Applied Zoology

Sericulture

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1. Introduction

1.1 History

Silk production has a long history. Silk was discovered by Xilingji (Hsi-ling-chi), wife of China's 3rd Emperor, Huangdi (Hoang-Ti), in 2640 B.C. While making tea, Xilingji accidentally dropped a silkworm cocoon into a cup of hot water and found that the silk fiber could be loosened and unwound. Fibers from several cocoons could be twisted together to make a thread that was strong enough to be woven into cloth. Thereafter, Hsi-ling chi discovered not only the means of raising silk worms, but also the manners of reeling silk and of employing it to make garments.

Later sericulture spread throughout China, and silk became a precious commodity, highly sought after by other countries. Demand for this exotic fabric eventually created the lucrative trade route, the historically famous **Silk Road or Silk Route** named after its most important commodity. This road helped in taking silk westward and bringing gold, silver and wool to the East. With the mulberry silk moth native to China, the Chinese had a monopoly on the world's silk production.

After 1200B.C. Chinese immigrants who had settled in Korea helped in the emergence of silk industry in Korea. During the third century B.C. Semiramus, a general of the army of Empress Singu-Kongo, invaded and conquered Korea. Among his prisoners were some Sericulturists whom he brought back to Japan. They helped in the establishment and growth of sericulture industry in Japan. Another story is that a Chinese princess married an Indian prince. She carried silkworm eggs/mulberry cocoons in her elaborate head dress. She disclosed the secret of raising silkworms thus, silk production spread in India. In 550A.D. moth eggs and mulberry seeds were smuggled from China by two Nestorian monks, sent by Emperor Justinian-I and silk production began in Byzantium. The technique of sericulture spread throughout the Mediterranean countries during the 7th century AD and then to Africa, Spain and Sicily. During latter part of the 19th century, modern machinery, improved techniques and intensive research helped the growth of sericulture industry in Japan. At present, Japan, China, Korea, Italy, Soviet Union, France, Brazil and India are the chief silk producing countries in the World.

1.2 Indian Scenario

Silk is Nature's gift to mankind and a commercial fiber of animal origin other than wool. Being an eco-friendly, biodegradable and self-sustaining material; silk has assumed special relevance in present age. Promotion of sericulture can help in ecosystem development as well as high economic returns.

Sericulture is practiced in India and India is the 5th largest producer of silk in the World. It has been identified as employment oriented industry. All the sections of sericulture industry, viz. mulberry cultivation, silkworm seed production, silkworm rearing, reeling and weaving of silk and collection of byproducts and its processing provide a large scale employment, thereby a source of livelihood for the rural and tribal people. Sericulture industry is rated as the second largest employer in India.

Owing to this peculiar nature, the Indian planners have identified sericulture as one of the best-suited occupations for ideal growth and development of rural India. Mulberry sericulture has been traditional occupation in Karnataka, Tamil Nadu, A.P. and Kashmir; Tasar one, in M.P., Chota Nagpur Division and Orissa; Muga one, in Assam, Nagaland,

Tripura and Eri one in Assam and West Bengal. North-eastern part of India is the only region in the world where all four varieties of silk are produced.

Central and State level Government Silk Departments are actively engaged in addressing the objective of promotion of sericulture in traditional as well as non-traditional regions. With the launching of massive developmental schemes, it is expected to gain an accelerated tempo of sericultural activities in the country, paving way for doubling the employment opportunities in phased manner, and thereby, it may set to bring a soothing touch to the burning problem of acute unemployment in rural India and thus can check the rural migration to urban areas to a certain extent.

Sericulture is an agro-based cottage industry involving interdependent rural, semi-urban and urban-based activities in which estimated participation of women is about 60%. Thus, in contrast to any other agro-based profession the role of women in sericulture industry is dominating which will be helpful for improving the status of women in family enterprises. In the light of women welfare through Sericulture industry, the **Central Silk Board**, a statutory organization, under the Ministry of Textiles, Government of India has established a special component of assistance to Women and NGO's' into the National Sericulture Project.

There are four major research centres for Sericulture in India:

1. Central Sericulture Research and Training Institute, Behrampur (Orissa).
2. Central Sericulture Research and Training Institute, Mysore (Karnataka).
3. Central Tasar Research and Training Institute, Ranchi (Jharkhand).
4. Central Silk Technological Research Institute, Bangalore (Karnataka).

1.3 Sericulture and its components

Commercial rearing of silk producing silkworm is called sericulture. It is an agro-based industry comprising three main components: i) cultivation of food plants of the worms, ii) rearing of silk worms, and iii) reeling and spinning of silk. The first two are agricultural and the last one is an industrial component. There are four varieties of silkworms in India, accordingly sericulture is classified into **Mulberry Culture, Tasar Culture, Muga Culture** and **Eri Culture**, and each one is described separately in the following text.

2. Taxonomy

Silk producing insects are commonly referred to as **serigenous insects**. Silkworm is a common name for the silk-producing caterpillar larvae of silk moths. Silk moths belong to Phylum - Artropoda, Class - Insecta, Order - Lepidoptera, Super family - Bombycoidea. Bombycoidea comprises eight families of which only Bombycidae and Saturnidae are the two important families the members of which produce natural silk. There are several species of silkworm that are used in commercial silk production .These are:

(i) Mulberry silk worm

- *Bombyx mori* (Bombycidae)
- *Bombyx mandarina* (Bombycidae)

(ii) Tasar silk worm

- *Antheraea mylitta* (Saturnidae)

- *Antheraea pernyi* (Saturnidae)
- *Antheraea yamamai* (Saturnidae)
- *Antheraea paphia* (Saturnidae)
- *Antheraea royeli*(Saturnidae)

(iii) **Muga Silkworm**

- *Antheraea assama* (Saturnidae)

(iv) Eri silk worm

- *Philosamia ricini* (Saturnidae)

3. Mulberry Culture

3.1 Biology of Mulberry Silkworm

The insect producing mulberry silk is a domesticated variety of silkworms, which has been exploited for over 4000 years. All the strains reared at present belong to the species *Bombyx mori* that in believed to be derived from the original Mandarina silkworm, *Bombyx mandarina* Moore. China in the native place of this silk worm, but now it has been introduced in all the silk producing countries like Japan, India, Korea, Italy, France and Russia.

