6.1 INTRODUCTION

Silk is a natural protein fibre, some forms of which can be woven into textiles. The protein fibre of silk is composed mainly of fibroin and produced by certain insect larvae to form cocoons.\(^{468}\)

The best-known type of silk is obtained from the cocoons of the larvae of the mulberrysilk worm *Bombyxmori* reared in captivity (sericulture). The shimmering appearance of silk is due to the triangular prism-like structure of the silk fibre, which allows silk cloth to refract incoming light at different angles, thus producing different colors.

Silks are produced by several other insects, but generally only the silk of moth caterpillars has been used for textile manufacturing. There has been some research into other silks, which differ at the molecular level.\(^{469}\)

Many silks are mainly produced by the larvae of insects undergoing complete metamorphosis, but some adult insects such as web spinners produce silk, and some insects such as raspy crickets produce silk throughout their lives.\(^{470}\)

Silk production also occurs in Hymenoptera (bees, wasps, and ants), silverfish, mayflies, thrips, leafhoppers, beetles, lacewings, fleas, flies and midges. Other types of arthropod produce silk, most notably various arachnids such as spiders.

The word silk comes Old English *sioloc*, from Greek *serikos*, silken, ultimately from an Asian source (cf. Chinese *si* "silk," Manchurian *sirghe*, Mongolian *sirkek*).\(^{471}\)

HISTORY

Commercial silks originate from reared silkworm pupae which are bred to produce a white colored silk thread with no mineral on the surface. The pupae are killed by either dipping them in boiling water before the adult moths emerge or by piercing them with a needle. These factors all contribute to the ability of the whole cocoon to be unravelled as one continuous thread, permitting a much stronger cloth to be woven from the silk. Wild silks also tend to be more difficult to dye than silk from the cultivated silkworm.\(^{472,473}\)

A technique known as demineralizing allows the mineral layer around the cocoon to be removed,\(^{474}\) leaving only variability in color as a barrier from creating a
commercial silk industry based on wild silks in parts of the world where wild silkworms thrive, such as Africa and South America.

China

Silk fabric was first developed in ancient China, with some of the earliest examples found as early as 3500 BC. In July 2007, archeologists discovered intricately woven and dyed silk textiles in a tomb in Jiangxi province, dated to the Eastern Zhou Dynasty roughly 2,500 years ago. Although historians have suspected a long history of a formative textile industry in ancient China, this find of silk textiles employing "complicated techniques" of weaving and dyeing provides direct and concrete evidence for silks dating before the Mawangdui-discovery and other silks dating to the Han Dynasty (202 BC-220 AD).

The Emperors of China strove to keep knowledge of sericulture secret to maintain the Chinese monopoly. Nonetheless sericulture reached Korea around 200 BC, about the first half of the 1st century AD had reached ancient Khotan, and by AD 140 the practice had been established in India.

The silk fabric is soaked in extremely cold water and bleached before dyeing to remove the natural yellow coloring of Thai silk yarn. To do this, skeins of silk thread are immersed in large tubs of hydrogen peroxide. Once washed and dried, the silk is woven on a traditional hand operated loom.

Silk in the Indian subcontinent

Silk Sari Weaving at Kanchipuram

Silk, known as "Paat" in Eastern India, Pattu in southern parts of India and Resham in Hindi/Urdu, has a long history in India. Recent archaeological discoveries in Harappa and Chanhu-daro suggest that sericulture, employing wild silk threads from native silkworm species, existed in South Asia during the time of the Indus Valley Civilization, roughly contemporaneous with the earliest known silk use in China. According to an article in Nature by Philip Ball, while there are various evidences for silk production in China back to around 2570 BC, newly discovered silk objects from the Indus valley in eastern Pakistan are believed to date from between 2450 BC and 2000 BC, "making them similarly ancient". Shelagh Vainker, a silk expert at the Ashmolean Museum in Oxford, sees evidence for silk production in China "significantly earlier" than 2500–2000 BC, however suggests "people of the
Indus civilization either harvested silkworm cocoons or traded with people who did, and that they knew a considerable amount about silk." Silk is widely produced today. India is the second largest producer of silk after China. About 97% of the raw silk is produced in the five Indian states of Karnataka, Andhra Pradesh, Tamil Nadu, West Bengal and Jammu and Kashmir. The North Bangalore regions of Muddenahalli and Kanivenarayanapura, the upcoming sites of a $20 million "Silk City" and Mysore contribute to a majority of silk production. Another emerging silk producer is Tamil Nadu where mulberry cultivation is concentrated in Coimbatore, Erode and Dharmapuri districts. Hyderabad, Andhra Pradesh and Gobichettipalayam, Tamil Nadu were the first locations to have automated silk reeling units.

India is also the largest consumer of silk in the world. The tradition of wearing silk sarees in marriages by the brides is followed in southern parts of India. Silk is worn by people as a symbol of royalty while attending functions and during festivals. Historically silk was used by the upper classes, while cotton was used by the poorer classes. Today silk is mainly produced in BhoodhanPochampally (also known as Silk City), Kanchipuram, Dharmavaram, Mysore, etc. in South India and Banaras in the North for manufacturing garments and sarees. "Murshidabad silk", famous from historical times, is mainly produced in Malda and Murshidabad district of West Bengal and woven with hand looms in Birbhum and Murshidabad district. Another place famous for production of silk is Bhagalpur. The silk from Pochampally is particularly well known for its classic designs and enduring quality. The silk is traditionally hand-woven and hand-dyed and usually also has silver threads woven into the cloth. Most of this silk is used to make sarees. The sarees usually are very expensive and vibrant in color. Garments made from silk form an integral part of Indian weddings and other celebrations. In the northeastern state of Assam, three different types of silk are produced, collectively called Assam silk: Muga, Eri and Pat silk. Muga, the golden silk, and Eri are produced by silkworms that are native only to Assam. The heritage of silk rearing and weaving is very old and continues today especially with the production of Muga and Pat riha and mekhela chador, the three-piece silk sarees woven with traditional motifs. Mysore Silk Sarees, which are known for their soft texture, last many years if carefully maintained.
Production Process

The entire production process of silk can be divided into several steps which are typically handled by different entities. Extracting raw silk starts by cultivating the silkworms on Mulberry leaves. Once the worms start pupating in their cocoons, these are dissolved in boiling water in order for individual long fibres to be extracted and fed into the spinning reel.486

Properties

Physical properties

Silk fibers from the Bombyxmori silkworm have a triangular cross section with rounded corners, 5-10 μm wide. The fibroin-heavy chain is composed mostly of beta-sheets, due to a 59-mer amino acid repeat sequence with some variations.487 The flat surfaces of the fibrils reflect light at many angles, giving silk a natural shine. The cross-section from other silkworms can vary in shape and diameter: crescent-like for Anaphe and elongated wedge for tussah. Silkworm fibers are naturally extruded from two silkworm glands as a pair of primary filaments (brin), which are stuck together, with sericin proteins that act like glue, to form a bave. Bave diameters for tussah silk can reach 65 μm.

Silk has a smooth, soft texture that is not slippery, unlike many synthetic fibers.

Silk is one of the strongest natural fibers but loses up to 20% of its strength when wet. It has a good moisture regain of 11%. Its elasticity is moderate to poor: if elongated even a small amount, it remains stretched. It can be weakened if exposed to too much sunlight. It may also be attacked by insects, especially if left dirty.

