1
Silk

1.1 Introduction and history

Silk has a whole series of connotations which transcend its actual technical characteristics. A simple experiment will suffice: say the word 'silk' to a woman and ask her what the word conjures up for her. It is likely that she will respond with words like 'sensuality', 'luxury', 'glamour'. These qualities may now be available, to a certain extent, among other fibres but it is very unlikely that the mention of nylon, polyester or polypropylene will spark off quite the same set of dream-like reactions.

Silk is also the only fibre which has inspired writers and poets over the ages. The very word 'silk' has entered everyday language in such phrases as 'smooth as silk', 'silken hair'. It has even gone beyond the realm of textiles, and its name is used to promote goods and services as diverse as cigarettes, shampoo, whisky and airlines. Which indicates that silk is not perceived as an ordinary fibre but one which has come to represent something almost magical.

This legendary quality of silk has several explanations:

- Its geographical origins.
- The way it is produced.
- How it was used in the past.
- Its real technical qualities.
- Its use in different textile applications.

There is also the fact that silk is a very small fibre in terms of global production quantities. In overall textile fibre production it accounts for less than 0.2 %, as compared with over 51 % for cotton and 40 % for synthetic fibres. As silk production declines and that of man-made fibres increases, this proportion is likely to become even smaller.

1.1.1 The origins

According to Confucius, the discovery of silk goes back to 2640 BC. Legend has it that a Chinese princess, Xi Lin Shi, was drinking tea in a mulberry garden when a cocoon dropped into her cup. The hot tea dissolved the hard outer layer of the cocoon. In trying to extract it with her long fingernail, she discovered that the cocoon contained a continuous filament. As she kept pulling on the thread, it continued to unwind. The princess had just invented the first technique of reeling silk.

At that time in China's history, weaving was already well-established, so it was possible to convert this new-found fibre into fabric. Although it is difficult to prove with certainty, it is highly likely that the discovery of silk went hand-in-hand with some important improvements in the technology of weaving. Recent archaeological discoveries in China, notably in Hubei province in 1982, have brought to light fragments of some highly elaborate fabrics, over 2000 years old, which could only have been produced on sophisticated looms. These fabrics included chiffons, brocades and gauzes and the majority of them were embroidered.

If the discovery of silk really did lead to vast improvements in weaving (and in other processes such as dyeing and printing) it is because of another special characteristic of silk, namely that it is the only natural fibre in the form of a continuous filament. All other natural fibres, wool, linen, cotton, cashmere, have to be spun into a yarn from short fibres. (This is also the way in which spun-silk is manufactured, as described later.)

Although today a single silk cocoon can yield up to 1600 metres of continuous filament, this is the result of centuries of selection and development of the silkworm, but in ancient times the yield was obviously much lower, possibly between 100 and 150 metres per cocoon. Nevertheless, the continuous nature of the silk thread made it much stronger and easier to weave than cotton, flax or wool.

The Chinese were quick to realise the potential of this extraordinary fibre which, in their own expression, 'came from heaven'. They took every precaution to make sure that the secret of its origin was carefully guarded and made the revelation of its derivation an offence punishable by death.

From the very beginning, silk was the object of two major orientations, one technical and the other marketing, which were to mark its development right up to present times. First of all, the Chinese set about domesticating the silkworm, originally an insect which lived in the wild, so as to optimise both the quantity and the quality of the filaments produced. Secondly, the final product, embroidered or printed fabrics and garments, was reserved for an exclusive market. Silk was used by the Empress and her court and as a means of payment for high-ranking civil servants. It was also the means of exchange for products which the Chinese wanted to import. From the first millennium, China was already exporting silk fabrics to India, central Asia and ultimately Europe. This trade became progressively more organised with the extension, in the first century BC, of the legendary Silk Roads. The Silk Roads, which were to become the first ever major trade route, are generally considered to have their starting point in the city of Ch'Ang'an (known today as Xi'an). They spread westwards into central Asia and India. In addition to the land routes, the maritime routes also made a major contribution to the spread of silk throughout Asia and Arabia.

1.1.2 Silk production outside China

Although silk fabrics were exported from China throughout south-east and central Asia, the most important fact for the future of silk was the loss of China's production monopoly. It was no doubt inevitable that one day the jealously guarded secret of the silkworm would be broken.

Silk as we know it is produced by the domesticated silkworm, *Bombyx mori*, which originated in the wild, but numerous other varieties of wild silkworm existed in various countries, notably India, which is still the world's major producer of wild silk. The basic idea of a fibre-producing insect was therefore probably familiar to other peoples. *Bombyx mori* sericulture is thought to have spread to India through Khotan in Chinese Turkestan around 140 BC.

Sericulture was introduced to Korea by Chinese immigrants in about 1200 BC and from there it reached Japan. There are several versions of the way in which the Japanese learned how to produce silk. It is likely that military conquest was the reason, for Japan invaded Korea in the third century BC and Korean prisoners, including many silk farmers, were brought to Japan.

The history of silk is not merely economic. It has always been intimately connected with the major political and military events of history. The Roman Empire, which in the first century BC extended throughout the Mediterranean basin, attempted to expand eastward from its frontier on the Euphrates. Seven Roman legions under the command of Marcus Licinius Crassus, their lines of communication stretched to the limit, came into conflict with an army composed of Parthian tribesmen near the city of Carrhae (today, Harran in Turkey). The result of the battle was a disastrous defeat for the Roman army and the death of its commander. Apart from the terrible efficiency of the Parthian archers, one of the factors which contributed to the utter demoralisation of the legionaries was the sight and sound of the banners which the Parthians unfurled near the end of the day. These brilliantly coloured and embroidered banners were the first contact the Romans had with silk.

From then on, silk was to become a feature of Roman life, either through trade or as the spoils of more successful campaigns beyond the eastern reaches of the Empire. Less than 50 years after the terrible defeat at Carrhae, silk had become so widespread in Rome, not only on ceremonial occasions but among the wealthier citizens for everyday wear, that the Senate had to limit its use to women. Although the official reason was that silk was considered too effeminate for men, the actual grounds were probably economic, because all silk was imported and hence responsible for a considerable outflow of capital. (About 1500 years later, the same reason led to the introduction of silk manufacture in France.)

In the early centuries of the Christian era, the main centre of the silk trade outside China was Persia. Weaving and finishing were also known in Syria, Greece and Egypt. The raw material, raw silk, was obtained by importing from China or by recovering silk yarn from imported fabrics. The Emperor Justinian was anxious to gain economic independence in the silk trade by eliminating middlemen as far as possible. In 552 BC, he sent two monks on a mission to the mysterious eastern territories, the land of the Sers. (Sers was the name given to the Chinese at that time and the root 'ser' is still found in such words as sericulture and sericin.) The ostensibly evangelical objective of the mission concealed its real purpose, which was to bring back the secret of silk production. The monks, whose knowledge of silk came from their having lived in China, were to be handsomely rewarded if they succeeded, which they duly did. They brought back silkworm eggs hidden in their hollowed-out canes, and this early example of industrial espionage marks the beginning of sericulture in Asia Minor and later in North Africa and Europe. This was by no means the beginning of the end of trade in silk, however, which continued to flourish and was to receive even more impetus after the next major political upheaval, the Arab conquest of Syria and Persia.

In the space of barely 100 years, Islam spread as far east as the frontiers of India and China and as far west as Spain. The Arabs not only assimilated the artistic traditions of the vanquished territories, they developed them even further. Their appreciation of the silk fabrics that they found in Syria and Persia led them to create workshops to provide new silk products. Damascus was to become the centre of silk creation under Arab rule. Its importance as a creative centre of weaving technology is reflected in the special type of fabric known as damask. The major centre of textile design and weaving in the Roman Empire, Alexandria, also fell to the Arab invaders and brought them not only advanced techniques in fabric production but also new artistic influences.

It was the Islamic conquests along the southern rim of the Mediterranean that led to the introduction of sericulture to North Africa, Sicily and Spain. In Spain, raw silk production started in Murcia and Valencia, while the industry was to flourish in Almeria, Granada and Cordoba. (It is interesting to note that if Charles Martell had not halted the Moorish invasion of France at Poitiers in 732, sericulture might well have started up in France some 860 years before it actually did.)

1.1.3 The development of silk in Europe

At this time, silk was used throughout Asia and the Arab world, but remained relatively rare in Europe. Silk fabrics were appreciated as trophies of war or as gifts from foreign ambassadors but their use was not widespread. One of silk's essential functions was as a means of exchange; goods could be bought or bartered using silk. Because of its exceptional resistance to the passage of time, silk was considered a solid investment.