The races of mulberry silk worm may be identified on the basis of geographical distribution as Japanese, Chinese, European or Indian origin; or as Uni-, Bi- or Multi-voltine depending upon the number of generations produced in a year under natural conditions; or as Tri-, Tetra- and Penta-moulters according to the number of moults that occur during larval growth; or as pure strain and hybrid variety according to genetic recombination.

3.2. Life Cycle

Life cycle of the silkworm consists of four stages i.e. adult, egg, larva, and pupa. The duration of life cycle is six to eight weeks depending upon racial characteristics and climatic conditions. Multi-voltine races found in tropical areas have the shortest life cycle with the egg, larval, pupal and adult stages lasting for 9-12 days, 20-24 days, 10-12 days and 3-6 days, respectively. Seven to eight generations are produced in multi-voltine races.

In uni-voltine races, the egg period of activated egg may last for 11-14 days; the larval period, 24-28 days; the pupal period, 12-15 days and the adult stage, 6-10 days. In nature, uni-voltine races produce only one generation during the spring and the second generation of eggs goes through a period of rest or hibernation till the next spring. In case of bi-voltine races, however, the second generation eggs do not hibernate and hatch within 11-12 days and produce second generation normally during summer and it is the third generation eggs which undergo hibernation and hatches in the next spring, and thus producing two generations in one year.

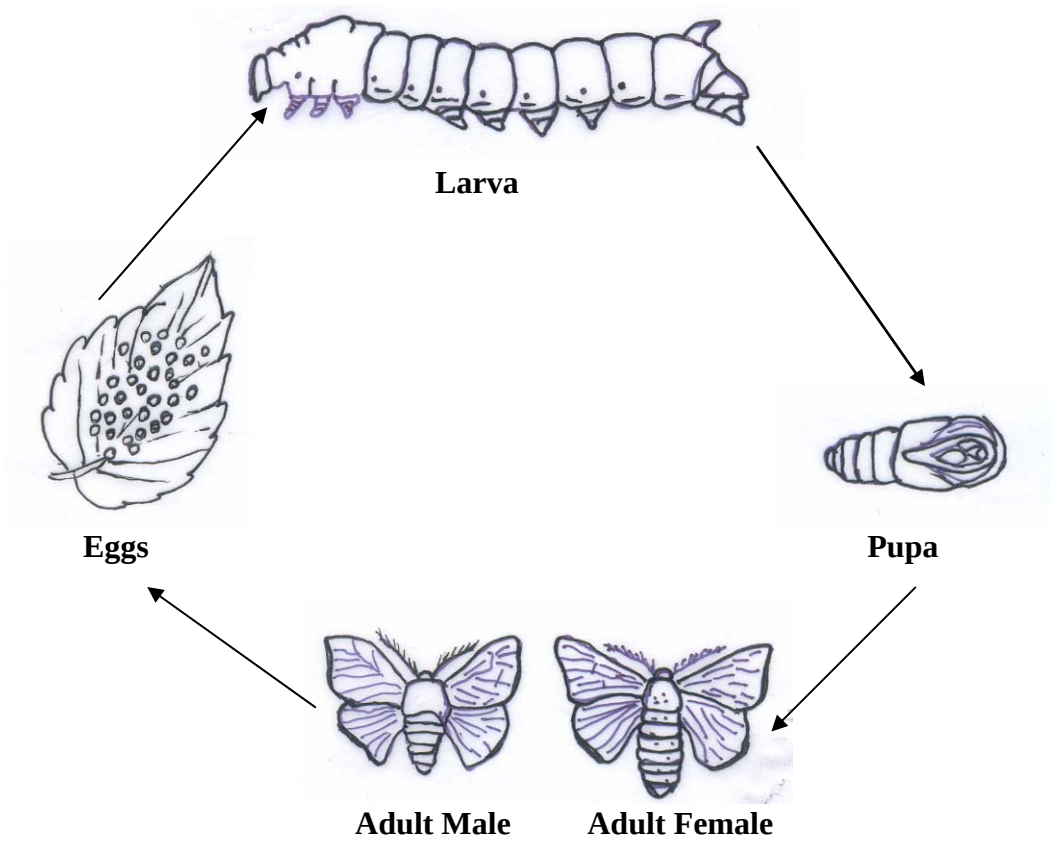

Fig.1. Life Cycle of *Bombyx mori.*

Egg

Egg is round and white. The weight of newly laid 2,000 eggs is about 1.0 g. It measures 1-1.3 mm in length and 0.9-1.2 mm in width. With time, eggs become darker and darker. Races producing white cocoons lay pale yellow eggs; while races producing yellow cocoons lay deep yellow eggs. In case of hibernating eggs laid by bi-voltine and uni-voltine races, the egg colour changes to dark brown or purple with the deepening of colour of the serosal pigments.

The eggs may be of diapause or non-diapause type. The diapause type of eggs are laid by the silkworms inhabiting in temperate regions; where as silkworms belonging to subtropical regions like India lay non-diapause type of eggs. During diapause all vital activities of the eggs cease.

Larva

After 10 days of incubation, the eggs hatch into larva called **caterpillar**. After hatching caterpillars need continuous supply of food, because they are voracious feeders. Newly hatched caterpillar is about 0.3 cm in length and pale yellowish white. The larval body in densely covered with bristles. As the larva grows, it becomes smoother and lighter in

colour due to rapid stretching of the cuticular skin during different instars of the larval stage. The skin consists of cuticle and hypodermis. Cuticle is made up of chitin as well as protein and is covered with a thin layer of wax, which is capable of being extended considerably to permit rapid growth of the larva during each instar. Nodules are found all over the surface of the body, and the distribution pattern differs according to the variety of silkworm. Larva bears four pairs of tubercles: sub-dorsal, supra-spiracular, infra-spiracular and basal tubercle. Each tubercle carries 3-6 setae.

