexa.*

The relation between the food habits of the insects and the chemical components of host plants attracted the attention of biologists with the primary study conducted by Verschaffelt (1910), who studied the feeding habit of the larvae of *Euproctis similes* which feed only on the leaves of the plants of Family Crucifereae. He revealed that this is due to the mustard oil glycoside which is a typical component of the cruciferous plants. Thorsteinson (1960) confirmed the results of the experiments carried out by Verschaffelt in 1910. Hamamura (2001) referred an unpublished work of VG Dethier, where it was mentioned that filter paper soaked in anethole, anisaldehyde and d-limonene which are oil contents of plants of Family Apiaceae strongly attracted the larvae of American butterfly (*Papilio machaon*). The mulberry silkworms have sensory receptors to receive the chemical stimuli and Torii and Morii (1948) reported that one pair of maxillae of the silkworm is sensitive to odour while the other pair is associated with feeding behaviour.

Oral administration of nutrients in the form of a solution tried with fifth instar *Bombyx mori* larvae to test the nutritive effects of various carbohydrates by Ito and Tanaka (1959; 1961a) indicated that only xylose was utilized by silkworm body and arabinose and rhamnose are found to be of little or no value. Ribose is slightly superior to the later two. Of the hexoses, glucose, fructose, and mannose are good; galactose is of moderate value, while sorbose is exceptionally poor. The di- and trisaccharides are uniformly good. Among alcohols, sorbitol and mannitol are utilized. Fraenkel (1959) pointed out that the food specificity of silkworm, *Bombyx mori* seemed to be due to compounds recognized by taste rather than by smell. Watanabe (1958) demonstrated that two volatile compounds, α, β-hexenal and β, γ-hexenol, both of which were isolated from mulberry leaves, were attractants for the larvae. Ito (1960) surveyed the effects of more than 20 sugars and related compounds on the feeding of the silkworm Bombyx *mori* by using agar diets. Sucrose stimulated feeding most, followed by fructose and raffinose, while glucose was a very weak stimulant. It was pointed out by Ito (1961 a, b, c) that ascorbic acid was a strong feeding stimulant and β-sitosterol a slight one. Yoshida (1955) revealed that role of Vitamin-A is certainly not as important in the silkworm *Bombyx mori* as in the vertebrates.

Volatile chemicals have been identified from flowers of several plants that are frequented by moths, and some of these chemicals attract moths. Phenylacetaldehyde from flowers of bladder flower attracts many species of moths (Cantelo and Jacobson, 1979). *Glossy abelia* flowers emit phenylacetaldehyde, benzaldehyde, 2–phenylethanol and benzyl alcohol, which are attractive to cabbage looper moths: (Haynes *et al.*, 1991). Five chemicals e.g., phenyl acetaldehyde, phenylethanol, Iimonene, methyl salicylate and methyl-2-methoxy benzoate identified from flowers of Drummond's gaura constitute a blend that attracts corn earworm moths, *Helicoverpa zea* (Lopez *et al.,* 2000). The alfalfa looper, a close relative of both the gamma moth and the cabbage looper, is a highly polyphagous caterpillar and a pest of numerous garden and farm crops. The moth of this species is attracted to some of the same volatile chemicals that are emitted by flowers discussed above.

Non-volatile compounds are larger molecules with lower vapour pressure, which do not spread easily in air. Therefore, they are acting over short distances and the induced behaviour is mediated by contact chemoreception (Foster & Harris, 1997). A common and general feeding stimulant is sucrose, which induces feeding in many insect species (Schoonhooven, 1982). For *Amyelois transitella*, a pest infesting cultures of different nuts, oil extracts from both almond and peanuts acted as attractants for mated females (Phelan *et al.*, 1991). They concluded that there were some compounds in the oil acting as cues for oviposition, since neither males nor unmated females were attracted. The compounds mediating the oviposition were identified as oleic acid and linoleic acid, two fatty acids found in almost all animal and vegetable fats. In an experiment with *Plodia interpunctella*, with the purpose of studying the chemicals responsible both for short-range attraction and feeding, extracts of corn, peanuts and wheat induced both orientation and feeding (Baker & Mabie, 1973). When analyzing the constituents they found that carbohydrates, mainly sugars, were powerful feeding stimulants; amino acids had no effect and fatty acids and sterols stimulated feeding only when presented together with sucrose.