The spread of the silk industry to Europe really began with the conquest of Sicily by Roger II in 1060. Not only did he foster the existing silk industry established in Palermo, but he also imported Greek and Jewish workers to develop the industry, both from a technical point of view and by the use of designs hitherto unknown in Sicily.

The next decisive step in the development of silk in Europe came from the Crusaders, who were in contact with the superb silk creations developed by the Persians, the Arabs and the inhabitants of Byzantium. Silk was no longer reserved for kings and emperors but began to find its way into the homes of wealthy merchants and soldiers.

In the early Middle Ages, Italy was composed of a number of flourishing city-states and it was in one of these, Lucca, that the silk industry started, with the help of refugees from the Norman conquest of Sicily. In this unstable period of Italian history, the fortunes of the city-states could change very quickly and Lucca was eventually supplanted by Florence as the chief silk-producing city in Italy. Florence already had a woollen industry and was thus able easily to assimilate silk weaving. Although the merchants of Lucca remained, many of the weavers moved to Florence, Bologna, Genoa and Venice.

During the twelfth and thirteenth centuries, the overland route used for silk trading with China had been closed by the Arabs, and commerce became highly unreliable or was diverted to the maritime silk routes. Once again, political events were to change the picture, not only in terms of trade but in terms of artistic influence. The conquest of central Asia by the Mongols pacified the territories crossed by the overland silk routes and trade between east and west underwent considerable development, not only in silk but in a vast range of goods such as gold and silver, porcelain, spices and horses in both directions. Italian art was at that point undergoing its most creative period, and the influx of Chinese and central Asian designs profoundly influenced the Italian artists of that time. Marco Polo's travels in China, at the end of the thirteenth century, also gave new sources of inspiration to the silk weavers in Italy, in particular to those in his native city, Venice.

Florence and Venice continued to vie for creative supremacy, especially in the field of velvets. The industry was well organised, under the aegis of the guilds and corporations, and already there were regulations governing what is known today as intellectual property.

It was not until the fifteenth century that silk manufacture really began to develop in France. Although there were silk weavers in Avignon, working to provide vestments and embroideries for the exiled Pope and his entourage, France was essentially involved in the trade of silk products but not yet their manufacture. The chief centre of this trade was Lyon, which was later to become the centre of the whole European silk industry.

The starting point for trade in silk was the existence of two annual trade-fairs established in Lyon by Charles VII in 1419. These fairs attracted merchants and bankers from Florence whose influence on the city of Lyon can still be seen today. The old quarter of Lyon is characterised by Florentine architecture. The Italians not only developed the silk trade but were also dressed in silk garments and thus served as a kind of walking advertisement for their wares. At the same time they proved that silk could be worn not only by kings and aristocrats.

The purchase of foreign silks began to represent a serious drain on the country's foreign exchange, to such an extent that Louis XI decided to initiate silk manufacture in France. Lyon's proximity to Italy and the presence of numerous Florentine bankers and merchants who lived there made it the ideal place to establish silk weaving. However, Louis XI's offer (1466) to grant Lyon the privilege of being the first centre of silk manufacture in France met with a very cool reaction from the Lyon Chamber of Commerce (or *Consulat* as it then was). Either the Lyonnais were afraid of spoiling their relationship with the Italians or more prosaically they were unwilling to pay the money the king was asking for the privilege. The most plausible explanation is that the Lyon silk merchants, influential members of the *Consulat*, were making so much money from importing Italian silks that they were loath to contribute to the creation of local competition. Whatever the reason, Louis XI tired of insisting and set up the first official manufacture of silk in Tours in 1470, followed by another in Nîmes, intended to compete with Avignon. Tours became an important centre of silk weaving, not only of fabrics for garments but chiefly for furnishing fabrics to embellish the châteaux along the Loire.

During this time, there were a few Italian weavers, from Piedmont and Genoa, working on a small scale in Lyon. The most enterprising of these immigrants was Etienne Turquet, a Piedmontese trader and weaver. Turquet was quick to see the possibilities of creating a silk industry in his adopted city, especially as one of the major producing areas, Genoa, was going through a period of political turmoil. Together with the city authorities, he obtained from the then king, François I, in September 1536, letters patent which gave the city of Lyon the right to establish a silk industry and also, what was even more important, the monopoly of raw silk imports. The king had no difficulty in acceding to the requests of the people of Lyon because he had always held the city in the highest esteem, and had even considered making it his capital. By this decision he was able to stem the outflow of currency and contribute to the downfall of a major competitor, Genoa. In order to hasten the development of the nascent silk industry, François I also decreed a certain number of privileges for silk workers, including tax exemptions, as a means of attracting foreign (i.e. Italian) craftsmen to Lyon. The skilled workers already installed in Nîmes and Tours moved to Lyon to benefit from these advantages, thus beginning the decline of the industry in the towns they left and the concentration of silk manufacture in Lyon. There was no lack of venture capital from the Florentine bankers already well acquainted with Lyon through its trade fairs.

For the time being, Lyon depended on imports of raw silk from Italy to supply its manufacturing industries. The next logical step in ensuring the industry's economic independence was to start silk production in France. Sericulture started up in the Rhône valley under Henri IV. The architect of this production was the agronomist Olivier de Serres and the initial purchases of mulberry saplings and silkworm eggs were financed by a special tax raised in Lyon, following a decree published by Henri IV in 1604.

From then on, Lyon was able to become less dependent on imports of foreign raw silk, but it was not until the middle of the nineteenth century that French production was able to make a really significant contribution to the industry's needs in terms of raw silk.

The Ottoman Empire was also a major centre of silk production and manufacture at this time, concentrated in the town of Bursa, where some silk production continues to this day. The Italian industry was also still extremely active, with Florence now the dominant force, but political and economic unrest hampered the progress of the Italian silk weavers and enabled Lyon to begin to position itself on the international market for silk fabrics. The relative peace that France enjoyed, at least after the end of the wars of religion, enabled the industry to prosper while the city-states of Italy were in almost permanent conflict with each other.

One of the strong points of the Lyonnais silk workers was their capacity to innovate, sometimes by improving on existing machinery. The draw-loom perfected in Lyon from an Italian design enabled the weavers to execute larger and more complicated patterns.

Throughout the seventeenth century Lyon continued to develop its weaving, but in 1685 the revocation of the Edict of Nantes, which for a hundred years had protected the Huguenots from religious and political persecution, dealt a serious blow to the silk industry. Huguenot refugees exported their technical skills and business acumen to other, more tolerant, European countries. The Netherlands, Germany, Switzerland and England were therefore able to benefit from the misfortunes of the Protestant silk workers and traders and create their own silk industries. In London, the silk industry was concentrated in Spitalfields.

The courts of Europe were the greatest patrons of the European silk industries in the eighteenth century. Catherine the Great of Russia, among others, placed orders for silk fabrics from the well-known designers of the time. The new designs being produced in France by such famous artists as Philippe de la Salle represented a break with the past. They were more figurative and less symmetrical than in the previous century. They were also more refined, while the constant development of weaving techniques made them more and more intricate.

Although it is not often realised, blended fabrics including silk were also commonly produced at this time. The silk manufacturers understood even then that they had to offer more than just the most luxurious fabrics if they were to reach a wider market.

In the nineteenth century, Lyon had established its leadership in luxurious furnishing fabrics. A major step forward came with the invention by Joseph-Marie Jacquard of the mechanism which bears his name. The idea of selecting individual yarns to compose the designs of a figured fabric was not new, but until Jacquard's invention it was done by hand. The 'draw-boy' (as a boy, Jacquard himself was one) pulled the cords which controlled the warp-yarns at each pick of the loom. Jacquard's process consisted of translating the required design onto a perforated card placed in a mechanism above the loom which replaced the draw-boy and also made the weaving quicker and more efficient. This enabled the Lyonnais to gain a technical advantage over their European competitors and produce fabrics appealing to a wider clientele. Nowadays, Jacquard designs are no longer realised through perforated cards but by computer, which is a very neat completion of a logical cycle. Jacquard is sometimes considered as the father of computer language, since the perforated-card system is an early example of binary language; there is a hole or there is no hole.