The larval body is composed of head, thorax and abdomen. The head consist of six fused segments. It carries the appendages: antennae, mandibles, maxillae and labium. Median epicranial suture, clypeus and labrum are well developed and prominent. Six pairs of larval eyes or ocelli are located a little above the base of antennae. Five segmented antennae are used as sensory organs. The mandibles are well developed, powerful and adapted for mastication. The maxillary lobe and palpi help in discriminating the taste of food. The prementum is also chitinized, and its distal part carries a median process known as spinneret through which silk is extruded out from the silk gland. The sensory labial palpi are found on both sides of the spinneret.

The thorax has three segments: prothorax, mesothorax and metathroax. Each of the thoracic segments carries ventrally one pair of true legs, which are conical in shape and carry sharp distal claws. These claws are not used for crawling but they help in holding the leaves while feeding.

Abdomen consists of eleven segments, though only nine can be distinguished, as the last three are fused together to from the apparent ninth segment. Third to sixth and last abdominal segment bear a pair of abdominal legs, which are fleshy, unjointed muscular protuberance. Eighth abdominal segment bears caudal horn on the dorsal side.

The abdominal segments carry the sexual markings on ventral side, which are developed distinctly during fourth and fifth instars in the eighth and ninth segments. In females, the sexual marking appear as a pair of milky white spot in each of the eighth and ninth segments and are referred to as **Ishiwata's Fore Gland** and **Ishiwata's Hind Gland** respectively. In males a small milky white body known as **Herold's Gland** appears ventrally in the centre between eighth and ninth segments. Nine pairs of spiracles are present: one pair on the first thoracic segment and eight pairs one on each side of the first to eighth abdominal segments, respectively.

The larval growth is marked by four moultings and five instar stages. The full-grown caterpillar develops a pair of sericteries or silk glands. **Sericteries** or **silk glands** are modified labial glands. These glands are cylindrical and divided into three segments: Anterior-, middle- and posterior-segments. The inner lining cells are characterized by the presence of large and branched nucleus. These glands secrete silk which consists of an inner tough protein, **fibroin**, enclosed by a water soluble gelatinous protein, **sericin**. In *Bombyx*, the fibrinogen which on extrusion is denatured to fibroin is secreted in the posterior segment of the gland and form the core of the silk filament in the form of two very thin fibres called **brins**. The sericin, a hot water soluble protein, secreted by middle segment of the gland, holds the brins together and covers them. The duct from another small gland called **Lyonnet's gland**, that lubricates the tube through which the silk passes, joins the ducts of the silk glands. Finally, the silk is moulded to a thread as it passes through the **silk press** or **spinneret.**

Pupa

Pupa is the inactive resting stage of silkworm. It is a transitional period during which definite changes take place. During this period, biological activity of larval body and its internal organs undergo a complete change and assume the new form of adult moth. The mature silkworm passes through a short transitory stage of pre- pupa before becoming a pupa. During the pre-pupal stage, dissolution of the larval organs takes place which is followed by formation of adult organs. Soon after pupation the pupa is white and soft but gradually turns brown to dark brown, and the pupal skin becomes harder.

A pair of large compound eyes, a pair of antennae, fore and hind-wings, and the legs are visible. Ten segments can be seen on the ventral side, but only nine are visible on the dorsal side. Seven pairs of spiracles are present in abdominal region, the last pair being non-functional. Sex markings are prominent and it is much easier to determine the sex of pupa. The female has a fine longitudinal line on the eighth abdominal segment, where as such marking is absent in case of male. The pupa is covered within a thick, oval, white or yellow silken case called cocoon. The pupal period may last for 8-14 days after which the adult moth emerges slitting through the pupal skin and piercing the fibrous cocoon shell with the aid of the alkaline salivary secretion that softens the tough cocoon shell.

Adult

The adult of *Bombyx mori* is about 2.5 cm in length and pale creamy white. After emergence the adult is incapable of flight because of its feeble wings and heavy body. It does not feed during its short adult life. The body of moth has general plan of insect body organization .The ocelli are absent. The antennae are conspicuous, large and bipectinate. The meso- and meta-thorax bear a pair of wings. The front pair overlapp the hind pair when the moth is at rest.

The moth is unisexual and shows sexual dimorphism. In male eight abdominal segments are visible; while in female, seven. The female has comparatively smaller antennae. Its body and the abdomen are stouter and larger, and it is generally less active than male. The male moth possesses a pair of hooks known as harpes at its caudal end; while the female has a knob like projection with sensory hair. Just after emergence, male moths copulate with female for about 2-3 hours, and die after that. The female starts laying eggs just after copulation, which is completed within 24 hours. A female lays 400-500 eggs. The eggs are laid in clusters and are covered with gelatinous secretion of the female moth.

3.3. Rearing of Mulberry Silkworm

3.3.1. Mulberry Cultivation

Cultivation of mulberry plants is called moriculture. There are over 20 species of mulberry, of which four are common: *Morus alba*, *M. indica*, *M. serrata* and *M latifolia*. Mulberry is propagated either by seeds, root- grafts or stem cuttings, the last one being most common. Cuttings, 22-23 cm long with 3-4 buds each and pencil thick, are obtained from mature stem. These are planted directly in the field or first in nurseries to be transplanted later. After the plants have grown, pruning is carried out routinely which serves two purposes, induction of growth and sprouting of new shoots.

Harvesting of leaves for feeding larva is done in three ways: leaf picking, branch cutting and top shoot harvesting. In leaf picking, individual leaves are handpicked. In branch cutting method, entire branch with leaves are cut and offered to 3^{rd} instar larva. In top shoot harvesting, the tops of shoots are clipped and given to the 4^{th} & 5^{th} instars. The yield and quality of leaf depend upon the agronomic practices for cultivation of mulberry

trees, namely irrigation, application of fertilizers etc. It is estimated that 20,000 to 25,000 kg of leaves can be harvested per hectare per year under optimum conditions. It has also been estimated that to rear one box of 20,000 eggs, 600-650 kg of leaves are required for spring rearing and 500-550 kg for autumn rearing in Japan. In India, to rear 20,000 eggs the quantity of leaves required is about 350-400 kg.