One example of the durable nature of silk over other fabrics is demonstrated by the recovery in 1840 of silk garments from a wreck of 1782: 'The most durable article found has been silk; for besides pieces of cloaks and lace, a pair of black satin breeches, and a large satin waistcoat with flaps, were got up, of which the silk was perfect, but the lining entirely gone ... from the thread giving way ... No articles of dress of woolen cloth have yet been found.'488

Silk is a poor conductor of electricity and thus susceptible to static cling.
Unwashed silk chiffon may shrink up to 8% due to a relaxation of the fiber macrostructure, so silk should either be washed prior to garment construction, or dry cleaned. Dry cleaning may still shrink the chiffon up to 4%. Occasionally, this shrinkage can be reversed by a gentle steaming with a press cloth. There is almost no gradual shrinkage nor shrinkage due to molecular-level deformation.

Natural and synthetic silk is known to manifest piezoelectric properties in proteins, probably due to its molecular structure.\textsuperscript{489}

Silkworm silk was used as the standard for the denier, a measurement of linear density in fibers. Silkworm silk therefore has a linear density of approximately 1 den, or 1.1 dtex.

\textbf{Table 6.1: Comparison of silk fibers}

<table>
<thead>
<tr>
<th>Type of silk worms \textsuperscript{490}</th>
<th>Linear Density (dtex)</th>
<th>Diameter (μm)</th>
<th>Coeff. Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moth: \textit{Bombyxmori}</td>
<td>1.17</td>
<td>12.9</td>
<td>24.8%</td>
</tr>
<tr>
<td>Spider: \textit{Argiopeaurentia}</td>
<td>0.14</td>
<td>3.57</td>
<td>14.8%</td>
</tr>
</tbody>
</table>

\textbf{Chemical properties}

The silk glands of the \textit{Bombyxmori} are structured like tubes consisting of a Posterior, Middle and Anterior section. The Posterior is long and thin. The Middle is short with a diameter measuring 3-4 mm. The Anterior is extremely thin, leading to the spinneret in the head of the larvae from which the silk is excreted.

Fibroin is secreted in the Posterior and transferred by peristalsis to the Middle section, which acts as a reservoir. Here it is stored as a viscous aqueous solution until required for spinning. The majority of the sericin is created within the walls of the Middle section. In fact, these two proteins are reserved side by side in the Middle section without mixing one into the other. The fibroin core is covered with a layer of sericin and the secretions from the two proteins join at the junctions where the sericin is fused into one layer. The Filipis glands discharge a liquid protein. To form its cocoon, the silkworm draws out the thread of liquid protein and internally adds layer after layer to complete this protective covering.

Silk emitted by the silkworm consists of two main proteins, sericin and fibroin, fibroin being the structural center of the silk, and sericin being the sticky material surrounding it. Fibroin is made up of the amino acids Gly-Ser-Gly-Ala-Gly-
Ala and forms beta pleated sheets. Hydrogen bonds form between chains, and side chains form above and below the plane of the hydrogen bond network.

The high proportion (50%) of glycine, which is a small amino acid, allows tight packing and the fibers are strong and resistant to breaking. The tensile strength is due to the many interceded hydrogen bonds, and when stretched the force is applied to these numerous bonds and they do not break.

Silk is resistant to most mineral acids, except for sulfuric acid, which dissolves it. It is yellowed by perspiration.

Uses of silk

Silk filaments being unraveled from silk cocoons, Cappadocia, Turkey, 2007.

Silk’s absorbency makes it comfortable to wear in warm weather and while active. Its low conductivity keeps warm air close to the skin during cold weather. It is often used for clothing such as shirts, ties, blouses, formal dresses, high fashion clothes, lingerie, pyjamas, robes, dress suits, sun dresses and Eastern folk costumes. Silk’s attractive lustre and drape makes it suitable for many furnishing applications. It is used for upholstery, wall coverings, window treatments (if blended with another fiber), rugs, bedding and wall hangings. While on the decline now, due to artificial fibers, silk has had many industrial and commercial uses, such as in parachutes, bicycle tires, comforter filling and artillerygunpowder bags.

A special manufacturing process removes the outer irritant sericin coating of the silk, which makes it suitable as non-absorbable surgical sutures. This process has also recently led to the introduction of specialist silk underclothing for children and adults with eczema where it can significantly reduce it.\textsuperscript{491,492} New uses and manufacturing techniques have been found for silk for making everything from disposable cups to drug delivery systems and holograms.\textsuperscript{493} To produce 1 kg of silk, 104 kg of mulberry leaves must be eaten by 3000 silkworms. It takes about 5000 silkworms to make a pure silk kimono.\textsuperscript{494} The construction of silk is called sericulture. The major silk producers are China (54%) and India (14%).
Table 6.2: Top Ten Cocoons (Reelable) Producers — 2005

<table>
<thead>
<tr>
<th>Country</th>
<th>Production (Int $1000)</th>
<th>Footnote</th>
<th>Production (1000 kg)</th>
<th>Footnote</th>
</tr>
</thead>
<tbody>
<tr>
<td>People's Republic of China</td>
<td>978,013</td>
<td>C</td>
<td>290,003</td>
<td>F</td>
</tr>
<tr>
<td>India</td>
<td>259,679</td>
<td>C</td>
<td>77,000</td>
<td>F</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>57,332</td>
<td>C</td>
<td>17,000</td>
<td>F</td>
</tr>
<tr>
<td>Brazil</td>
<td>37,097</td>
<td>C</td>
<td>11,000</td>
<td>F</td>
</tr>
<tr>
<td>Iran</td>
<td>20,235</td>
<td>C</td>
<td>6,088</td>
<td>F</td>
</tr>
<tr>
<td>Thailand</td>
<td>16,862</td>
<td>C</td>
<td>5,000</td>
<td>F</td>
</tr>
<tr>
<td>Vietnam</td>
<td>10,117</td>
<td>C</td>
<td>3,000</td>
<td>F</td>
</tr>
<tr>
<td>Democratic People's Republic of Korea</td>
<td>5,059</td>
<td>C</td>
<td>1,500</td>
<td>F</td>
</tr>
<tr>
<td>Romania</td>
<td>3,372</td>
<td>C</td>
<td>1,000</td>
<td>F</td>
</tr>
<tr>
<td>Japan</td>
<td>2,023</td>
<td>C</td>
<td>600</td>
<td>F</td>
</tr>
</tbody>
</table>

No symbol = official figure, F = FAO estimate, * = Unofficial figure, C = Calculated figure;
Production in Int $1000 have been calculated based on 1999-2001 international prices
Source: Food And Agricultural Organization of United Nations: Economic And Social Department: The Statistical Division

Cultivation of Cocoon

Silk moths lay eggs on specially prepared paper. The eggs hatch and the caterpillars (silkworms) are fed fresh mulberry leaves. After about 35 days and 4 moltings, the caterpillars are 10,000 times heavier than when hatched and are ready to begin spinning a cocoon. A straw frame is placed over the tray of caterpillars, and each caterpillar begins spinning a cocoon by moving its head in a pattern. Two glands produce liquid silk and force it through openings in the head called spinnerets. Liquid silk is coated in sericin, a water-soluble protective gum, and solidifies on contact with the air. Within 2–3 days, the caterpillar spins about 1 mile of filament and is completely encased in a cocoon. The silk farmers then kill most caterpillars by heat, leaving some to metamorphose into moths to breed the next generation of caterpillars. Harvested cocoons are then soaked in boiling water to soften the sericin holding the silk fibers together in a cocoon shape. The fibers are then unwound to produce a continuous thread. Since a single thread is too fine and fragile for commercial use, anywhere from three to ten strands are spun together to form a single thread of silk.495
Physical characteristics of cocoons

Sericulture occupies a very important position in the Indian economy. Its structure comprising of mulberry cultivation, silkworm rearing, silk reeling and fabric weaving spreads across the agriculture sector, industrial sector as well as cottage industries and export units. Thus it plays a pivotal role in economic development of the country by generating employment, incomes as well as foreign exchange. By the very nature of its structure, sericulture faces the problems associated with both agriculture and industries, especially cottage industries. It is one particular segment of sericulture namely the reeling segment, which faces the brunt of the problems associated with both the sectors, namely the agriculture and industry.