Although Lyon was to establish its advantage over its competitors, particularly the Italians, the nineteenth century also saw the decline of silk production in France. The first major event was an outbreak of a disease endemic to the silkworm, pébrine, which decimated production in the Rhône valley in the middle of the century. Although a young scientist then at the beginning of his career, Louis Pasteur, discovered the causes of this deadly disease and devised means of combating it, the epidemic was the start of the slow decline of French sericulture. Despite a revival of production in the years 1865–1870, the French silk industry began to look for its raw material supplies elsewhere. Commercial exchanges with China and Japan were beginning to develop and the opening of the Suez Canal in 1872 meant that Asian raw silk could be shipped direct to Marseilles, instead of going through London. London was a major centre of the raw silk trade because of the superiority of Britain's shipping, built on the experience of trade in tea and other commodities from Asia and the efficiency of the clipper ships.

In the United Kingdom at this time, the silk manufacturing centre was Macclesfield. However, the British silk industry benefited from protectionist trade measures which were abolished in the context of the free trade movement which gained strength in England in the 1860s. Foreign, mainly French, silks were able to enter the UK much more freely, and this obliged many of the Macclesfield weavers to emigrate, in particular to Paterson, New Jersey. Macclesfield nevertheless continued to be a centre of quality silk production but on a smaller scale.

In the latter part of the nineteenth century there were still 60 000 looms in Great Britain but strong competition for the British silk industry also came from Krefeld in Germany (with 70 000 looms) and Zürich, which counted over 30 000.

1.2 Silk fibre and its characteristics

As mentioned before, silk is a natural fibre, in common with others such as cotton, wool, linen, cashmere and mohair.

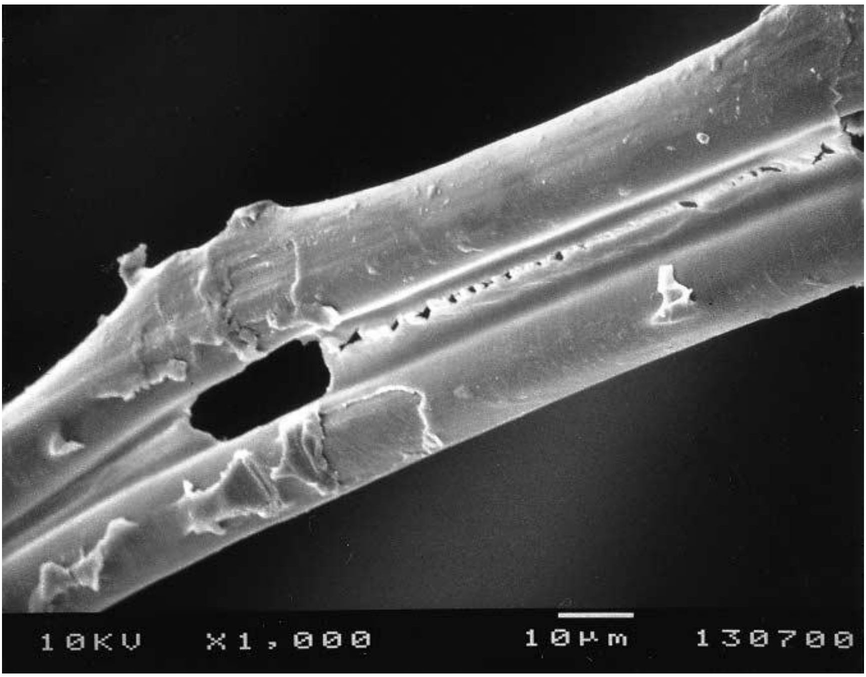
Silk is a protein fibre and its amino acid composition is close to that of the human skin. The proteins composing the outer layer of sericin are soluble in hot water while the proteins in the fibre itself are insoluble. When pure, silk fibre is hygienic and non-allergenic, but the various treatments to which it is subjected during its processing may introduce elements that can cause irritation of the skin.

Compared with the other natural fibres, silk has certain specific characteristics which set it apart. These specific properties of silk are summarised in Table 1.1.

Table 1.1 Some properties of silk

Physical properties	Mechanical properties
Moisture regain: 11%	Tenacity: 5 gr/denier
Shrinkage (wet): 0.9%	Elongation: 17%–25% (dry), 30% (wet)
Specific gravity: 1.3	Rigidity modulus: 2.5

These physical characteristics are determined by the structure of the macromolecule composing the fibroin as shown in Fig. 1.1. Part of the macromolecule is made up of amino acids with a low molecular weight, offering a series of crystalline regions which confer a high degree of tenacity on the fibre. The rest of the macromolecule is characterised by the presence of amorphous areas enclosing amino acids of a relatively higher molecular weight. The presence of both crystalline and amorphous zones makes for a combination of strength, flexibility and elasticity.



1.1 Silk micrograph (ITF).

Silk is composed of two protein groups, forming respectively the fibroin and the sericin. In the fibroin, alanine and glycine together account for 70 % of the total composition, whereas in the sericin they make up about 15 %. The chief component of sericin is another amino acid, serine (30 % of the total).

– Silk is the only natural fibre which exists as a continuous filament. Each *Bombyx mori* cocoon can yield up to 1600 metres of filament. These can be easily joined together using the adhesive qualities of sericin to form a theoretically endless filament.
– The silk fibre's triangular cross-section gives it excellent light reflection capability.

- The silk fibre is smooth, unlike those of wool, cotton and others. This is one of the reasons why silk fabrics are so lustrous and soft.
- Silk can absorb up to 30 % of its weight in moisture without creating a damp feeling. When moisture is absorbed it generates 'wetting-heat' which helps to explain why silk is comfortable to wear next to the skin.
- Silk has a tenacity of approximately 4.8 grammes per denier, slightly less than that of nylon.
- Silk has poor resistance to ultraviolet light and for this reason is only recommended for those curtains that are lined or not exposed to direct sunlight.

From the nineteenth century, attempts have been made to reproduce the qualities of natural silk. It is no coincidence that rayon was initially known as 'artificial silk' before the term was banned. The basic principle of the production of synthetic fibres is the extrusion of a semi-liquid mix through a tiny hole to form a filament that hardens on contact with the air, and this is exactly the same principle that is used by the silkworm.

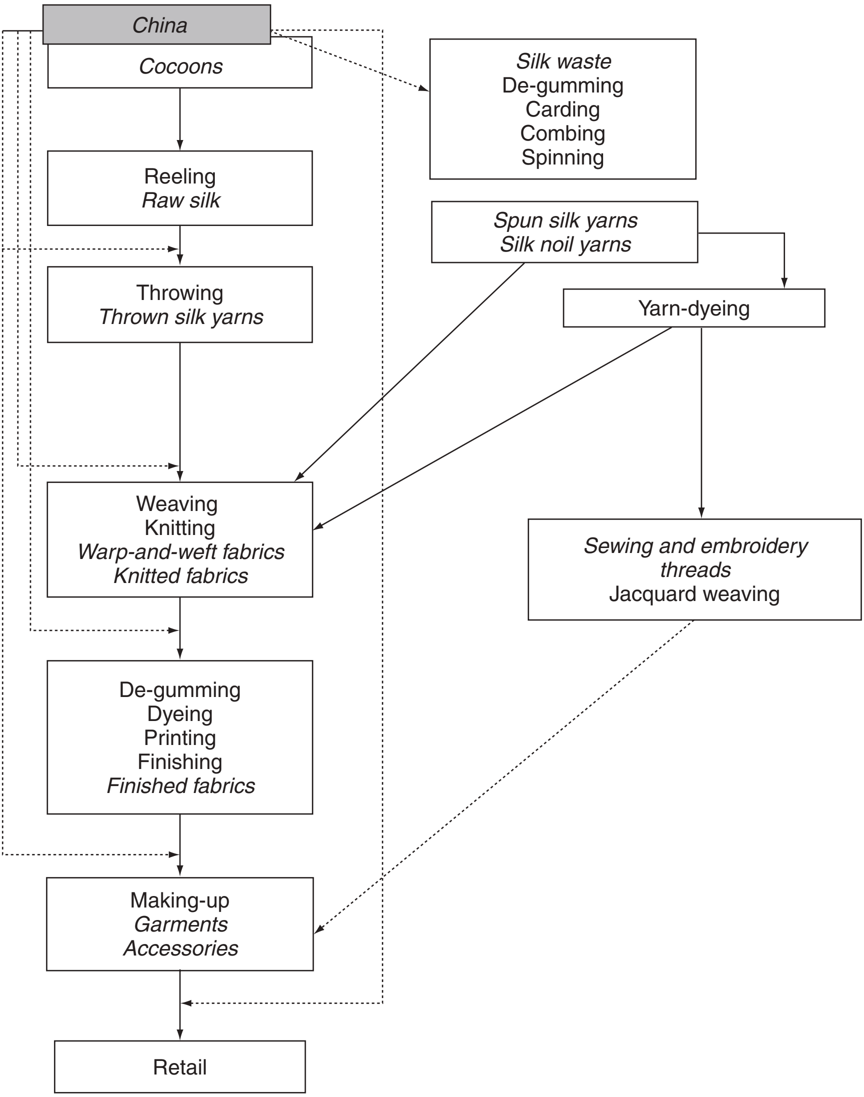
Although the chemical composition of natural silk is extremely well-known and the 'recipe' can be reproduced, no one has so far succeeded in spinning a continuous filament of natural silk. This is because the molecular organisation of the sericin-plus-fibroin combination is not the same when it is in the body of the silkworm and when it is extruded. For the time being, only *Bombyx mori* knows how to rearrange the molecules into a continuous fibre.