One group of the non-volatile compounds isolated from wheat germ is the triglycerides, a lipid consisting of glycerol esterified with three carboxylic acids and found in both animal fats and vegetable oils. The triglycerides which caused significant aggregation of *Triboilum confusum* were identified as 1-palmito-2, 3-diolein, 2-linoleo-1,3-dipalmitin and 1-palmito-2-linoleo-3-olein, all three are present in hexane extract of wheat germ (Tamaki *et al.*, 1971). When testing methanol extracts of wheat germ, probably containing different compounds than hexane extracts, the *T. castaneum* beetles responded to the extract only by intensive feeding rather than aggregation, indicating that the compounds causing feeding and aggregation differ. Palmitic acid, stearic acid and oleic acid, common fatty acid moieties of triglycerides, can induce both aggregation and feeding when being presented as individual compounds (Loschiavo, 1965). Other feeding stimulants for *T. confusum* are maltose and gluten.

Hamamura (2001) indicated the feeding mechanism of mulberry silkworm on the basis of the findings based on series of experiments conducted for several years. He summarized the mechanism of feeding actions as follows: Firstly the silkworms are attracted by the odour of mulberry leaves. Next when they come in contact with the leaves they are stimulated by some substance in the mulberry, which stimulates the biting behaviour. Once the feed enters the mouth some factor in the mulberry leaves stimulates the continuous swallowing. In other words the 3 forms of behaviour, namely, attracting, biting and swallowing are automatically induced by the stimuli of 3 different substances. This results in continuous feeding behaviour.

The outcome of the research study conducted by Hamamura was summarized as follows:

Attracting factor: This is obtained in the ether soluble fraction of the methanol extract of the mulberry leaves and it is a neutral fraction. When it is subjected to gas chromatography analysis, it is found to be mainly composed of 4 terpenes, namely citral, linalool, linalyl acetate and terpinyl acetate.

Attraction tests of the four chemicals in pure form were carried out on the silkworms with varied degree of attraction.

Watanabe had reported that the silkworms are attached by both fresh leaf alcohol and fresh leaf aldehyde which are the typical components of green leaves. According to Hirao and Ishikawa (1964) besides those indicated by the author there are several terpenes and esters, which also have the same action.