Cocoon testing and grading

In spite of India being a large producer of raw silk, cocoons are transacted without testing and the cocoon price is purely based on the subjective assessment of quality made by the buyer at the time of purchase. There is neither a system for scientific assessment of the quality of cocoons prior to transaction nor a systematic approach for fixing the price based on their quality and market conditions.\(^{496}\)

It has been established that cocoon quality contributes to the tune of about 80 per cent of the raw silk quality\(^{497}\).

As a result, some form or the other of quality index as a measure of cocoon quality exists in countries more advanced in sericulture especially Japan and China\(^{498}\).

These countries have realized the importance of cocoon quality in the price fixation and made the cocoon testing mandatory prior to marketing. In addition, the cocoon price in these countries is fixed on the basis of the cocoon quality as well as the price of raw silk, which is fixed on an annual basis.

At the same time, the national standards used by other sericultural countries cannot be adopted as such in the Indian context\(^{499}\). Therefore, there is a need for developing an objective method of assessing the quality of cocoons based on the parameters so that an organizational mechanism to bring its implementation to cocoon transactions can be set up.

Cocoon quality is governed by several parameters, each of them being associated with a certain level of importance\(^{500}\).
Some of the important quality parameters usually considered are: Shell Ratio percentage, Defective Cocoon Percentage, Average Filament Length, Average Non Broken Filament Length, Denier, and Reelability percentage. Of these, Shell Ratio percentage and Defective Cocoon percentage have been identified as the most significant ones especially because these are relatively easy to determine requiring minimum facilities, infrastructure and time.\textsuperscript{501, 502}

It has been established that each of the quality parameters has its own relative significance on the reeling efficiency and raw silk quality. The procedures for assessment of a few of these parameters are quite involved, while it is relatively easy for a few others. A few tests are nondestructive (as in the case of Defective Cocoon percentage), while a few are destructive (as in the case of Shell Ratio percentage). Thus, each of the parameters is associated with a certain extent of ease or difficulty in assessment.

The important characteristics that define the quality of cocoons are described below:\textsuperscript{503}

i. **Single cocoon weight (SCW):** This is simply the average weight of a cocoon. This is usually calculated by selecting 25 cocoons at random, then taking the total weight and then calculating the average of a single cocoon weight. This is measured in grams or centigrams.

ii. **Shell weight (SW):** This is the average of the single shell weight. The shell is that portion of the cocoon after removing the pupae. This is calculated by taking the same 25 cocoons that are used for calculation the single cocoon weight. The pupae are removed from these 25 cocoons and then the average weight of the shells is calculated. The shell yields the raw silk and hence the higher is the shell weight, the higher is the yield of the raw silk. This is also measured in grams or centigrams.

iii. **Shell Ratio (SR):** This is defined as the ratio average shell weight to the average single cocoon weight and expressed as a percentage. This ratio actually estimates the raw silk content of each cocoon. Thus the higher the shell ratio, the better is the quality.

iv. **Filament length (FL):** This is the total length of the silk filament reeled from the cocoon. This is measured in meters.
v. **Filament size (FS):** This is the thickness of the silk filament. This is also expressed as the denier. The denier is expressed as the weight of the silk filament measured in grams for 9000 meters of the filament. A lower denier implies finer silk filament and hence is more desirable.

vi. **Reelability (RY):** This is a measure of the re-reelability of the silk filament. It is the ratio of the cocoon reeled without break and the total number of cocoons casted and it is measured as a percentage. This ratio is calculated from the number of times of casting filaments and the number of cocoons reeled. This characteristic actually measures the frequency of breakages of the filament during reeling.

vii. **Raw silk (RS):** This is a measure of the raw silk expressed as a percentage. It is the ratio of the number of kilograms of cocoons required to produce one kilogram of raw silk and expressed as a percentage.

viii. **Neatness (N):** This measures the neatness of the silk filament. This is expressed as a percentage. The number of small knots, loops and the frequency of distribution on raw silk are represented as percentage by comparing a sample of 20 panels taken on a Seri plane board, with the standard photographs for neatness defects. This characteristic has an impact on the quality of the fabrics woven from the silk.

ix. **Boil Loss (BL):** Boil loss or degumming loss is the loss of sericin that is used as the gum for binding the silk filaments together in the form of a cocoon. Cocoons selected for reeling are boiled in soap solution for removing the gum or sericin. This is the ratio of the weight of cocoons after degumming, to the original weight of cocoons (green cocoons) and expressed as a percentage.

Percentage of defective cocoons is another characteristic used by reelers in determining the price of cocoons. This is the percentage of defective cocoons in a given lot. Even though it is an important characteristic in determining the price offered for the lot, it is not a determinant of the quality of the cocoons with respect to the reeling aspects.

In addition to these characteristics of the cocoon, three more pre-cocoon characteristics are defined. These three characteristics are observed at the larval stage of the silkworm.
These are:

i. **Hatching percentage (HP):** The number of hatched larvae per df (disease free laying). This is expressed as a percentage.

ii. **Total larval period (TLP):** Total period of the larval stage measured in days from the hatching of the larva from the eggs till the time of spinning the cocoon.

iii. **Pupation Percentage (PP):** The mature silkworm larvae pass into the pupal stage. Sometimes, some of the matured larvae are unable to stay alive inside the cocoon after cocoon formation. Thus this measure is the ratio of the number of cocoons with live pupae as a percentage of the total larvae. This is expressed as a percentage.

iv. **Cocoon yield (CY):** The total weight of cocoons harvest per 100 df. This is measured in grams or Kilograms.

Some of the characteristics such as single cocoon weight and single shell weight can be easily measured. On the other hand, some of the other characteristics can be measured only through a detailed analysis and actual process of reeling.

These parameters have challenged the effort to unify equipment and testing methods.

**Visual Inspection of cocoons**

**Colour**

Colour is a characteristic particular to the species. It is the presence of pigments in the sericin layers, which cause the colour. This colour is not permanent and washes away with the sericin during the degumming process, there are diverse hues of colour including but limited to white, yellow, yellowish green and golden yellow.

**Shape**

Cocoon shape, as colour, is peculiar to the given species. At the same time shape can be affected by the execution of the mounting process especially during the cocoon spinning stage. Generally, the Japanese species is peanut-shaped, the Chinese elliptical, European a longer elliptical and the polyvoltine species spindle-like in
Hybrid cocoons assume a shape midway between the parents for example, the case of a longer ellipsoid or shallowly enclosed peanut form. The shape of cocoons assists in identifying the variety of species plus evaluating reelability.

Wrinkle

The deflossed cocoon has many wrinkles on its surface. Wrinkles are coarser on the outer layer than within the interior layer. The outline of the wrinkle is not uniform, but various according to species and breeding conditions. Spinning employs high temperature and low humidity settings, which render fine wrinkles or cotton-like textures of, cocoon layers. These provisions discourage the agglutination of the baves resulting from accelerated drying. It is recognized that coarse wrinkled cocoons reel poorly.

Size

Cocoon size or volume is a critical characteristic when evaluating raw materials. The size of the cocoon differs according to silkworm variety, rearing season and harvesting conditions. The number of cocoons per litre, ranging between 60 and 100 in bivoltine species calculates size. Multivoltine species measure considerably higher.