Obviously, chemical fibres have made and continue to make enormous progress. They often possess characteristics which are far superior to those of silk, particularly in the field of washing and ironing. They even, in some cases, have the appearance and the feel of silk. However, not one of the new fibres, for all their undoubted qualities, has so far succeeded in bringing together all the characteristics associated with silk, and in particular its specific combination of handle, drape, appearance, lustre and comfort when worn. One of the greatest tributes to silk is the number of brand names and advertisements for synthetic fibres which describe them by using such adjectives as 'silky' and 'silk-like'.

1.3 Silkworm rearing and cocoon production

Figure 1.2 shows the flow chart for silk manufacturing.

There are hundreds of varieties of Lepidoptera which produce silk in the wild. The silk thread presents extraordinary properties of physical strength and insulation, hence its use in building prey-catching structures or protective 'housing'.



1.2 Silk manufacturing flow chart.

Over the centuries, one of these species, *Bombyx mori,* has been progressively domesticated to fulfil its two most important functions and nothing else, namely to produce a textile fibre and to perpetuate the race. Today, *Bombyx mori* is the only totally domesticated animal, that is to say it is entirely dependent on man for its survival, unlike other 'domestic' animals, cats or dogs for example, which could survive if abandoned to their own devices.

This domestication has taken the form of suppressing the silkworm moth's ability to fly, so that it is entirely captive. This means that its production of eggs can be totally controlled. The moth has no digestive tube, so after mating and laying its eggs it dies. It is also sightless.

Bombyx mori (literally 'mulberry silkworm') is so named because mulberry leaves are its only food. Here we have one of the first and most important constraints on sericulture, namely there must be an accessible and abundant supply of mulberry leaves to feed the silkworms. Hence, sericulture is confined to areas where such factors as temperature, hygrometry and soil conditions are favourable to mulberry cultivation.

In the past, this meant that sericulture was concentrated in temperate-zone countries, where the white mulberry, *Morus alba*, was well-established. Southern Europe, the Mediterranean basin, central Asia, northern India, China, Korea and Japan were ideal places for sericulture for this reason.

The mulberry is a very hardy tree and can adapt to many different climates. Some varieties have been developed which can thrive in subtropical conditions, which means that silkworms can be fed practically throughout the year. In temperate areas, however, the mulberry tree only yields leaves twice a year, in May and September. Since the silkworm will eat nothing else, it is leaf production which determines when the worms can be reared. Silkworm eggs can be stored until they need to be hatched, but there is no point in hatching them if there is no food available. Consequently, in economic terms, farmers in temperate zones cannot live on silkworm rearing (and therefore cocoon production) all the year round. This is one of the reasons which resulted in the decline and eventual disappearance of sericulture in France, Italy, Spain and Portugal, as well as in Korea. In other countries, for example in Colombia, continuous cocoon production is possible because the climatic conditions allow for year-round leaf production.

In Japan, Italy and France attempts are being made to replace mulberry leaves as the sole food of the silkworm. An artificial diet, containing some mulberry-leaf powder but also protein from other sources, such as soy, is being developed. Although this type of feeding is not yet viable on an industrial scale, except in Japan, and is consequently expensive, it offers a hope of solving two major problems: the need to wait for propitious periods of the year to hatch the silkworm eggs and, secondly, the need to rear silkworms in close proximity to the mulberry plantations. The silkworm is not only very fussy about its source of food, but the leaves also have to be perfectly fresh. Despite attempts to dehydrate or freeze-dry mulberry leaves, the silkworm will only recognise the real thing.

The silkworm begins its existence as a tiny egg, the size of a pin-head. In just over one month, the egg will develop into a fully grown silkworm. In this respect *Bombyx mori* can lay claim to another record, namely the fastest rate of growth in the animal world. From the egg to the adult caterpillar, the weight is multiplied 10000 times.

Silkworm eggs are prepared in grainage stations, which select the appropriate eggs for the area and the season in which they are to be used. The eggs are usually delivered in boxes of 20000 (or 33000 in some countries). Once the rearing season can begin, i.e. when the temperature is right and there are enough mulberry leaves, the eggs are put into incubation at 25 °C and the young silkworms hatch roughly 12–14 days later. The newly hatched worms immediately start looking for something to eat and at the beginning of their growth have to be fed at regular intervals with tender young mulberry leaves.

During the feeding period, eating is the silkworm's preoccupation. Its appetite is voracious and it has to be constantly looked after. Not only is it a very finicky eater, but it requires specific rearing conditions which have been described in sericultural manuals ever since ancient Chinese times: no noise (such as a dog's barking), no odours (the minders should not eat garlic), harmonious development of all the worms simultaneously (malingerers should be eliminated and fed to the fishes) and so forth. The growth of the silkworm is spread over five ages or 'instars', and is so rapid that the worm quickly outgrows its skin and has to stop eating four times during its lifetime in order to shed its skin and then resume its feasting. Each age is separated from the next by this period of moulting. The instars are of unequal duration: first instar 3–4 days; second 2–3 days; third 3–4 days; fourth 5–6 days; fifth 7–8 days. (These periods include moulting.) In Fig. 1.3 the feeding of fourth age silkworms is shown.

Silkworm rearing therefore requires an abundant and accessible supply of fresh mulberry leaves as well as a large number of individuals to pick the leaves, chop them into a manageable size, feed the silkworms, clean out their litter and so on. The rearing houses must be kept meticulously clean and disinfected regularly in the interval between rearings. Figure 1.4 shows the rearing mat being cleaned.

The labour intensive nature of sericulture is one of the causes that led to its decline and ultimate disappearance in Europe. The future of sericulture is in countries which have, apart from the right climate, an abundant source of inexpensive labour. Even then, cocoon production will most often be an addition to the farmer's revenue rather than its mainstay.

Once the silkworm has reached the limit of its adult development, it stops eating and prepares to spin its cocoon. The cocoon is a shelter designed to protect the silkworm from predators while it metamorphoses into a chrysalis, the intermediate stage between the larva and the moth. To build its cocoon the silkworm extrudes the semi-liquid silk contained in its two silk glands which are disposed in a zigzag manner throughout the length of its body, and are therefore much longer than the silkworm itself. They

1.3 Feeding fourth age silkworms.

1.4 Cleaning out the rearing mat.

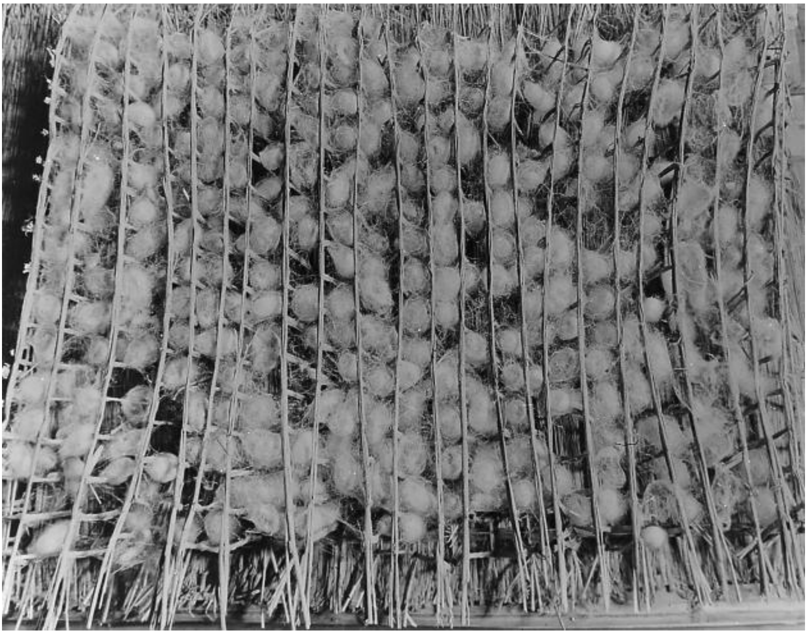
1.5 Preparing silkworms for cocooning.

contain a large amount of silk, of which the worm actually 'empties' itself through spinning its cocoon, and this is why people often ask how such a large worm can 'fit into' such a small cocoon. Figure 1.5 shows the silkworms being prepared for cocooning.