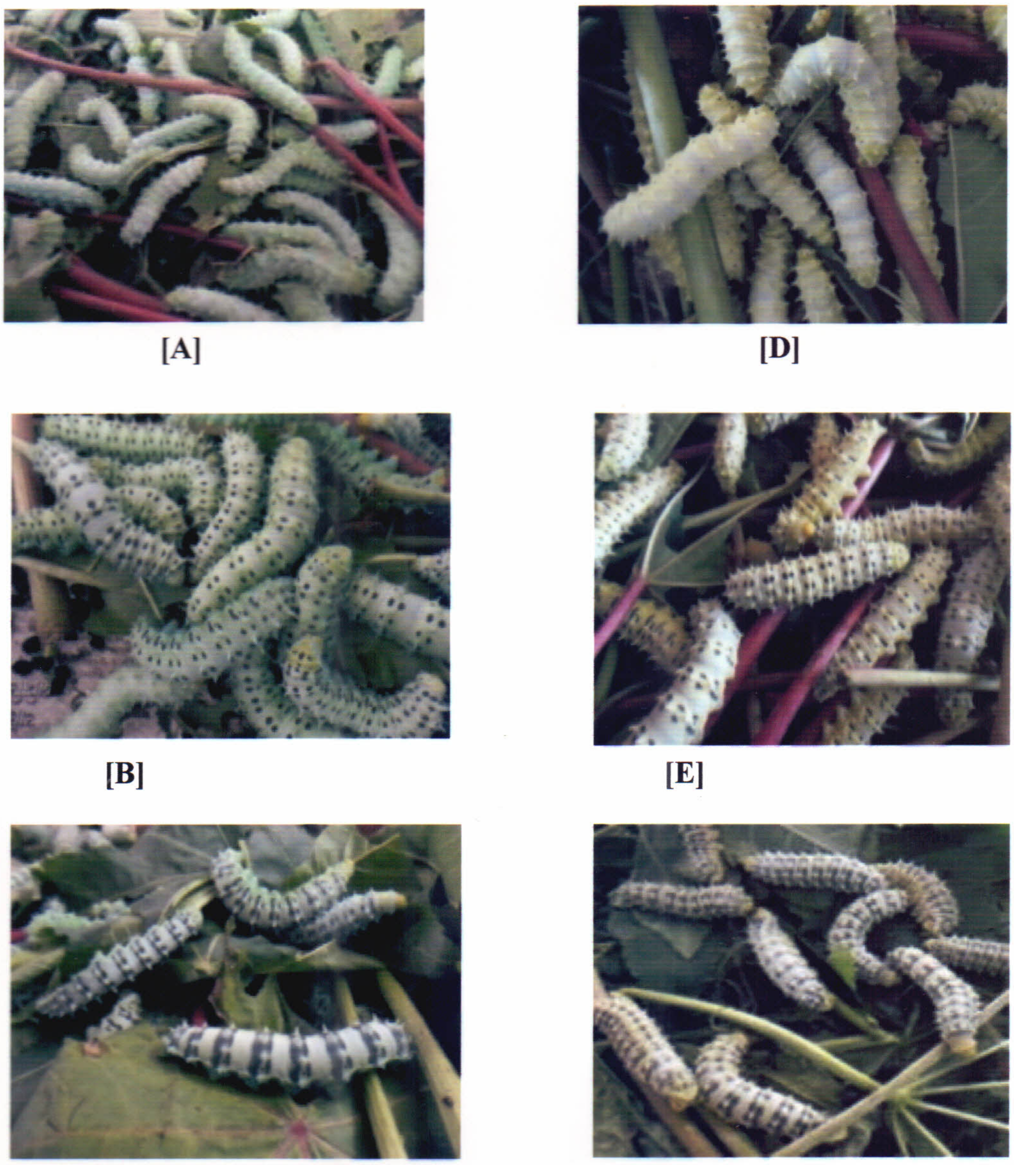
Biting factor: There are two types, one of which is ether soluble and the other is water-soluble. The former is ß-sitosterol and the latter is isoquercitrin of the flavon group. The pigments morin isolated from the mulberry also has the same action.

ß-sitosterol is present in the waxy material covering the surface of the mulberry leaves and provides the stimulus to the maxillae of the silkworms. Isoquercitrin is present in the cells of the leaves and is believed to assist the action of ß-sitosterol.

Swallowing factor: This factor is present in the methanol extracted residue of the mulberry leaves and it is mainly cellulose. However, cellulose alone is not sufficient to effect this action; the presence of potassium phosphate is required to reinforce the action. Sugar or inositol present in the water soluble part is essential to obtain complete swallowing action.

All the works done on muga host plants and the silkworm so far is largely on estimation of primary metabolites present in host plants and in silkworm body at different larval instars during different season, and then simply correlating them with rearing performance parameters. These studies do not focus on overall requirement of the metabolites for proper growth and development of the silkworm. Moreover, there exists a large variation of the contents of different constituents in the silkworm body as well as its host plant leaves as reported by different workers.

In view of the above-mentioned review of literature, the analysis of biochemical constituents of leaves of *Ailanthus species* and evaluation of rearing performance of eri silkworm feeding on different species of *Ailanthus* as well as other food plants was the new efforts to make the ericulture sustainable and more environments friendly venture for rural livelihood security.



[A] [D]

[B] [E]

[C] [F]

Plate. 6 (A-F). Different strains of eri silkworm (A) Greenish Blue Plain (B) Greenish Blue Spotted (C) Greenish Blue Zebra (D) Yellow Plain (E) Spotted Yellow (F) Yellow Zebra