Cocoon weight

The most significant commercial feature of cocoons is weight. Cocoons are sold in the marketplace based on weight as this index signals the approximate quantity of raw silk that can be reeled. The whole weight of a single cocoon is influenced by silkworm species, rearing season and harvest conditions. Pure breeds range from 2.2 to 1.5 g, while hybrid breeds weight from 2.5 to 1.8 g. In nature, the weight of a fresh cocoon does not remain constant but instead continues diminishing until the pupae transforms into a mother and emerges from the cocoon. This weight occurs gradually as moisture evaporates from the body of the pupae and as fat is consumed during the metamorphosis process.

6.2 COCOON TESTING AND GRADING

Cocoon testing and grading may be accomplished with a compact automatic reeling machine as well as a multi-ends reeling machine, which is typical equipment
in major sericultural countries. Testing methods used by major sericulture countries are displayed in Table 10.

The quantity of fresh cocoons, which are taken out of a lot for testing purposes depends on the actual weight of the lot on offer.

The cocoons on offer are divided into three batches.
Batch weighing up to 1 000 kgs
Batch weighing up to 2 000 kgs
Batch weighing up to 4 000 kgs

The sample size of fresh cocoons taken out of each batch for testing is as follows:
1st batch - 2.0 kgs
2nd batch – 4.5 kgs
3rd batch – 6.0 kgs

In the case of dry cocoons, the quantities taken out for testing from each batch are as follows:
1st batch up to 400 kgs of dry weight – 0.8 kgs taken out for testing.
2nd batch up to 800 kgs of dry weight – 1.8 kgs taken out for testing.
3rd batch up to 1 600 and over - 2.4 kgs taken out for testing.

1. Drying of the cocoon test sample.

The cocoons received must be dried as soon as possible and to an acceptable degree. To do this, the moisture content of the fresh pupa and the cocoon shell percentage must be measured. The percentage of drying is calculated according to the formula.
### Table 6.3: Cocoon classification systems of major sericultural countries

<table>
<thead>
<tr>
<th>CHINA</th>
<th>INDIA</th>
<th>JAPAN</th>
<th>KOREA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visual and mechanical test</strong></td>
<td><strong>Visual test</strong></td>
<td><strong>Mechanical test</strong></td>
<td><strong>Mechanical test</strong></td>
</tr>
<tr>
<td>A. Visual inspection</td>
<td>A. Estimated Renditta constant</td>
<td>A. Cocoon testing items</td>
<td>A. Cocoon testing items</td>
</tr>
<tr>
<td>- cocoon shell weight (g/20 p.c.s. of bivoltine or 40 p.c.s. of polyvoltine)</td>
<td>= \frac{\text{shell} % \text{ of cocoon lot constants : 165-133}}{100}</td>
<td>- Raw silk percentage of cocoon (%)</td>
<td>- Raw silk percentage of cocoon (%)</td>
</tr>
<tr>
<td>- 1 ~11 grade</td>
<td>weight of 100 shells shell% =\frac{x}{100} weight of 100 cocoons</td>
<td>- Percentage if eliminated cocoon (%)</td>
<td>- Percentage of eliminated cocoon (%)</td>
</tr>
<tr>
<td>: 9.0-7.0 g (Jiangsu)</td>
<td></td>
<td>- Reelability percentage (%)</td>
<td>- Length of cocoon filament (m)</td>
</tr>
<tr>
<td>: 9.4-6.4 g (Sichuen)</td>
<td></td>
<td></td>
<td>B. Classification of cocoons</td>
</tr>
<tr>
<td>B. Mechanical test</td>
<td>B. Cocoon pricing cost of cocoon per kg.</td>
<td>B. Grading of cocoon</td>
<td>B. Classification of cocoons</td>
</tr>
<tr>
<td>(Multi-ends reeling)</td>
<td>Kakame cost = \frac{\text{Kakame cost}}{\text{Renditta}}</td>
<td>- Length of cocoon filament</td>
<td>- Grade : Reelability percentage</td>
</tr>
<tr>
<td>- Length of non-broken cocoon filament (major item)</td>
<td>= \frac{\text{Kakame cost}}{\text{Renditta}}</td>
<td>10 class (33.5-42.5 point)</td>
<td>5A : 100-85</td>
</tr>
<tr>
<td>: 1~20 grades</td>
<td>+ \text{income from by-products}</td>
<td>- Cocoon reelability percent</td>
<td>4A : 84-80</td>
</tr>
<tr>
<td>(950-340 m)</td>
<td>- (\text{cost of manufacture + profits})</td>
<td>10 class (43.5-52.5 point)</td>
<td>3A : 79-75</td>
</tr>
<tr>
<td>- Percentage of good cocoons (auxiliary item)</td>
<td></td>
<td>Final grade (1+2)</td>
<td>A : over 90</td>
</tr>
<tr>
<td>: 1~8 grades</td>
<td></td>
<td>A : over 90</td>
<td>B : 88-89</td>
</tr>
<tr>
<td>(94-82%)</td>
<td></td>
<td>B : 88-89</td>
<td>C : 86-87</td>
</tr>
<tr>
<td>- Size of cocoon filament</td>
<td></td>
<td>C : 86-87</td>
<td>D : 84-85</td>
</tr>
<tr>
<td>and percent of inside stained cocoons (correction items)</td>
<td></td>
<td>D : 84-85</td>
<td>E : below 83</td>
</tr>
</tbody>
</table>

\[
\text{Drying percent of cocoon} = (0.0115 \times \text{mc of fresh pupa} - 0.2104) \\
x (\text{percent of cocoon shell 1.15}) \\
x (\text{mc of fresh cocoon + 115}) \\
(\text{mc : moisture content of the cocoons})
\]
Drying should be accomplished in one continuous process where the temperature is gradually decreased from 98°C to 60°C until the required ratio is obtained.

2. Test to calculate percentage of eliminated cocoons

This evaluation usually happens on a table under natural light. If natural light is insufficient based on time of day or weather conditions, elimination takes place under artificial light of 500 lux to calculate the percentage of eliminated cocoons according to terms and conditions defined by cocoon classification, the following types of cocoons must be removed: double cocoons, thin-end cocoons, scaffold marked cocoons, malformed cocoons, flimsy cocoons.

3. Batching of cocoon sampled for reeling

Table 6.4: Batching of cocoons for reeling, after elimination of the bad cocoons

<table>
<thead>
<tr>
<th>Batch</th>
<th>Sample cocoon (fresh weight)</th>
<th>Cocoon for reeling (dried weight)</th>
<th>Preliminary cooking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg</td>
<td>grams</td>
<td>grams</td>
</tr>
<tr>
<td>I</td>
<td>2.0</td>
<td>300 x 2</td>
<td>80</td>
</tr>
<tr>
<td>II</td>
<td>4.5</td>
<td>300 x 2</td>
<td>80 x 2</td>
</tr>
<tr>
<td>III</td>
<td>6.0</td>
<td>300 x 3</td>
<td>80 x 2</td>
</tr>
</tbody>
</table>

4. Cooking of the cocoon sample

A small sample of cocoons must be cooked to determine the correct cooking conditions for the specific batch. Once these parameters are established, actual cooking of the entire sample batch can be completed.

5. Reeling of cocoon sample

Table 6.5: The ideal conditions for reeling

<table>
<thead>
<tr>
<th>Item</th>
<th>Multi-end reeling</th>
<th>Automatic reeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature of groping end part</td>
<td>85°C</td>
<td>80°C</td>
</tr>
<tr>
<td>Reeling velocity</td>
<td>90 m/min</td>
<td>160 m/min</td>
</tr>
<tr>
<td>No. of reeling silk ends (per basin)</td>
<td>10 pcs.</td>
<td>3 pcs.</td>
</tr>
<tr>
<td>Length of croissure</td>
<td>10 cm</td>
<td>8 cm</td>
</tr>
<tr>
<td>No. of cocoons or objective size per reeling thread</td>
<td>8 pcs.</td>
<td>21 denier</td>
</tr>
</tbody>
</table>
Chapter – VI  Evaluation Of Silk Cocoon Parameters

6. Re-reeling

This should be carried out on large reels with a circumference of 1.5 m and the standard re-reeling speed of 160 r.p.m.