Each silk gland produces one strand and the two strands are bound together by the sericin as they leave the silkworm's body through the tiny hole in its lower lip, the spinneret. The function of sericin is to stiffen the two filaments and protect them from damage, in the same way that the plastic covering of an electric cable protects the copper wire inside.

The worm begins by fixing a few individual filaments to a support in order to anchor its cocoon. Traditionally, the support used for this was a sprig of heather, but in modern times racks of small cardboard compartments are used, or sometimes a plastic 'hedgehog'. In Fig. 1.6 the traditional Japanese cocooning frame is shown.

Once the initial strands have been put in place, the silkworm can begin the construction of its cocoon. The sericin-plus-fibroin hardens on contact with air so the resulting cocoon offers good protection and at the same time remains porous which enables its occupant to breathe. The silkworm will take three or four days to complete its cocoon by rotating its head in a rough figure-of-eight movement to enclose its body completely. Inside its cocoon, the larva will change into a chrysalis, which will take about three



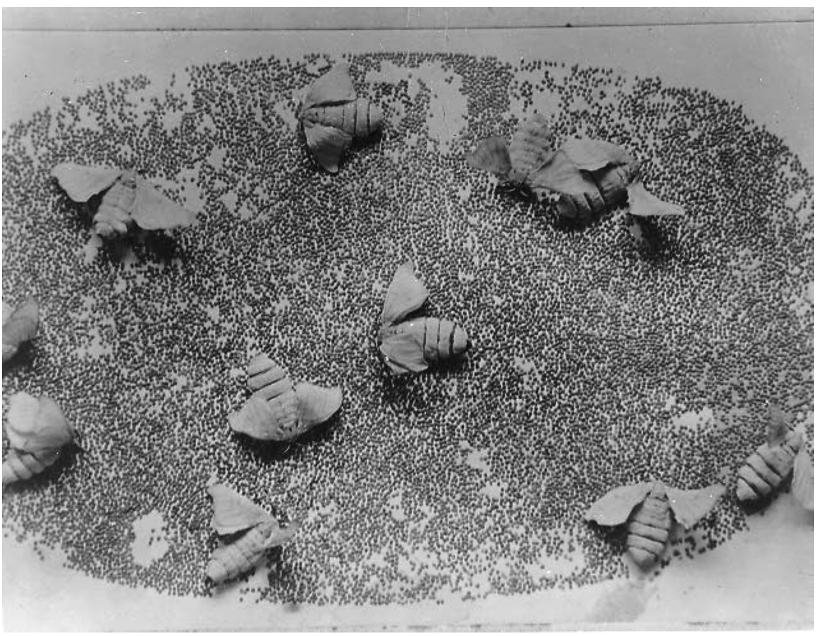
1.6 Traditional Japanese cocooning frame.

or four days. Another ten days later, the chrysalis will in turn change into a moth that will emerge from the cocoon by dissolving the gum which binds the filaments together. Should the cocoon be damaged in this way by the emergence of the moth the silk filaments will be damaged and cannot be reeled. Figure 1.7 shows the harvesting of fresh cocoons.

The development of the chrysalis into a moth is therefore interrupted. The cocoons are 'stifled', i.e. they are subjected to hot air which kills the chrysalis and so ensures that the cocoon remains intact. There are different stifling methods. The one which takes the longest time consists of stifling at a steady temperature of 110 °C over a period of about 8 hours. Another method consists of stifling at different temperatures, starting at 110 °C, for short periods. The stifling process is followed by drying in a drying chamber, so as to remove the high moisture content of the fresh cocoons and enable them to be stored until they are required for reeling. A certain percentage of cocoons are allowed to reach the end of their cycle, i.e. the emergence of the moth, for reproduction purposes.

As soon as they hatch, the moths begin to mate. As they are blind, they are attracted to each other by the female's powerful pheromones. A male is capable of mating with several females. Mating generally lasts 3 days, at the end of which the female lays between 350 and 500 eggs and then dies. Figure 1.8 shows the female laying eggs.

1.7 Harvesting fresh cocoons.



1.8 Egg laying.

1.9 Silk moths being crushed to test for pébrine.

Tests are carried out at this point to detect the presence in the moths of any of the diseases which affect the silkworm. The deadliest of these diseases, pébrine, is highly contagious and can wipe out a whole rearing, hence the need to ensure disease-free layings. Once it has been determined that no diseases are present, the eggs are put into hibernation at a low temperature until they can be hatched at the next rearing season. Figure 1.9 shows silk moths being crushed to test for pébrine.

The selection, conservation and cross-breeding of the eggs is the work of grainage stations. It is important to select and to develop silkworm strains adapted to different conditions of climate, humidity and so forth. There are basically two main 'families' of silkworms, bivoltine and multivoltine, that have their specific characteristics. Bivoltine silkworms are capable of two generations per year, while multivoltine strains can produce several.

These two main groups have different properties that can be defined as follows:

Bivoltine strains:

- Produce large quantities of thread per cocoon, up to 1600 metres or more.
- Produce thread of good quality, even, lustrous and strong.
- Are highly vulnerable to disease.

– Require very strict rearing conditions in terms of hygiene and temperature- and humidity-control.
– Are much better suited to temperate than to sub-tropical or tropical climates.

Multivoltine strains:

– Are very hardy and resistant to disease.
– Will accept imperfect rearing conditions.
– Are well-suited to sub-tropical and tropical climates.
– Produce relatively low quantities (400–800 metres per cocoon).
– Produce a thread of fairly poor quality in terms of physical characteristics.

The obvious answer to overcoming the disadvantages and combining the advantages of the two main branches of silkworm strains lies in cross-breeding, and this is carried out regularly in the silk-producing countries. The best example is shown by India, where sericulture is practised mainly in the south of the country, in the Bangalore/Mysore region. The climate and the rearing conditions are not propitious to bivoltine strains but cross-breeds are frequently used to attempt to produce more and better qualities of raw silk. The main difficulty at present is that the genome of the silkworm is not yet fully known, so the attempts to combine the best characteristics of the two strains are not very certain. However, this situation is due to change in the very near future. Genetic research is developing rapidly and, as is discussed later, a scientific breakthrough was achieved in January 2000 that now makes transgenesis of the silkworm a practical reality. This means that once the *Bombyx mori* genome has been fully plotted it will be possible to endow the bivoltine silkworm with the best qualities of its multivoltine cousin, to make it less vulnerable to disease, for example, and at the same time make the tough multivoltine varieties produce larger and better qualities of raw silk filament.

1.4 Reeling and yarn production

Before the cocoons are dried, they are carefully sorted to eliminate those which are unfit for reeling because they are stained, deformed, double or otherwise inadequate. These cocoons are not totally discarded and can be used at least partly for producing silk waste, used for the production of spun-silk yarns, and subsequently for some by-products. In some Asian countries the chrysalis is sold to restaurants as a delicacy.

The first operation in the reeling process consists of softening the gum (sericin) which binds the thread together because the cocoons are at this stage too dry and too hard to reel. This operation, known as 'cooking', consists of passing the dry cocoons through a series of wet processes designed to soften the sericin bond. The sericin is not removed at this point because its protective qualities are needed throughout the initial industrial processes of throwing and weaving.