3.3.2. Rearing Equipments

i) **Rearing house**: The rearing house should meet certain specification, as the silk worms are very sensitive to weather conditions like humidity and temperature. The rearing room should have proper ventilation optimum temperature and proper humidity. It should be ensured that dampness, stagnation of air, exposure to bright sunlight and strong wind should be avoided.

ii) **Rearing stand:** Rearing stands are made up of wood or bamboo and are portable. These are the frames at which rearing trays are kept. A rearing stand should be 2.5 m high, 1.5 m long and 1.0 m wide and should have 10 shelves with a space of 20 cm between the shelves. The trays are arranged on the shelves, and each stand can accommodate 10 rearing trays.

iii) **Ant well:** Ant wells are provided to stop ants from crawling on to trays, as ants are serious menace to silk worms. They are made of concrete or stone blocks 20 cm square and 7.5 cm high with a deep groove of 2.5 cm running all round the top. The legs of the rearing stands rest on the centre of well filled with water.

iv) **Rearing tray:** These are made of bamboo or wood so that they are light and easy to handle. These are either round or rectangular.

v) **Paraffin paper:** This is a thick craft paper coated with paraffin wax with a melting point of 55^{o} C. It is used for rearing early stages of silk worms and prevents withering of the chopped leaves and also help to maintain proper humidity in the rearing bed.

vi) **Foam rubber strips:** Long foam rubber strips 2.5 cm wide and 2.5 cm thick dipped in water are kept around the silkworm rearing bed during first two instar stages to maintain optimum humidity. Newspaper strips may also be used as a substitute.

vii) **Chopsticks:** These are tapering bamboo rods (1cm in diameter) and meant for picking younger stages of larvae to ensure the hygienic handling.

viii) **Feathers:** Bird feathers preferably white and large are important items of silkworm rearing room. These are used for brushing newly hatched worms to prevent injuries.

ix) **Chopping board and Knife:** The chopping board is made up of soft wood it is used as a base for cutting leaves with knife to the suitable size required for feeding the worms in different instar stages.

x) **Leaf chambers:** These are used for storing harvested leaves. The sidewalls and bottom are made of wooden strips. The chamber is covered on all sides with a wet gunny cloth.

xi) **Cleaning net:** These are cotton or nylon nets of different mesh size to suit the size variations of different instars of the silk worm. These are used for

cleaning the rearing beds, and at least two nets are required for each rearing tray.

xii) **Mountages:** These are used to support silkworm for spinning cocoons. These are made up of bamboo, usually 1.8 m long and 1.2 m wide. Over a mat base, tapes (woven out of bamboo and 5-6 cm wide) are fixed in the form of spirals leaving a gap of 5-6 cm. They are also called **chandrikes**. Other types of mountage such as **centipede rope mountage**, **straw cocooning frames** etc. are also used.

xiii) **Hygrometers and Thermometers:** These are used to record humidity and temperature of the rearing room.

xiv) **Feeding stands:** These are small wooden stands (0.9 m height) used for holding the trays during feeding and bed cleaning.

Other equipments like feeding basins, sprayer, and leaf baskets may also be required.

3.3.3. Rearing Practices

Silkworms must be reared with utmost care since they are susceptible to diseases. Therefore, to prevent diseases, good sanitation methods and hygienic rearing techniques must be followed. The appliances and the rearing room should be thoroughly cleaned and disinfected with 2-4% formaldehyde solution. Room temperature should be maintained around 25^0 C.

Procurement of quality seeds

The most important step in silkworm rearing is the procurement of quality seeds free from diseases. Seeds are obtained from grainages, which are the centers for production of disease free seeds of pure and hybrid races in large quantities. These centers purchase cocoons from the certified seed cocoon producers. These cocoons are placed in well-ventilated rooms with proper temperature (23-25^o C) and humidity (70-80 %), and emergence of moth is allowed. Grainage rooms may be kept dark, and light may be supplied suddenly on the expected day of emergence to bring uniform emergence. Emerging moths are sexed and used for breeding purposes to produce seed eggs. Three hours of mating secures maximum fertilized eggs. The females are then made to lay eggs on paper sheets or cardboard coated with a gummy substance. Egg sheets are disinfected with 2% formalin, and then washed with water to remove traces of formalin and then dried up in shades. The eggs are transported in the form of egg sheet. However, it is easy to transport loose eggs. To loosen the eggs, the sheets are soaked in water. The loose eggs are washed in salt solution of 1.06-1.10 specific gravity to separate out unfertilized eggs and dead eggs floating on surface. Prior to the final washing, the eggs are disinfected with 2% formalin solution. Eggs are dried, weighed to the required standard and packed in small flat boxes with muslin covers and dispatched to buyers.

Brushing

The process of transferring the silkworm to rearing trays is called brushing. Suitable time for brushing is about 10.00 am. Eggs at the blue egg stage are kept in black boxes on the days prior to hatching. The next day they are exposed to diffused light so that the larvae hatch uniformly in response to photic stimuli. About 90% hatching can be obtained in one day by this method.

In case of eggs prepared on egg cards, the cards with the newly hatched worms are placed in the rearing trays or boxes and tender mulberry leaves are chopped into pieces

and sprinkled over egg cards. In case of loose eggs a net with small holes is spread over the box containing the hatched larvae and mulberry leaves cut into small pieces are scattered over the net. Worms start crawling over the leaves on the net; the net with worms is transferred to rearing tray.

Preparation of feed bed and feeding

After brushing, the bed is prepared by collecting the worms and the mulberry leaves together by using a feather. The bed is spread uniformly using chopsticks. The first feeding is given after two hours of brushing. Feed bed is a layer of chopped leaves spread on a tray or over a large area. The first and second instar larvae are commonly known as **chawki worms**. For chawki worms, paraffin paper sheet is spread on the rearing tray. Chopped mulberry leaves are sprinkled on the sheet and hatched larvae are brushed on to the leaves. A second paraffin paper sheet is spread over the first bed. In between two sheets water soaked foam rubber strips are placed to maintain humidity.