Calculation of results

The results of at least two or three reeling tests must be taken in order to calculate the classification. The resultant raw silk weight divided by the sample cocoon weight will indicate the raw silk percentage. The cocoon classification items are worked out by the following method:

1. Percentage of cocoon shell

\[
\text{Percentage of cocoon shell} = \frac{\text{Weight of cocoon shell (g)}}{\text{Weight of whole cocoon}} \times 100
\]

Points to be observed for testing percentage of cocoon shell are as follows:

- The percentage of the cocoon shell can be calculated from the weight of the whole cocoon and cocoon shell obtained from 200 cocoons from which 100 cocoons are taken separately.
- If possible, equal amounts of female and male cocoons should be selected for the sample.
- No defective cocoons should be included in the sample.
- As atmospheric conditions make the moisture content of the cocoons too variable, the sample should be selected from a point 10 cm beneath the surface of the batch of cocoons.

The average value of the percentage of the cocoon shell obtained from repeating the test twice must be graded within a 0.3 percent deviation. But if the difference between both samples is + 0.3 percent another test should be taken.

2. Estimated cocoon percentage

\[
= \frac{\text{Weight of eliminated cocoon}}{\text{Weight of sample cocoon (g)}} \times 100
\]
The result should be expressed to one decimal place where the weight of sample cocoons is the sum of eliminated cocoons plus the weight of the good cocoons.

3. Length of cocoon filament

\[
\text{Raw silk length (m) } = \frac{\text{Ave. reeling cocoon number per thread} \times \text{Ave. reeling cocoon number per thread}}{\text{Total reeled cocoon number}}
\]

Where, total reeled cocoon number

\[
= \text{Sample cocoon number} - \text{Converted carry over cocoon number}
\]

\[
\text{Ave. reeling cocoon number per thread} = \frac{-\text{Sum of reeling cocoon number per thread}}{\text{Sum of reeling ends number checked}}
\]

Length of raw silk is checked by the gauge. Sum of reeling cocoon number per thread is the total number of reeling cocoon verified 20 times during the reeling (this means once per unit work process). The length is based on the average of every reeling block. It is expressed by total number to the one decimal place. Converted unreelable cocoon number and carry over cocoons are calculated by converting them into length and expressed by full cocoon number to the one decimal place.

The cocoon number converted to full cocoon length

\[
= 1.00P + 0.77H + 0.39M + 0.12L (1)
\]

Where P : number of newly cooked cocoons but unreelable

H : number of heavy shell cocoons but unreelable or carried over

M : number of middle shell cocoons unreelable or carried over

L : number of light shell cocoons unreelable or carried over

The reeling cocoon number per thread is estimated down to two decimal places. The reeling work is not completed to the last single cocoon, but up to about 50 cocoons. The remaining cocoons are "carry over cocoons". They are divided into three kings: (H)...cocoons where only the outside layer has been reeled, (M)...cocoons reeled up to middle layer, and (L)...cocoons reeled up to inner side layer. These cocoons can be reeled along with other cocoons. That is why they should be converted into full cocoon length or weight and then the converted number has to be deducted from the total sample of cocoons to obtain the exact raw silk percentage or actual sample.
Chapter – VI  Evaluation Of Silk Cocoon Parameters

The converted number of full cocoon number is called "carry over cocoon number" which is calculated by multiplying the number of cocoons with Heavy layer, Middle layer and Light layer by cocoon convert indices. Also, the unreelable cocoons during the reeling or after reeling are converted into full cocoon number by applying the same indices as for carry over cocoon.

4. Reelability percentage:

Reelability is defined as the fitness of cocoons for economically feasible reeling. Industry practice measured the case with which the cocoon yields the have in reeling. Poor reelability causes a variety of production problems such as halts in production due to filament breakage and high degrees of waste product. Reelability is greatly affected by careful action during cocoon spinning, drying, storage, pre-processing, reeling machine efficiency and operator skill.

\[
\text{Reelability} = \frac{\text{Reeled cocoon number}}{\text{Number of ends feeding}} \times 100
\]

Where reeled cocoon number = number of sample cocoon
- number of unreelable new cocoons
+ number of converted carry over cocoons

Number of ends feeding = number of cocoons fed
+ number of carry over cocoons
- number of converted carry over cocoons

5. Raw silk percentage of cocoon:

This index is the most important for the value of the cocoon as it has a direct impact on both the market price of cocoons and the production costs of raw silk. The normal range is 65 to 84 percent for the weight of the cocoon shell and 12 to 20 percent for the weight of the whole fresh cocoon.

\[
\text{Raw silk percentage} = \frac{\text{condition silk weight (g) + carry over cocoon silk yield}}{\text{weight of cocoons}} \times 100
\]

Now, converted carry over cocoon silk (g)
= weight of bave (g) x number of carried over cocoons to be converted to full ones.

Here, weight of bave = \frac{\text{condition silk weight (g)}}{\text{number of reeled cocoons}}
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Where, number of reeled cocoons
= number of sample cocoons
- number of converted unreelable cocoons
+ number of converted carry over cocoons to full one

**Note:** Raw silk percentage is estimated to two decimal places. The weight of bave is estimated down to three decimal places. The converted unreelable cocoons and carry over cocoons are based on the weight system, and the number of converted cocoons is estimated on the total to one decimal place.

For example: The cocoon number converted to full cocoon weight
= 1.00P + 0.73H + 0.30M + 0.8L (2)

Where, P – number of newly cooked cocoons, but unreelled
H – number of heavy shell cocoons, but unreelable or carried over
M – number of middle shell cocoons, but unreelable or carried over
L – number of light shell cocoons, but unreelable or carried over

6. **Denier (d):** Single cocoon filament

The size of the cocoon filament expressed as Wt. In grams of 9000 mtrs.length.

\[
\text{Denier(d)} = \frac{\text{Wt.of cocoon filament in gms.} \times 9000}{\text{Length of the cocoon filament (m)}}
\]

OR

\[
\text{Denier(d)} = \frac{\text{Weight of raw silk reeled} \times 9000}{\text{Length of the silk reeled} \times \text{No. of cocoons maintained end}}
\]

7. **Shell percentage or Shell Ratio**

As the entire cocoon including the pupa is sold as part of the raw material, it is essential to quantify the ratio of the weight of the silk shell versus the weight of the cocoon. This is calculated in the formula:

\[
\frac{\text{Weight of the cocoon shell}}{\text{Weight of the whole cocoon}} \times 100
\]

This value gives a satisfactory indication of the amount of raw silk that can be reeled from a given quantity of fresh cocoons under transaction. The calculation assists in estimating the raw silk yield of the cocoon and in deriving an appropriate price for the cocoons. The percentage will change based on the breed of the
silkworms, rearing and mounting conditions. Percentage rates are altered based on the age of the cocoons as the pupa loses weight as metamorphosis continues. In newly evolved hybrids, recorded percentages are 19 to 25 percent, where male cocoons are higher than female cocoons.

**Cocoon grading method**

In cocoon classification, the result for length of cocoon filament and result of reelability percent is shown in Table 6.6 (1), (2) added up to the grading result which is applied to the cocoon grading shown in Table 6.6 (3).

Cocoon classification is divided into 5 grades: A, B, C, D and E.