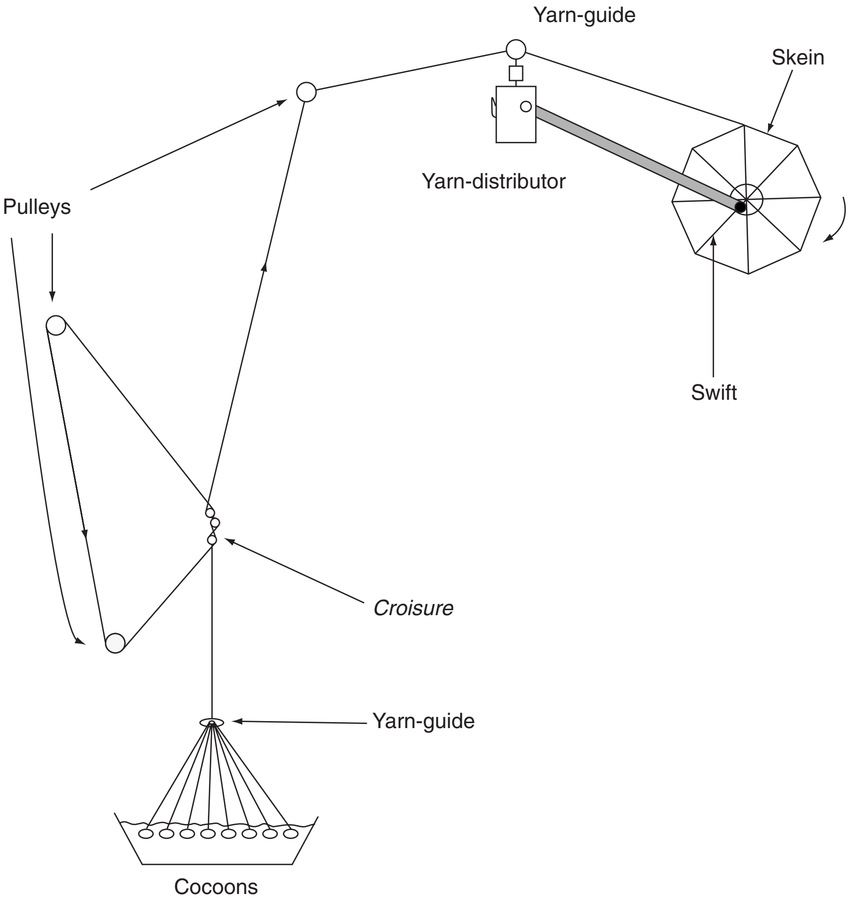
Reeling, like every other operation in the silk process, was once done entirely by hand and in some countries still is. In Thailand, a major part of raw silk production is hand-reeled, and this gives Thai silk its coarse, irregular and rustic appearance and feel, which are so highly prized by the market. In India, part of the cocoon production is reeled on simple domestic reeling machines known as *charkha* or on improved versions called cottage-basins. The yarn produced by these simple devices is well-suited to handloom weaving, which remains the mainstay of Indian fabric production. However, if raw silk yarn is required for processing on sophisticated, high-speed textile machines, the necessary quality can only be obtained through using very good multi-end or automatic reeling machines.

The 'cooked' cocoons are brushed with a stiff rotating brush to find the end of the continuous filament which forms the cocoon. During this process a certain amount of silk waste is produced and set aside for future use in spinning. (Note that in English 'reeling' is used for the production of continuous filament, and 'spinning' for the processing of short fibres.)

Reeling is a critical operation in achieving good quality silk yarn. One of the chief characteristics of a good quality yarn, of any fibre, is its evenness. However, since silk is a natural and not a synthetic fibre a certain degree of irregularity of diameter is inevitable. Thus, the natural unevenness of a silk filament can be attenuated by the quality of the reeling, in which the filaments of several cocoons are combined into one yarn. The filaments from the cocoons are reeled together using the adhesive properties of the sericin to bind them together. As the filaments are fed through a yarn guide on the reeling machine they cross each other in a phase known as *croisure* (traverse). The *croisure* (shown in Fig. 1.10) squeezes out the excess water and gives the filaments a very slight twist to ensure their cohesion.

The single filament of one cocoon weighs about 2 deniers. (The silk trade continues to use the denier as a system of weight, one denier being the weight in grams of 9000 metres of yarn.) Consequently, in order to achieve the thickness (denier) of yarn required, several cocoons are reeled together.

This quality of a silk yarn depends, in the case of semi-automatic reeling, on the skill of the reeler. Seven, eight or ten cocoons are being reeled together to produce a yarn of 13/15, 17/19 or 20/22 denier. Obviously, each cocoon does not contain exactly the same length of filament as the others, so the reeler has to be constantly alert to finding a cocoon which is exhausted, injecting a new cocoon into the basin and joining it up with the others so as to maintain the same diameter of yarn. If the reeler is not vigilant enough, the diameter of the yarn will go, for instance, from eight



1.10 Croisure.

filaments to seven or six and then back to eight, thus creating an irregular yarn which will cause problems at later stages of processing, particularly during weaving.

Today, raw silk is often reeled on automatic reeling machines that have been developed, particularly in Japan, to improve the quality of raw silk and at the same time save on labour costs.

A set of electronic sensors permanently measures the diameter of the yarn and detects any variations. As soon as one cocoon is exhausted, the machine will automatically stop the reeling in that particular basin and inject a new cocoon and then resume the reeling process so as to maintain the evenness of the yarn. Although an operative is still necessary to join up the new filament, one operative can look after several basins at a time, thus making for a considerable saving in labour.

During the reeling process, the silk is reeled first of all onto small reels then re-reeled onto larger reels. This double operation is designed to enable the yarn to dry and to avoid the formation of gum spots, where the sericin has accumulated on the still wet yarn. After re-reeling, the raw silk is packaged into hanks, or skeins as they are called in the silk industry. The skeins are twisted into their characteristic torsaded shape and made up into bales of 60 kilogrammes.

1.4.1 Dupion

Mention must be made at this point of another type of reeling. While the silkworms are spinning their cocoons, it sometimes happens that two worms are so close to each other that they spin a double cocoon instead of two separate ones. These double cocoons cannot be reeled in the conventional way but have to be processed on a special machine. This is known as dupion (douppion) reeling, dupion literally meaning 'double'. The two filaments thus produced are intermingled, and when added to normal filaments in fabric manufacturing produce irregular slubs which create an effect very much in demand for making special fabrics, particularly for bridal wear. These fabrics are often mistakenly known as 'wild silk', because they appear natural and irregular.

1.4.2 Wild silk

In addition to silk produced by the domesticated *Bombyx mori*, there are several varieties of wild silk that are produced by totally different insects. Wild silk comes from insects that live in wild or semi-domesticated conditions, notably in India, China and Vietnam. The largest group of wild silk producing insects belongs to the *Antheraea* family and the silk they produce is variously known as tasar, tussah or tussore. These insects feed on oak leaves, not mulberry, in areas such as the foothills of the Himalaya where small oak trees grow in abundance. Although tasar cocoons contain some continuous filament, it is very difficult to extract and most wild silk thread is used for spinning rather than reeling. Tasar silk is widely used for women's and men's clothing and furnishing fabrics. In China, the chief wild silk producing area is in the north-east of the country, in Liaoning province in particular.

India is also the home of two other wild silk varieties, muga and eri. Muga is a gold-coloured discontinuous fibre while eri comes from a variety of silkworm that feeds on castor leaves.

Wild silk production is very small compared with that of cultivated silk. World raw silk production (*Bombyx mori*) was around 70 000 tonnes in 1999, while known wild silk production was about 3000 tonnes.

1.4.3 Spun silk and noil

During the initial stages of silk processing, particularly during reeling but also at later stages, a certain quantity of waste silk is produced. This is composed of short fibres as opposed to the continuous filament known as raw silk. Waste silk is also derived from unreelable cocoons, i.e. those discarded during the pre-drying sorting. Pierced cocoons are a major source of waste silk.

The term 'waste silk' is something of a misnomer because it suggests a product of inferior quality barely worth commercialising. In fact, waste silk is a quality raw material that is processed into two by-products, spun silk and silk noil, both highly valued by the processing industries. It occasionally happens that when there is a shortage of waste silk its price can actually be higher than that of raw silk. While the term 'schappe' is commonly used with reference to spun silk in general, the expression was originally used to designate waste silk that had been degummed using the natural fermentation method, in which the bacteria present in the silk waste are allowed to ferment in a warm, humid atmosphere and begin to break up the sericin present on the fibre. This facilitates the subsequent washing and rinsing of the waste. The washing agents used are based on olive oil soap and other alkaline agents such as sodium carbonate. This is particularly important for the silk waste produced from the discarded cocoons, to make sure it contains no foreign matter such as fragments of pupa and cocoon-shell. In addition, pupa residues present in the waste will add to the total amount of fatty acids.

The silk waste is then processed in a way which is similar to the processes used for wool and other staple fibres. The silk waste is carded, combed and spun into yarns. These are then singed ('purged') to remove hairiness. This yarn can be dyed and made into sewing and embroidery threads or used for weaving. Fabrics woven from silk spun yarns have their own particular appearance, handle and drape and produce very attractive apparel and furnishing fabrics. Alternatively, the short fibres can be blended with other natural fibres such as cotton, wool and linen which have staple fibres of approximately the same length, to give a range of blended fabrics offering various properties such as warmth (silk-and-wool) or coolness (silk-and-linen).

During the carding and combing silk waste prior to spinning some even shorter fibres, noils, are produced.