The 4th and 5^{th} instars are reared in wooden or bamboo trays by any of the three methods: viz., shelf-rearing, floor-rearing and shoot-rearing. In shelf rearing, the rearing trays are arranged one above the other in tiers on a rearing stand which can accommodate 10 -11 trays. This method provides enough space for rearing, but it is uneconomical as it requires large number of laborers to handle the trays. Chopped leaves are given as feed in this method. In floor rearing, fixed rearing sheets of 5-7x1-1.5m size are constructed out of wooden or bamboo strips in two tiers one meter apart. These sheets are used for rearing. Chopped leaves are given as feed. This method is economical than the first one because it does not involve much labour in handling of trays. Shoot-rearing is most economical of the three methods. The rearing sheet used is one meter wide and any length long in single tier and the larvae are offered fresh shoot or twigs bearing leaves. This method can be practiced both outdoors and indoors depending upon the weather.

Each age of the silk worms could be conveniently divided into seven stages. First feeding stage, sparse eating stage, moderate eating stage, active eating stage, premoulting stage, last feeding stage, moulting stage. The larvae have good appetite at first feeding stage and comparatively little appetite at sparse and moderate eating stages. They eat voraciously during active stage to last feeding stage after which they stop feeding.

Bed Cleaning

Periodical removal of left over leaves and worms' excreta may be undertaken and is referred to as bed cleaning. It is necessary for proper growth and proper hygiene. Four methods are adopted: conventional method, husk method, net method, and combined husk and net method.

Spacing

Provision of adequate space is of great importance for vigorous growth of silkworms. As the worms grow in size, the density in the rearing bed increases and conditions of over crowding are faced. Normally it is necessary to double or triple the space by the time of moult from one to other instar stage, with the result that from the first to third instar the rearing space increases eight fold. In 4^{th} instar, it is necessary to increase the space by two to three times and in 5^{th} instar again twice. Thus, the rearing space increases up to hundred folds from the time of brushing till the time of maturation of worms.

Mounting

Transferring mature fifth instar larvae to mountages is called mounting. When larvae are fully mature, they become translucent, their body shrinks, and they stop feeding and start searching for suitable place to attach themselves for cocoon spinning and pupation. They are picked up and put on mountages. The worms attach themselves to the spirals of the mountages and start spinning the cocoon. By continuous movement of head, silk fluid is released in minute quantity which hardens to form a long continuous filament. The silkworm at first lays the foundation for the cocoon structure by weaving a preliminary web providing the necessary foot hold for the larva to spin the compact shell of cocoon. Owing to characteristic movements of the head, the silk filament is deposited in a series of short waves forming the figure of eight. This way layers are built and added to form the compact cocoon shell. After the compact shell of the cocoon is formed, the shrinking larva wraps itself and detaches from the shell and becomes pupa or chrysalis. The spinning completes within 2-3 days in multi-voltine varieties and 3-4 days in uni- and bi-voltine.

3.3.4. Harvesting of Cocoons

The larva undergoes metamorphosis inside the cocoon and becomes pupa. In early days, pupal skin is tender and ruptures easily. Thus, early harvest may result in injury of pupa, and this may damage the silk thread. Late harvest has a risk of threads being broken by the emerging moth. It is, therefore, crucial to harvest cocoons at proper time. Cocoons are harvested by hand. After harvesting the cocoons are sorted out. The good cocoons are cleaned by removing silk wool and faecal matter and are then marketed.

The cocoons are sold by farmers to filature units through Cooperative or State Govt. Agencies. The cocoons are priced on the basis Rendita and reeling parameters. Rendita may be defined as number of kg of cocoon producing 1 kg of raw silk.

3.4. Post Cocoon Processing

It includes all processes to obtain silk thread from cocoon.

3.4.1. Stifling

The process of killing pupa inside cocoon is termed as stifling. Good-sized cocoon 8-10 days old are selected for further processing. Stifling is done by subjecting cocoon to hot water, steam, dry heat, sun exposure or fumigation.

3.4.2. Reeling

The process of removing the threads from killed cocoon is called reeling. The cocoons are cooked first in hot water at 95-97^{o}C for 10-15 minutes to soften the adhesion of silk threads among themselves, loosening of the threads to separate freely, and to facilitate the unbinding of silk threads. This process is called cooking. Cooking enables the sericin protein to get softened and make unwinding easy without breaks. The cocoons are then reeled in hot water with the help of a suitable machine. Four or five free ends of the threads of cocoon are passed through eyelets and guides to twist into one thread and wound round a large wheel. The twisting is done with the help of **croissure**. The silk is transferred finally to spools, and silk obtained on the spool is called the **Raw Silk** or **Reeled Silk**. The Raw silk is further boiled, stretched and purified by acid or by fermentation and is carefully washed again and again to bring the luster. Raw Silk or Reeled Silk is finished in the form of skein and book for trading.

The waste outer layer or damaged cocoons and threads are separated, teased and then the filaments are spun. This is called **Spun Silk**.

4. Tasar Culture

4.1 Tasar Silkworm

Several species of *Antheraea* are exploited for production of wild silk known as tasar silk. These are *Antheraea mylitta, A. pernyi, A.yamamai, A.paphia and A.royeli. A. mylitta* and *A. paphia* are reared in central and north eastern parts of India. Many regional strains known by different local names are also found. Three types of voltinism, namely Uni-, Bi- and Multi-voltine are found in *A. mylitta* and *A. paphia*. These are reared on trees of *Terminalia tomentosa* (Vern. Asan), *Terminalia arjuna* (Vern. Arjun), *Shorea robusta* (Vern. Saal) and *Zizyphus jujuba* (Vern. Ber). Rearing of *A. pernyi* and *A. royeli* has been introduced recently in Manipur. These are reared on *Quercus* or Oak. *A. pernyi* and *A.yamamai* are the tasar silk worms of China and Japan respectively. These species feed on Quercus or Oak trees and are normally bivoltine.

The tasar moths are fairly large insects. Females are larger and yellowish brown in colour, while males are smaller and brick red in colour. Both have prominent and colourful eye spots on their wings. The antennae of males are bushy, and abdomen is narrower in comparison to female.

4.2 Rearing of Tasar Silkworm

Cultivation of food plants is generally avoided, as tasar silkworms are wild in nature and need to be reared outdoors. However, modern sericulturists prefer to cultivate the food plants for better supervision. Cultivation is done with seeds or saplings being raised in nurseries. Saplings are transplanted to fields 20-25 feet apart. Agronomic practices are carried on regularly. Pruning is done regularly to maintain better foliage growth.