**Table 6.6: Cocoon classification**

<table>
<thead>
<tr>
<th>(1) Grading of cocoon filament length (m)</th>
<th>Length of cocoon filament</th>
<th>below 920</th>
<th>991 to 1060</th>
<th>1131 to 1200</th>
<th>1271 to 1340</th>
<th>1411 to 1480</th>
<th>1481 over</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mark</td>
<td></td>
<td>33.5</td>
<td>34.5</td>
<td>35.5</td>
<td>36.5</td>
<td>37.5</td>
<td>38.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(2) Grading of cocoon reelability percent</th>
<th>Reelability percent</th>
<th>multi-end</th>
<th>below 39</th>
<th>40 to 45</th>
<th>46 to 51</th>
<th>52 to 56</th>
<th>57 to 62</th>
<th>63 to 68</th>
<th>69 to 73</th>
<th>74 to 80</th>
<th>81 to 86</th>
<th>87 over</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>automatic</td>
<td>below 34</td>
<td>34 to 39</td>
<td>40 to 45</td>
<td>46 to 51</td>
<td>52 to 57</td>
<td>58 to 63</td>
<td>64 to 76</td>
<td>70 to 76</td>
<td>77 to 82</td>
<td>83 over</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mark</td>
<td>43.5</td>
<td>44.5</td>
<td>45.5</td>
<td>46.5</td>
<td>47.5</td>
<td>48.5</td>
<td>49.5</td>
<td>50.5</td>
<td>51.5</td>
<td>52.5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(3) Final grade ([1] + [2])</th>
<th>Grade</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Result</td>
<td>over 90</td>
<td>88-89</td>
<td>86-87</td>
<td>84-85</td>
<td>below 83</td>
<td></td>
</tr>
</tbody>
</table>

6.3 EXPERIMENT

Commercial silkworm hybrid cocoons selected for the present study were: Kolar gold, CSR18 xCSR19, CSR2, CSR4, and CSR2xCSR4 developed by CSRTI Mysore, for south Indian climatic conditions.
Cocoon parameters, such as raw Silk percentage, filament length, reliability, denier and shell ratio were determined as per standard procedure.\textsuperscript{504}

### 6.4 RESULTS

The quality of the silk is determined by cocoon parameters, such as raw Silk percentage, filament length, reelability, denier and shell ratio. Out of the above mentioned, some cocoon parameters of all the 5 cocoon hybrids is tabulated in the Table-6.7 to 6.11.

**CSR-2:** CSR-2 fed with V-1 variety irrigated with 33\% spentwash appeared to be the best quality than 50\% spentwash and raw water, with 25.70\% raw silk, 1201.67 m of filament length, 87.16\% reelability, 3.25 denier and 26.52 shell ratio. The same cocoonhybrids fed with M-5 variety irrigated with 33\% spentwash showed 21.50\% raw silk, 1225.67 m of filament length, and 90.20\% reelability with 3.98 denier and 28.70 shell ratios.

**CSR4:** CSR-4 fed with V-1 variety irrigated with 33\% spentwash appeared to be the best quality than 50\% spentwash and raw water with 21.22\% raw silk, 1072.33 m of filament length, 82.11\% reelability, 3.21 denier and 24.52 shell ratios. The same cocoonhybrid fed with M-5 variety. Irrigated with 33\% spentwash showed 19.22\% raw silk, 1010.45 m of filament length, and 83.25\% reelability with 3.39 denier and 23.10 shell ratios.

**CSR2xCSR4:** CSR2xCSR4 fed with V-1 variety irrigated with 33\% spentwash appeared to be the best quality than 50\% spentwash and raw water, with 20.00\% raw silk, 1150.0 m of filament length, 85.00\% reelability, 3.00 denier and 23.50 shell ratio. The same cocoonhybrid fed with M-5 variety irrigated with 33\% spentwash showed 23.50\% raw silk, 1290.00 m of filament length, and 90.00\% reelability with 3.32 denier and 25.20 shell ratios.

**KolarGold:** Kolar gold fed with V-1 variety irrigated with 33\% spentwash appeared to be the best quality than 50\% spentwash and raw water, with 15.60\% raw silk, 864.66 m of filament length, 88.90\% reelability, 2.75 denier and 20.78 shell ratio. The
same cocoon hybrid fed with M-5 variety irrigated with 33% spentwash showed 14.89% raw silk, 878.34 m of filament length, and 88.20% reelability with 2.56 denier and 20.00 shell ratios.

**CSR18xCSR19:** CSR18 xCSR-19 species with 20.50% raw silk, 1100 m of filament length, 81.50% reelability, denier 2.80 and shell ratio 21.78 fed with V-1 variety irrigated with 33% spentwash appeared to be the best quality than 50% spentwash and raw water. The same cocoon hybrid fed with M-5 variety irrigated with 33% spentwash showed 19.20% raw silk, 1010.00 m of filament length, and 81.25% reelability with 2.82 denier and 21.75 shell ratios.

In our previous studies also found that 33% PTSW irrigation favours the growth, yield and nutrients of plants. This could be due to the maximum absorption of NPK by the plants at 33% dilution. In the case of 50% PTSW irrigation the yields were low. However, the values of cocoon parameters is maximum in the case of mulberry plants cultivated with 33% PTSW irrigation and minimum in case of raw water and moderate in 50% PTSW irrigation. It concludes that, in 33% PTSW irrigation the plants are able to absorb maximum amounts of nutrients (NPK) both from the soil and the spentwash resulting high yield and enhance the nutrients in plants leaves which in turn influence the better growth of silk worms containing higher proportion of silk proteins yields spinning of long silk threads in cocoons resulting in increased weight of cocoons, minimizes the cost of cultivation, and increase the yield of cocoons resulting in high silk production, this elevates the economy of the farmers, since cultivation of mulberry is made without using fertilizer. In our previous studies also found that 33% PTSW irrigation favours the growth, yield and nutrients of plants. This could be due to the maximum absorption of NPK by the plants at 33% dilution. In the case of 50% PTSW irrigation the yields were low.

### 6.5 DISCUSSION

Sericulture, also called silk farming is an agro-based industry which involves the rearing of silkworms for the production of raw silk, which is the yarn obtained out of cocoon spun by certain species of lepidopterous insects. However, the best quality raw silk is produced by the silkworm *Bombyxmori* (L) (Sericulum 2000). The *Bombyxmori* is essentially survives solely on mulberry leaves (*morusspp.*) which play
Chapter – VI  Evaluation Of Silk Cocoon Parameters

an important role in the nutrition of the silkworms, and in turn cocoon and silk production$^{505}$.

The nutritional elements of mulberry leaves determine the growth and development of the larvae and cocoon production$^{506}$.

The quality of the leaves has a profound effect on the superiority of silk produced by the *B. mori*$^{507}$.

In this regard, the production of good cocoon crop is totally dependent on the quality of leaves. Leaves of superior quality enhance the chances of good cocoon crop$^{508}$.

It has also been demonstrated that the dietary nutritional management has a direct influence on quality and quantity of silk production in *B. mori*$^{509}$.

Cocoon and shell weights are the major traits evaluated for productivity in sericulture and have been used for more than half a century. Cocoon weight is an important commercial characteristic used to determine approximately the amount of raw silk that can be obtained. Shell weight gives a better weight of the pupa$^{510}$.

But the determination of the shell weight is not recommended for the commercial purposes as it involves the destruction of the cocoon, which affects the total yield. In this point of view the present investigator only concentrated on the total weight and external parameters of the cocoon such as weight, shape and size.$^{511}$

Use of high protein diet effectively increases the quality of cocoon shell. However in this study author observed the significant differences in cocoon weight obtained with spentwash treated mulberry fed silkworm group as opposed to low cocoon weights in the control group. Many scientists have observed that the growth and development of silkworm are greatly influenced by the nutritional content of the mulberry$^{512, 513, 514}$.