1.5 Raw silk testing and classification

Before raw silk is traded it has to be tested and classified. Testing has two purposes: (a) to determine the characteristics of each lot (usually 600 kg) of silk and decide for what end-uses it can be employed, and (b) to classify the silk into different grades and thus determine its price.

Raw silk is classified according to an international system drawn up by the International Silk Association (ISA) in the years following the Second World War. Representatives of the main producer and consumer countries formed a 'Classification Committee' and agreed on the international system which is the world-wide standard, although some minor differences may exist in certain national classification systems.

There are 11 grades in the international system of classification, ranging from 6A (the top) through 5A, 4A down to F. These grades apply to raw silks of three different categories: 18 deniers and below, 19–33 deniers and 34 deniers and above. In countries where high-speed machinery is used in twisting and weaving, the minimum grade required is 3A.

The grade of the silk is determined after the silk has been subjected to a series of tests. These tests include those for such criteria as evenness, cleanness, neatness, tenacity, winding, size-deviation (average and maximum), elongation, breaking strength and cohesion. There are also some more subjective criteria such as lustre, handling and colour that must be determined.

These tests are carried out on small skeins of silk, known as sizing skeins, drawn from the lot of raw silk to be tested. The scope of each of the tests, i.e. what they are aimed at testing, can be summarised as shown in Table 1.2.

Raw silk testing is still carried out using a visual system based on an apparatus called the seriplane; this presents a number of standard panels for each of the major criteria. For example, when testing neatness, the operator posts a standard photographic panel for neatness. He then draws samples of the raw silk under test and winds them onto a black panel which is placed below the standard photograph. He then compares the samples against the standard and reaches a judgement on this criterion, for example 95 % neatness. Figure 1.11 shows the testing of raw silk with the aid of a seriplane and Fig. 1.12 demonstrates testing raw silk for cohesion with a Duplan tester.

The 'scores' obtained for each of the major tests are gathered together to reach the classification. A poor result in one of the tests is enough to declassify the lot of raw silk. However, what counts for the user is the final purpose for which he or she wants the raw silk. If a particular lot has obtained a low mark in evenness, this may not be disqualifying if the silk is intended for doubling and twisting using a large number of ends, where the relatively poor evenness will be less critical than for an application in chiffon, for example, which requires only two ends with a low twist. It is for this reason that it is not enough for the throwster and weaver to know the grade resulting from the different test results. The raw silk merchant, skilled in interpreting the test certificate, advises the industrial user on the possi-

Table 1.2 Quality control testing of silk skeins

Test	Result
Winding test	The number of breaks in raw silk threads over a certain period of winding.
Size-deviation test	The degree of size deviation within the test pieces of sizing skeins.
Maximum deviation test	The maximum amount of deviation from the average size.
Average size test	The average size of the silk thread at conditioned weight.
Evenness variation test	The degree and frequency of size variations in silk threads over approximately the same length as the sizing skeins.
Cleanness test	The type and number of cleanness defects. These defects are categorised as super major defects, major defects and minor defects. 'Major' defects include: waste filaments, large slugs (thick places), long knots, corkscrews and loops.
Neatness test	The percentage of neatness of raw silk. Neatness defects are smaller than minor cleanness defects and include: nibs (small thick places), loops, hairiness and fuzziness, raw knots (less than 3 mm), fine corkscrews.
Tenacity and elongation	The tenacity of a 20/22 denier raw silk is 4–5 gr/denier. The elongation of the same raw silk is 18%. The tenacity (strength) of the raw silk per denier and the amount of stretch up to breaking point.
Cohesion test	The degree of agglutination of the cocoon filaments making up the silk thread.

ble applications of each lot. Given the relatively subjective and old-fashioned nature of the seriplane method of raw silk testing, there is increasing demand for a new testing method based on electronic systems. In recent congresses of the International Silk Association, testing institutes in Switzerland and Japan have proposed modern alternatives to the seriplane system. If one of these systems were to be officially adopted by ISA, this would probably lead to the drawing up of a new classification system with a reduced number of grades. However, at the present moment no consensus has been reached among producers and consumers on the adoption of a new electronic testing method.

Every lot of raw silk which is exported must be accompanied by an official test certificate issued by the competent testing authority in each country. (In China the body responsible for these tests is the China Commodities Inspection Bureau or CCIB.) The test certificate accompanies the

1.11 Testing raw silk with the aid of a seriplane.

1.12 Testing raw silk for cohesion with a Duplan tester.

shipment of the raw silk and is used as the basis for the price. In a very general way, the price difference between two grades, between say 4A and 5A, is roughly US$1 per kg. This can make a considerable difference in an order of 10 tonnes.

On arrival in the importing country, buyers can have the raw silk retested by a local testing laboratory if they have any doubts about the reliability of the test certificate or if their first use of the raw silk has been unsatisfactory. In Japan it is common for all imported raw silk to be systematically retested. In addition to international standards for raw silk classification, the International Silk Association also publishes trade rules for international trade in raw silk and other silk products. These rules form a basis for transactions between sellers and buyers and although they do not have force of law they have the merit of providing a mutually recognisable framework for international trade in silk. (These International Trade Rules for Raw Silk are reproduced in Appendix 1.)

1.6 Yarn and fabric manufacture

Silk is traded in many different forms and at various stages of finishing. From the point of view of the processing countries in Europe, the traditional stages are:

– Raw silk imported from China or Brazil.
– Throwing (twisting).
– Weaving or knitting.
– De-gumming, dyeing, printing and finishing.
– Making-up (garments and accessories).

1.6.1 Throwing

The throwster is responsible for supplying the weaver or knitter with thrown (twisted) yarns for a specific purpose. Raw silk yarn is generally too fine to be woven with no twist, except for some special fabrics such as habutae which are not made in Europe. This means that several yarns have to be assembled and twisted together to form a substantial yarn for weaving or knitting. The continuous filaments reeled from the cocoons have to be joined together as they enter the twisting frame. It is more convenient for the workers to do this operation at waist level and this is why silk is up-twisted rather than down-twisted, which is usual for other textile fibres.

The most common types of twist are:

– Tram: several single yarns assembled and twisted to 100–150 turns per metre.

- Organzine: two or more yarns, each of which has been S-twisted and the assembled yarn Z-twisted crêpe: an assembly of several single yarns which have each received a high twist of 2000–3500 turns per metre.
- Crêpe: an assembly of several single filaments which have each received a high twist of 2000–3500 turns per metre.

Immediately before the thrown yarns are sized they are lubricated, using a mineral oil-based lubricant, to reduce friction during weaving. In silk weaving, a full beam is used, but sectional warping may be employed in the case of weaving dyed yarns into stripes or checks, for example. According to the density of the fabric to be woven, over 20 000 yarns can thus be arranged on the beam in rigorously parallel order and under strictly uniform tension.

1.6.2 Weaving and knitting

The thrown yarns are delivered to the weaver or knitter on different types of packaging such as bobbins, cones and perforated tubes. Silk fabrics may be yarn dyed or piece dyed. In the case of yarn dyeing, the yarns are delivered to the dyer generally on skeins or perforated tubes to be dyed before weaving into figured (jacquard) fabrics or other fabrics (e.g. taffeta) made from dyed yarns. The yarns in this case have previously been de-gummed (see below), but in the normal weaving process they still contain the original sericin. This enables the sericin to fulfil its natural function of protecting the fibre from the stresses and strains to which it will be subjected during throwing and weaving.

Silk is woven on a wide variety of looms. In countries such as India and Thailand, handlooms are still commonly used. The irregular quality of the silk yarns used and the desire to produce fabrics with a characteristic appearance and feel mean that handlooms will be used for several years. In addition, they have an important social and economic value because they offer employment to a large number of people.

In developed silk processing countries on the other hand, handlooms have all but disappeared. They survive in some countries, such as France, Italy and the United Kingdom, for reproducing, restoring or copying ancient fabrics, particularly furnishing fabrics, that can only be woven on the traditional type of loom. In most cases, however, silk is now woven on modern weaving machines, rapier or air-jet, at speeds of up to 450 picks per minute and in widths of up to 270 cm.

Because silk is such a small part of total world textile production, no machine builder manufactures looms specifically for weaving silk. Those modern weaving machines designed for weaving filament yarns are intended for synthetic fibres and can operate at high speeds because these yarns are sufficiently level to avoid yarn breaks even when the machine is running at high speed. This means that silk must be as level as any synthetic yarn if it is to be woven efficiently and quickly.

Silk lends itself admirably to knitting. Being a naturally highly elastic fibre, its qualities are brought out to the full by the additional elasticity conferred by the knitting process. Knitted fabrics, through their specific structure, give stability, elasticity and comfort. They also have excellent draping qualities and high crease-resistance. That they are not used more extensively is probably due to their higher cost compared with woven fabrics and to a lack of consumer education.