It is the bi-voltine variety of tasar worm that is used for commercial purpose. The cocoons of bi-voltine variety harvested in November/December go into diapause at pupal stage and moths generally emerge in May/June of following year. The rearing of worms from eggs produced in May/June is completed by June/July. This is the summer crop. These cocoons do not undergo diapause. The moths emerge in 15-20 days, and the layings prepared out of this crop are used for rearing the second crop during September/October. The summer crop is seed crop for second crop which is commercial crop. The rearers usually keep the necessary quantity of seed cocoons from the previous year crop for preparation of egg laying. Emergence is usually in the evening. The males are active and copulate with the females soon after emergence. After copulation the females are decoupled and kept in bamboo baskets for about 48 hours to lay eggs. A single female lays about 150-200 eggs in 2 days. The eggs are oval and dorso-ventrally flattened. Eggs are soaked in 2% formalin, washed with water, dried and allowed to hatch. Life cycle of tasar worm consists of adult, egg, larva and pupal stages.

The larvae hatch out in ten days. The hatching larvae are kept in cups made up of leaves and the cups are uniformly distributed over the host trees. These larvae crawl in search of food. The larval period lasts for 30-35 days in summer, which may prolong in winter. The larvae pass through four moults and 5 instar stages. The hatched 1st instar larvae are brown and change to green colour at second instar. There are a number of tubercles on the body, which carry the setae. The final instars are green in colour with violet tubercles distributed over the body. A prominent brown and yellowish lateral line is visible on either side of the body. The tubercles are violet. The dorsal tubercle carries brick red dorsal spots, and lateral tubercles carry mirror like shining lateral spots.

The larvae feed voraciously on leaves and defoliate trees. In *Antheraea*, cocoon formation takes about in two days. It follows gut purging, initiated by ecdysone production in which

larva expels gut contents by a series of waves of contraction passing along the abdomen from front to back. Subsequently, the larva enters an active wandering phase, which ends when it finds a suitable site in which to pupate. The first phase of cocoon formation is the construction of a scaffold of silk threads between leaves of food plant and the production of stalk or peduncle which attaches the cocoon to the leaf petiole /tree twig. Subsequent behavior consists of a series of cycles in which the larva weaves loops of silk by figure-of-eight movements of the head to construct one end of the cocoon and then turns through 180^{o} to form the other end. After a period of about 14 hours, by which time a complete layer of silk has been produced, the insect turns from one end of the cocoon to the other at much shorter intervals, and at the same time, it coats the inside of cocoon with a liquid from the anus containing crystals of Calcium Oxalate produced by the Malpighian tubules. The hydration of silk by secretion promotes cross-linking and tanning of the silk protein sericin, and the wall of cocoon becomes stiff and yellowish-brown. This period of impregnation lasts for an hour. After this more silk is added to the inside of the cocoon. The rearers then harvest the cocoons. In addition to systemic rearing, the cocoons are collected in forests by the tribes and forest men, as the tasar worms thrive naturally in wild.

4.3 Post Cocoon Processing

Cocoon are first soaked in 5% Soda (Na_2CO_3) solutions for 18 hours and then subjected to steam cooking in pressure chambers for 2½ hours to bring about the stifling of cocoon. After 24 hours, the stifled cocoons are washed in 0.5% formalin for 15-20 minutes followed by washing with water. Water is then squeezed out, and cocoons are reeled on reeling machine.

The waste outer layer, damaged cocoons and peduncles are teased, and then silk thread is spun on earthen mutka. The spun silk is commonly known as **katia matka.**

5. Muga Culture

5.1 Muga Silkworm

Muga is an Assamese word which indicates the golden brown (amber) colour of the cocoon. The Muga silk worm, *Antheraea assama* is mainly confined to the Brahmaputra valley of Assam and foothills of East Garo hills of Meghalaya. Its distribution in the wild state, however, extends from western Himalaya to Nagaland, Cachar district of Assam and south Tripura. However, commercial exploitation is restricted only to north eastern India. The Muga silk worm is multivoltne and passes through four moults and five instar stages. Generally 4-5 crops are raised in a year. Muga silkworm is a polyphagous insect. It feeds on the leaves of several kinds of trees, but *Machilus bombycine* (Vern. som) and *Litsaea polyantha* (Vern. soalu) are the two principal host food plants of muga silkworm. The host plants are cultivated through propagation by seeds or vegetatively by air layering. The plants are trained and pruned regularly.

Like other Lepidopterans, muga silkworm is a holometabolous insect passing through a complete metamorphosis from egg (Koni) to adult (Chakari) stage through two intermediate stages of larva (Polu) and Pupa (Leta). The entire life cycle lasts for about 50 days in summer and 120 days in winter. The wings and body of the male moth are copper brown to dark brown, while those of female, yellowish to brown. Both pair of wings bears eye spots. Besides colouration, the male moth can be distinguished from the female by its slightly smaller size, slender abdomen, bushy antennae and sharply curved forewing tips.

It is a semi-domesticated species in the sense that only the larval stage is spent in open, and the ripening worms are brought indoors for spinning the cocoons.

5.2 Rearing of Muga Silkworm

The seed cocoons intended for preparation of eggs are obtained from commercial rearers or from Government grainages. These are then laid in a single layer in trays to facilitate the emergence of moths. Emergence starts from dusk and continues till morning. Male moth is smaller in size has slender abdomen and bushy antennae. The emerging adults are allowed to mate and in the coupled state itself the pair is tied with a piece of cotton thread to 1.5-2 feet long stick made of dried straw which is known as **Kharika**. After overnight mating, the couples separate in the morning and if they do not decouple naturally they are made to do so by heat of fire lighted some distance away. The female moth lays about 150-250 eggs on Kharika. During summer, the worms hatch out in the morning in about 8 days. The Kharikas with the hatched worms are hanged on the host plants. The larvae immediately crawl and start feeding. When the leaves are exhausted, the larvae crawl down and are collected on triangular bamboo sieves with long handles (Chaloni), which are again hanged on a fresh tree. A band of straw with a little sand or ash is tied around the tree trunk 1-1.2 m above the ground to prevent the worms from crawling down the ground. The larvae feed voraciously, pass through 4 moults and reach the mature stage. In the final stage, larvae become greenish blue with prominent tubercles. Larval period lasts for 30-35 days. The ripe worms come down the trees searching for a suitable place for spinning of cocoon. They are then collected by rearers and put in baskets containing mango twigs and leaves, which are set as cocoonages (Jali) for the spinning of cocoons. The jalies are then hung and left undisturbed in separate rooms or at some shady place till cocoons are formed. Spinning takes about 2-3 days in summer and 7 days in winter. Muga cocoon is golden or light brown, 4-6 cm long and 2-3 cm broad with a rudimentary peduncle without ring.