The concentration of carbohydrates and carbohydrases as well as the midgut protease activity varied among the larvae when fed with different types of leaves$^{515, 516, 517}$ found out that nutritional value of mulberry leaves was directly reflected on the larval growth and cocoon characters of *B. mori* silkworm. The nutritive value of mulberry leaves depends on various factors of agro-climatic nature and any deficient quantities of nutrients from leaves affect silk synthesis by
silkworms. In this study it was observed that the yields of all the five varieties cocoons produced by rearing the silk worms using V-1 variety of mulberry leaves cultivated by irrigation in 33% PTSW were maximum and moderate in 50% PTSW and minimum in raw water irrigations. It concludes that, in 33% PTSW irrigation the plants are able to absorb maximum amounts of nutrients (NPK) both from the soil and the spentwash resulting high yield and enhance the nutrients in plants leaves which in turn influence the better growth of silk worms containing higher proportion of silk proteins yields spinning of long silk threads in cocoons resulting in increased weight of cocoons. The current study involved the spentwashas sources of organic manures and inorganic fertilizers when applied to mulberry might have increased the crude protein content, potassium and sulphur content in leaves which in turn influenced the cocoon and post cocoon parameters. These results are in agreement with results obtained\textsuperscript{467} reported that, application of nitrogen to mulberry significantly influenced the cocoon production, since it has profound influence on larval, cocoon and shell weights, shell percentage and cocoon yield as nitrogen promotes protein content in mulberry leaf. Significantly better performance of silkworms with respect to cocoon and post cocoon parameters were obtained by feeding the silkworms with leaves fertilized by different sources of N with or without biofertlilizers, which may be due to enhanced leaf quality through better uptake of nutrients induced by spentwash irrigation. The productivity depends on fifth instar larval duration as well as shell weight which were significantly better in desired direction in hybrids fed with the leaves of these genotypes which were nutritionally superior with regard to moisture content, total sugar and crude protein. From the present study it is obvious that, organic manures are having strong hold not only on the growth and development of silkworm, but also have a direct effect on the cocoon, pupal and silk weight and quality. Mulberry on treatment with 1% foliar applicant resulted in significant increase in major nutrients quantity of mulberry leaf especially in rainy season. These results are on par with the results\textsuperscript{518}

By usage of foliar applicant invariably proved the efficiency of greenleaf in increasing the protein content and carbohydrates of mulberry leaves. Similar results were also reported\textsuperscript{519} that foliar application had enriched mulberry leaf with macromolecules. The digestive enzymes such as amylase,\textsuperscript{520} that the enzyme activity was found to be higher in the later stage of larval development and the dietary intake
has a role to play. Allied studies cite that disparity in cocoon weight may be influenced by other factors points out that the cocoon weight also varies with the sex of the silkworm. The study on mulberry leaves of the same variety was obtained from the same field. Consequently the difference in larval weights can only be attributed to Silkworms hatched from the same dfls were used in this study to minimize varietal differences in performance. The overall data of the present study reveals that out of all the five cocoonhybrids, Kolar gold yielded was more with better quality of the cocoon. This may be due to the high resistance character of the species. Quality silk filaments in terms of strain are highly inheritable, are affected by additive gene action and allow a better response to selection. Regarding the silkworm races, the seed production is mainly controlled by the government and hence, farmers have less chance to choose. Presently, a bivoltine hybrid (CSR2 x CSR4) and a multivoltine hybrid Kolar Gold (CSR2 x Pure Mysore) are the two potential hybrids recommended and distributed to the farmers of Karnataka. Farmers choose between these two hybrids depending on the season and their rearing capacity (technology). The bivoltine hybrids are sensitive, need much care and which are reared mainly during the favourable season. The amount of bivoltine (BV) and multivoltine (MV) reared by the sample farmers in Karnataka 120 sample farmers, 117 farmers rear kolar gold (MV). A study was conducted to compare the performance and economics of bivoltine and multivoltine silkworm hybrids, Kolar Gold (PM × CSR2), CSR- (CSR2 × CSR4) and PM × C. Nichi hybrids raised by farmers in Karnataka to draw suitable policies to increase quality silk production in India. In the rain fed area, Kolar Gold cocoon productivity was more than that of C. Nichi hybrids. The average cocoon yield of 38 kg/100 dfls was observed for Kolar Gold whereas, 28 kg/100 dfls was observed for C. Nichi hybrids.

The present report shows significantly higher values of cocoon weight, for kolar gold fed on M-5 than the other tested cocoon species. However the productivity depends on fifth instar larval duration as well as digestion capacity which were significantly better in desired direction in hybrids fed with the leaves of these genotypes which were nutritionally superior with regard to moisture content, total sugar and crude protein. From the present study it is obvious that, spentwash, rich in nutritive components is having strong hold not only on the growth and development
of silkworm, but also has a direct effect on the cocoon, pupal and silk weight and quality.

Table 6.7: Cocoon parameters of CSR2 reared with V-1 and M-5 mulberry varieties irrigated with different dilutions of spentwash

<table>
<thead>
<tr>
<th>Parameters</th>
<th>V-1 variety</th>
<th>M-5 variety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RW</td>
<td>50% PTSW</td>
</tr>
<tr>
<td>Raw Silk (%)</td>
<td>21.33±0.022</td>
<td>22.40±0.015</td>
</tr>
<tr>
<td>Filament length (m)</td>
<td>1003.33±0.003</td>
<td>1040.00±0.009</td>
</tr>
<tr>
<td>Reelability (%)</td>
<td>79.66±0.012</td>
<td>82.06±0.015</td>
</tr>
<tr>
<td>Denier</td>
<td>2.69±0.011</td>
<td>2.85±0.009</td>
</tr>
<tr>
<td>Shell ratio</td>
<td>24.24±0.016</td>
<td>24.80±0.019</td>
</tr>
<tr>
<td></td>
<td>RW</td>
<td>50% PTSW</td>
</tr>
<tr>
<td></td>
<td>19.60±0.012</td>
<td>20.10±0.014</td>
</tr>
<tr>
<td></td>
<td>1000.50±0.006</td>
<td>1180.00±0.007</td>
</tr>
<tr>
<td></td>
<td>80.90±0.010</td>
<td>86.23±0.012</td>
</tr>
<tr>
<td></td>
<td>3.00±0.013</td>
<td>3.21±0.005</td>
</tr>
<tr>
<td></td>
<td>24.80±0.012</td>
<td>26.63±0.010</td>
</tr>
</tbody>
</table>

Figure 6.1 (a): Raw Silk Percentage of CSR2 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash
Figure 6.1 (b): Filament Length of CSR2 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

![Filament Length Chart]

Figure 6.1 (c): ReelabilityPercentage of CSR2 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

![Reelability Percentage Chart]
Figure 6.1 (d): Denier of CSR2 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

![Graph showing CSR2 - Denier with different dilutions of spentwash for V-1 and M-5 varieties.]

Figure 6.1(e): Shell Ratio of CSR2 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

![Graph showing CSR2 - Shell ratio with different dilutions of spentwash for V-1 and M-5 varieties.]