5.3 Post Cocoon Processing

The muga cocoon is compact and leathery in structure. The length of continuous silk filament ranges from 350-450 meters with 4 to 5 breaks.

5.3.1 .Stifling

Immediately after removal from the mountages, cocoons are spread on bamboo mats in sun during hot hours of the day that partially kills the chrysalis. These are then subjected to heating in oven that kills the chrysalis completely, and the cocoons are stifled.

5.3.2 Degumming

It is the process by which gummy substance is softened and compact filaments are released for reeling. Cocoons are boiled in mild alkaline solutions for about 15-20 minutes.

5.3.3 Reeling

Almost entire reeling is done with a primitive machine called **Bhir**. The cocoons are kept in basin with warm water. Reeling requires two persons: one person releases the filaments from cocoons while the other twists the filament into one thread and wind it on Bhir. Two persons can reel around 100g raw silk per day on an average. Only 40-45% silk filament is reeled and rest is rejected as waste.

The other reeling machines include different types of Charkha: Chaudhary, Trivedi, Bharali, CMERS, Golden Muga, RMRS-I, RMRS II, RMRS III, Ambar Charkha. Reeling

with these machines is economical, as it requires only one person. Standard wild silk thread is made up from 8 cocoons and averages 32/34 deniers. The typical finished fabrics are Rajah, Shartaug, Tussah, and Pongee etc.

6. Eri Culture

6.1 Eri Silkworm

The silk produced by *Philosamia ricini* is called Eri silk. The distribution of Eri silk worm is confined to Assam and bordering districts of West Bengal. The Eri silkworm is multivoltine and reared indoors 5-6 times a year. Optimum conditions required are 24-28^{o}C temperature and 85-90% humidity. Adult moths emerge from morning to mid day; males emerge earlier than the females. After an hour of emergence mating occurs and continues till evening. Males are then separated. Both male and female have brown (chocolate), black or green coloured wings with white crescent markings and woolly white abdomen. The male is smaller than female and bear bushy antennae and narrow abdomen.

Eri worms are polyphagous having primary as well as secondary food plants (hosts). Primary food plants are *Ricinus communis* (Vern. Castor) and *Heteropenax fragrans* (Vern. Kasseru). Castor plants are of two varieties; the green leaved and violet leaved. Both are equally suitable for feeding the Eri silkworms. These plants are grown by seed sowing. Kasseru grows wild but may be cultivated as regular plantations on embankments around homestead land. It is grown by seed sowing and also vegetatively by stem cuttings. The secondary food plants are *Manihot utilissima* (Vern. Tapioca), *Evodia flaxinifola* (Vern. Payam), *Plumeria acutifolia* (Vern. Plum) and *Carica papaya* (Vern. Papaya).

6.2 Rearing of Eri Silkwom

Disease free seed cocoons are obtained from Grainages or Agencies and reared fully indoors. Healthy cocoons are spread on bamboo trays in cool dark room. On hatching, active males are separated from passive females and are then allowed to mate in quiet dark room. Fertilized females are then tied to 'kharikas' by passing a thread around the shoulder joint of the right wings. Kharikas are then suspended from a string. Eggs are laid within 25 hours on Kharika are normally selected for rearing. The eggs are white, oval and covered with a gummy substance, which makes them adhere to one another. The eggs are disinfected with 2% formalin solution and then washed thoroughly with water. Eggs are incubated at 26^{o} C, the colour changes to blue on the day prior to hatching. Hatching takes place in the morning after ten days of incubation. The newly hatched larvae are yellow with black segments. These larvae are brushed to rearing trays over which few tender leaves are spread, and crowding is avoided. As the worms advance in age, older leaves can be given as feed at four hour interval for four to five times.

Bed cleaning is carried out at regular interval in the same way as for the Mulberry silkworm. The growing worms undergo four moults and have five instar stages. Total larval period lasts for 30-35 days. The 5th instar mature larvae stop feeding and start searching for a proper place to spin the cocoon. At this stage, the mature worms are picked up and transferred to mountages (Chandrikes). In wild, cocoons are spun between folds of leaves. The spinning is completed in 2-3 days. The cocoons are open mouthed, white or brick red, 5 cm long in case of female and 4.6 cm in male, tapering at one end and flat rounded at open end, flossy and without a peduncle. The silk filaments are not continuous.

6.3 Post Cocoon Processing

Stifling is done by spreading and exposing the cocoons to sun for 1-2 days. For degumming, cocoons are tied in a cloth sac and dipped in boiling soda solution. After sufficient boiling, the cocoons are taken out, washed with water several times to remove soda, squeezed to remove water and then spread on mats to dry. Being open mouthed, the thread of the cocoons is discontinuous. So, the thread can only be spun and not reeled. Traditionally spinning is done in wet condition on **takli** and in semi dried condition on a **charkha**. Improved spinning machines like **N.R. Das type charkha** and **Chaudhury type charkha** are also available for spinning of silk from Eri cocoons.

7. Diseases And Pests Of Silkworms

7.1 Diseases

- *Pebrine:* Pebrine is also known as **pepper disease** or **corpuscle disease**. The disease is caused by a sporozoan, *Nosema bombycis* (family Nosematidae). The main source of infection is food contaminated with spores. Infection can be carried from one larva to another by the spores contained in faeces or liberated in other ways by the moths carrying infection. Pebrinized eggs easily get detached from the egg cards. They may be laid in lumps. The eggs may die before hatching. The larva shows black spots. They may become sluggish and dull, and the cuticle gets wrinkled. Pupa may show dark spots. Moths emerging from pebrinized cocoons have deformed wings and distorted antennae. The egg laying capacityof the moth becomes poor.
- *Flacherie:* Flacherie is a common term to denote bacterial and viral diseases. It has been classified into following types:-

  i) **Bacterial diseases of digestive organs**: Due to the poor supply of quality mulberry leaves, the digestive physiology of the silkworm is disturbed, and multiplication of bacteria occurs in the gastric cavity. Bacteria like *Streptococci, Coli,* etc. have been found associated with this disease. Symptoms, like diarrhoea, vomiting, shrinkage of larval body may be seen.

  ii) **Septicemia**: Penetration and multiplication of certain kinds of bacteria in haemolymph cause septicemia. The principal pathogenic bacteria are large and small *Bacilli, Streptococci, and Staphylococci* etc. Symptoms like diarrhoea, vomiting, shrinkage of larval body may be seen. Appearance of foul odor is also a common symptom.

  iii) **Sotto disease**: It is caused by toxin of *Bacillus thuringensis*. The larvae become unconscious, soft, and darkish and rot off.

  iv) **Infectious Flacherie**: It is caused by a virus called *Morator* Virus which does not form polyhedra in the body of silkworm larvae. The infection occurs mainly through oral cavity. The virus multiplies in the midgut and is released into the gastric juice and is excreted in faeces.

  v) **Cytoplasmic polyhedrosis**: It is caused by a virus called *Smithia* which form Polyhedra are formed in the cytoplasm of the cylindrical cells of the midgut. The larva loses appetite. The head may become disproportionately large. Infection occurs through the oral cavity.

- *Grasserie:* The disease is also known as **Jaundice** or **Nuclear Polyhedrosis** It is caused by a virus called *Borrelina,* which form polyhedra in the nuclei of the cells of fatty tissues , dermal tissues, muscles, tracheal membrane ,basement membrane , epithelial cells of midgut and blood corpuscles. The infected larvae lose appetite,

become inactive, membranes become swollen, skin becomes tender and pus leaks out from skin. The larvae finally die.

- *Muscardine or Calcino*: It is of 3 types-

  i) **White Muscardine**: It is caused by the fungus, *Beuveria bassiana*. The larva loses appetite, body loses elasticity and they cease to move and finally die.

  ii) **Green Muscardine**: It is caused by *Metarrhizium anisopliae*. The larva loses appetite, appears yellowish, becomes feeble and dies.

  iii) **Yellow Muscardine**: It is caused by *Isaria farinosa*. Many small black specks appear on the skin. Larvae lose appetite and dies.

7.2 Pests

- ***Tricholyga bombycis***, a dipteran fly of the family tachinidae, commonly known as **Uzi fly**.It is a serious pest of silkworm larvae and pupae. It parasitizes Mulberry and Tasar silkworm.
- **Dermestid beetles**: These insects belong to the order Coleoptera, family dermestidae. This family contains many genera and a large number of destructive species. Some of them are: *Dermestes cadverinus, D.valpinus, D.vorax, D.frishchi, and Trogoderma versicolor*. The larvae bore inside the cocoon and eat the pupa. These pests cause great damage and economical loss, as the damaged cocoons cannot be reeled.
- **Mites:** *Pediculoides ventricosus* (order Acarina, class Arachnida) damage the larvae. The toxic substance produced by the mite kills the silkworms.
- In addition, ants, lizards, birds, rats and squirrel also cause considerable damage to silkworm larvae as well as the cocoons.

8. Silk and Its Use

8.1. ***Properties of the silk:***

Silk contains 70-75% fibroin and 25-30% sericin protein. The biochemical composition of fibroin can be represented by the formula $\mathbf{C_{15}H_{23}N_5O_6}$. It has the characteristic appearance of pure silk with pearly lustre. It is insoluble in water, ether or alcohol, but dissolves in concentrated alkaline solutions, mineral acids, and glacial acetic acid and in ammoniacal solution of oxides of copper. Sericin, a gummy covering of the fiber is a gelatinous body which dissolves readily in warm soapy solutions and in hot water, which on cooling forms a jelly with even as little as 1% of the substance. It is precipitated as a white powder from hot solutions by alcohol. Its chemical formula is $\mathbf{C_{15}H_{25}N_5O_8}$. It can be dyed before or after it has been woven into a cloth. The weight in gram of 900m long silk filaments is called a **denier** which represents size of silk filament.

Silk has following peculiar properties: -

1. Natural colour of Mulberry silk is white , yellow or yellowish green; that of Tasar brown; of Muga, light brown or golden; and of Eri, brick red or creamy white or light brown.
2. Silk has all desirable qualities of textile fibres, viz. strength, elasticity, softness, coolness, and affinity to dyes. The silk fibre is exceptionally strong having a breaking strength of 65,000-lbs/sq. inch.
3. Silk fibre can elongate 20% of original length before breaking.
4. Density is 1.3-1.37g/cm^3.

5. Natural silk is hygroscopic and gains moisture up to 11%.
6. Silk is poor conductor of heat and electricity. However, under friction, it produces static electricity. Silk is sensitive to light and UV- rays.
7. Silk fibre can be heated to higher temperature without damage. It becomes pale yellow at 110^{o} C in 15 minutes and disintegrates at 165^{o} C.
8. On burning it produces a deadly hydrocyanic gas.

8.2. ***Use of silk:*** Silk is used in the manufacture of following articles:

- ❖ Garments in various weaves like plain, crepe, georgette and velvet.
- ❖ Knitted goods such as vests, gloves, socks, stockings.
- ❖ Silk is dyed and printed to prepare ornamented fabrics for saries, ghagras, lehengas and dupattas.
- ❖ Jackets, shawls and wrappers.
- ❖ Caps, handkerchiefs, scarves, dhotis, turbans.
- ❖ Quilts, bedcovers, cushions, table-cloths and curtains generally from Eri-silk or spun silk.
- ❖ Parachutes and parachute cords.
- ❖ Fishing lines.
- ❖ Sieve for flour mills.
- ❖ Insulation coil for electric and telephone wire.
- ❖ Tyres of racing cars.
- ❖ Artillery gunpowder.
- ❖ Surgical sutures.