Table 6.8: Cocoon parameters of CSR4 reared with V-1 and M-5 mulberry varieties 
irrigated with different dilutions of spentwash

<table>
<thead>
<tr>
<th>Parameters</th>
<th>V-1 variety</th>
<th></th>
<th></th>
<th>M-5 variety</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RW</td>
<td>50% PTSW</td>
<td>33% PTSW</td>
<td>RW</td>
<td>50% PTSW</td>
<td>33% PTSW</td>
</tr>
<tr>
<td>Raw Silk (%)</td>
<td>17.31±0.020</td>
<td>19.10±0.012</td>
<td>21.22±0.011</td>
<td>16.75±0.018</td>
<td>18.55±0.009</td>
<td>19.22±0.009</td>
</tr>
<tr>
<td>Filament length (m)</td>
<td>913.67±0.008</td>
<td>1030.00±0.009</td>
<td>1072.33±0.009</td>
<td>750.65±0.006</td>
<td>900.00±0.006</td>
<td>1010.45±0.006</td>
</tr>
<tr>
<td>Reelability (%)</td>
<td>74.16±0.015</td>
<td>77.33±0.019</td>
<td>82.11±0.013</td>
<td>76.00±0.013</td>
<td>78.12±0.013</td>
<td>83.25±0.012</td>
</tr>
<tr>
<td>Denier</td>
<td>2.64±0.016</td>
<td>2.76±0.009</td>
<td>3.21±0.012</td>
<td>3.19±0.015</td>
<td>3.29±0.006</td>
<td>3.39±0.011</td>
</tr>
<tr>
<td>Shell ratio</td>
<td>21.57±0.018</td>
<td>23.80±0.014</td>
<td>24.52±0.016</td>
<td>21.30±0.013</td>
<td>22.00±0.012</td>
<td>23.10±0.012</td>
</tr>
</tbody>
</table>

Figure 6.2(a): Raw Silk Percentage of CSR4 reared with V-1 and M-5 mulberry 
cultivated by different dilution of spentwash
**Figure 6.2 (b): Filament Length of CSR4 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash**

![Graph showing filament length comparison](image)

**Figure 6.2 (c): Reelability Percentage of CSR4 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash**

![Graph showing reelability percentage comparison](image)
Figure 6.2 (d): Denier of CSR4 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

![Figure 6.2 (d)](image)

Figure 6.2(e): Shell Ratio of CSR4 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

![Figure 6.2(e)](image)
Table 6.9: Cocoon parameters of CSR2xCSR4 reared with V-1 and M-5 mulberry varieties irrigated with different dilutions of spentwash

<table>
<thead>
<tr>
<th>Parameters</th>
<th>V-1 variety</th>
<th>M-5 variety</th>
<th>V-1 variety</th>
<th>M-5 variety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50% PTSW</td>
<td>33% PTSW</td>
<td>50% PTSW</td>
<td>33% PTSW</td>
</tr>
<tr>
<td>Raw Silk (%)</td>
<td>18.00±0.018</td>
<td>18.75±0.009</td>
<td>20.00±0.008</td>
<td>20.00±0.013</td>
</tr>
<tr>
<td>Filament length (m)</td>
<td>1138.00±0.006</td>
<td>1147.00±0.003</td>
<td>1150.00±0.010</td>
<td>1147.00±0.004</td>
</tr>
<tr>
<td>Reelability (%)</td>
<td>79.00±0.012</td>
<td>81.00±0.015</td>
<td>85.00±0.010</td>
<td>85.00±0.008</td>
</tr>
<tr>
<td>Denier</td>
<td>2.69±0.011</td>
<td>2.73±0.002</td>
<td>3.00±0.009</td>
<td>2.57±0.012</td>
</tr>
<tr>
<td>Shell ratio</td>
<td>21.70±0.014</td>
<td>22.65±0.012</td>
<td>23.50±0.016</td>
<td>23.50±0.011</td>
</tr>
</tbody>
</table>

Figure 6.3(a): Raw Silk Percentage of CSR2xCSR4 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash
Figure 6.3 (b): Filament Length of CSR2x CSR4 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

Figure 6.3 (c): Reelability Percentage of CSR2x CSR4 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash
Figure 6.3 (d): Denier of CSR2x CSR4 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

![Graph showing filament length for different dilutions of spentwash for CSR2x CSR4 reared with V-1 and M-5 mulberry.]

Figure 6.3(e): Shell Ratio of CSR2x CSR4 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

![Graph showing shell ratio for different dilutions of spentwash for CSR2x CSR4 reared with V-1 and M-5 mulberry.]

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Table 6.10: Cocoon parameters of Kolar gold reared with V-1 and M-5 mulberry varieties irrigated with different dilutions of spentwash

<table>
<thead>
<tr>
<th>Parameters</th>
<th>V-1 variety</th>
<th>M-5 variety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RW</td>
<td>50% PTSW</td>
</tr>
<tr>
<td>Yield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Silk (%)</td>
<td>13.00±0.019</td>
<td>14.42±0.011</td>
</tr>
<tr>
<td>Filament length (m)</td>
<td>731.67±0.009</td>
<td>825.00±0.010</td>
</tr>
<tr>
<td>Reelability (%)</td>
<td>85.30±0.014</td>
<td>87.20±0.012</td>
</tr>
<tr>
<td>Denier</td>
<td>2.60±0.013</td>
<td>2.69±0.007</td>
</tr>
<tr>
<td>Shell ratio</td>
<td>18.66±0.015</td>
<td>19.6±0.011</td>
</tr>
</tbody>
</table>

Figure 6.4(a): Raw Silk Percentage of Kolar gold reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash
**Figure 6.4 (b): Filament Length of Kolar gold reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash**

![Bar chart showing filament length for different dilutions of spentwash with V-1 and M-5 varieties.](image)

**Figure 6.4 (c): Reelability Percentage of Kolar gold reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash**

![Bar chart showing reelability percentage for different dilutions of spentwash with V-1 and M-5 varieties.](image)
Figure 6.4 (d): Denier of Kolar gold reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

![Graph showing Denier of Kolar gold](image)

Figure 6.4(e): Shell Ratio of Kolar gold reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

![Graph showing Shell Ratio of Kolar gold](image)
Table 6.11: Cocoon parameters of CSR18 x CSR19 reared with V-1 and M-5 mulberry varieties Irrigated with different dilutions of spentwash

<table>
<thead>
<tr>
<th>Parameters</th>
<th>V-1 variety</th>
<th>M-5 variety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RW 50% PTSW 33% PTSW</td>
<td>RW 50% PTSW 33% PTSW</td>
</tr>
<tr>
<td>Raw Silk (%)</td>
<td>19.00±0.014 20.10±0.008 20.50±0.012</td>
<td>17.90±0.015 18.65±0.010 19.20±0.012</td>
</tr>
<tr>
<td>Filament length (m)</td>
<td>900.00±0.006 986.30±0.011 1100.00±0.009</td>
<td>895.00±0.008 970.25±0.010 1010.00±0.010</td>
</tr>
<tr>
<td>Reelability (%)</td>
<td>80.00±0.010 80.60±0.006 81.50±0.009</td>
<td>79.35±0.009 80.20±0.012 81.25±0.018</td>
</tr>
<tr>
<td>Denier</td>
<td>2.70±0.017 2.72±0.010 2.80±0.012</td>
<td>2.69±0.012 2.75±0.011 2.82±0.005</td>
</tr>
<tr>
<td>Shell ratio</td>
<td>20.65±0.011 21.10±0.010 21.78±0.012</td>
<td>20.50±0.013 21.36±0.009 21.75±0.015</td>
</tr>
</tbody>
</table>

Figure 6.5(a): Raw Silk Percentage of CSR18 x CSR19 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash
Figure 6.5 (b): Filament Length of CSR18 x CSR19 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

Figure 6.5 (c): Reelability Percentage of CSR18 x CSR19 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash
Figure 6.5 (d): Denier of CSR18 x CSR19 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash

Figure 6.5(e): Shell Ratio of CSR18 x CSR19 reared with V-1 and M-5 mulberry cultivated by different dilution of spentwash
Fig. 6.6: Silk Reeling and Silk Yarn

SILK REELING -1  SILK REELING -2  SILK REELING -3

SILK THREAD -1  SILK THREAD -2  SILK REELING CHARAKA

SILK YARN -1  SILK YARN -2  SILK YARN -3

SILK YARN -4  SILK YARN -5  SILK YARN -6