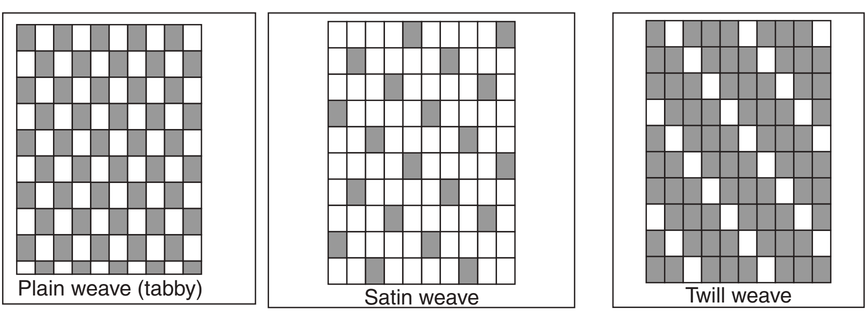
Although silk stockings are no longer produced in appreciable quantities, having been superseded by nylon, they were for many years the mainstay of the silk industry, particularly in the United States where, in 1938, 6 pairs of stockings out of 7 were made of silk, a total of 600 million pairs.

Silk is knitted on circular, flat-frame, warp, and on special 'Milanese' knitting machines. Silk knits are still extensively used in women's dresses, lingerie and sportswear. Interlock fabrics (such as for dresses) are woven on circular knitting machines as well as silk jerseys (lingerie, sportswear). Milanese is a type of knitted fabric designed to give the maximum resistance to laddering, even when subjected to very high tension.

1.6.3 Fabric types

Silk fabrics can be found in an almost infinite number of constructions, but there are four main families of weaves: tabby, sergé, satin and crêpes.

Tabby is the simplest form of weave, 'plain weave', one warp thread passing over one weft thread then under the next weft thread and so on (see Fig. 1.13). The tabby weave is frequently found in taffeta, made of dyed yarns. Taffeta is a crisp, structured fabric, much in favour for women's dresses. When the warp and the weft in a taffeta are of different colours, a



1.13 Plain weave (tabby), satin and twill point paper designs.

changing effect is produced when the fabric is viewed from different angles. This type of taffeta is known as shot silk, or *changeant*.

Sergé (twill) weaves are characterised by their diagonal appearance and are often used in the manufacture of scarves.

Satin is a weave which can be made from almost any fibre although the word 'satin' is often misinterpreted as the name of a fibre. The lustrous appearance of satin is due to the large number of warp yarns which are visible. A 6:1 satin is one in which each warp yarn covers six weft yarns before it passes under one weft yarn.

Crêpes exist in a large number of weaves, some of which can be very heavy to give better draping qualities. All crêpes have a characteristic 'grainy' appearance and feel, due to the high twist of the yarns from which they are made. Crêpe-de-Chine is made of a raw silk warp and a crêpe weft, while crêpe georgette is composed of crêpe yarns in the warp and the weft. Satin-backed crêpes are popular in fashion garments.

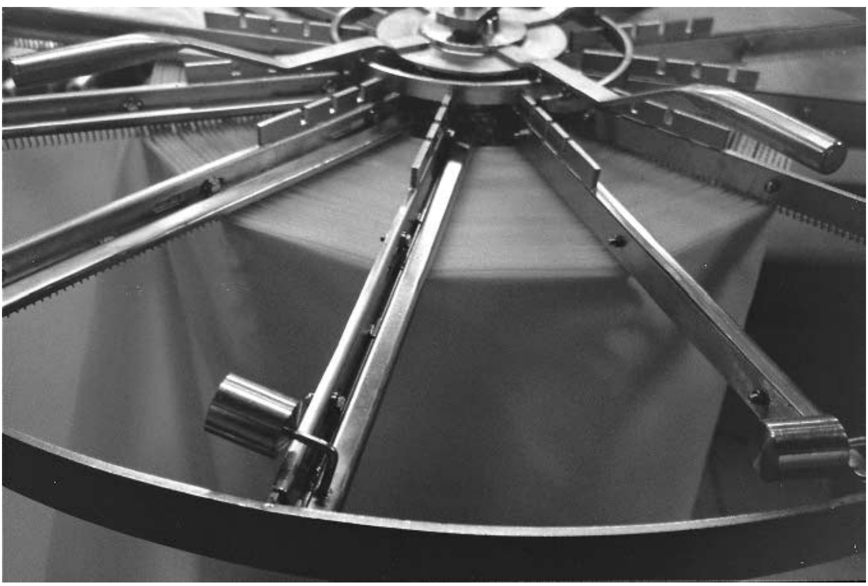
One of the most luxurious applications of silk has always been velvet. Silk velvet continues to be manufactured in relatively small quantities. There is still considerable production of 'burn-out' velvets, which are made from two fibres, usually silk (for the backing) and viscose (for the pile). In this type of fabric, the pattern to be picked out is protected from the rest of the pile of the velvet. The whole fabric is then subjected to an acid treatment, which 'burns out' the unprotected parts of the pile, leaving the desired pattern in relief. The chemical used does not affect the base fabric.

1.6.4 De-gumming and weighting

Once the fabric has been woven or knitted, it is almost ready for dyeing, printing and finishing. There is one important operation before these processes can be undertaken. As has been stated, the silk fabric (at this stage still a 'grey' fabric) contains the original sericin. However, the sericin has two disadvantages: it gives the fabric a stiff, cardboard-like feel and it prevents dyestuff from penetrating into the heart of the fibre. It therefore has to be removed before dyeing or printing. (There are some exceptions, such as organza, in which the sericin is only partially removed and the fabric is said to be 'dyed in the gum'.)

The sericin is removed by de-gumming or boiling off. This is a critical operation in the preparation of the fabric for further finishing. If the grey fabric is unevenly boiled off, some traces of sericin will remain on the yarn in places. The fault is difficult to detect before the fabric is dyed. After dyeing, when it is too late, this fault will appear as differences in shade in the finished fabric. The traditional method of de-gumming involves the use of olive oil ('Marseilles') soap as shown in Fig. 1.14. The fabric is soaked for

1.14 Bath of olive oil solution.



1.15 Silk fabric mounted on a star frame for de-gumming.

6 hours in a solution of Marseilles soap (3–5 g/l at 40–50 °C) then boiled off for 2–6 hours using a solution of soap at 8–10 g/l at 90–95 °C. The fabric is hooked onto a 'star' frame equipped with small hooks (see Fig. 1.15) and once installed resembles a loosely rolled cylinder of paper. The 'star' is then gently raised and lowered in the soap-and-water solution. After de-gumming, the silk is bleached in a bath of hydrogen peroxide (35 %, 15–20 ml/l) and rinsed in clean water. The text above details the procedure for *Bombyx mori* silk, but tussah silk has a natural yellowish-brown colour which it is practically impossible to remove totally without damaging the fibre. De-gumming also serves to remove the oiling and sizing auxiliaries used in weaving.

Although this is the traditional and gentlest way of de-gumming silk it is also slow and expensive, and olive oil soap is not available everywhere. Other de-gumming methods have been developed using enzymes or hot water at very high pressures, but the silk purists would still say that olive oil soap continues to be the best de-gumming agent.

After washing and drying the fabric is ready for printing or dyeing. The difference between a grey fabric and a boiled-off fabric is quite spectacular. Before de-gumming, the cloth is stiff, dull and unattractive; after the process the fabric 'breathes' and is lustrous and supple; in other words, it now feels like silk.

The weight lost in de-gumming must be made up, and this process is known as weighting. Sericin accounts for approximately 25 % of the weight of the yarn so the de-gummed fabric weighs 25 % less than before the process began. This weight loss has to be made up, not only to recover the initial weight of the fabric but to give it sufficient body and draping qualities. The return to the original weight is known as weight-for-weight, but in some cases, when a particular feel or bulk is required, the weighting added to the fabric may exceed the 25 % of the weight removed in de-gumming.

Silk was traditionally weighted using tin salts or stannic acid, which had the added advantage of conferring flame-resistant properties to the fabric. Mineral weighting is no longer used partly because of the expense involved and partly for ecological reasons. In some countries weighting by means of tin salts is prohibited.

Nowadays, silk is weighted using a different method, known as chemical grafting. Instead of applying a weighting agent to the fabric as a whole, the finishers graft a molecule of methyl methylacrylate to the polymers of the silk yarn. This chemical action achieves the desired result of restoring bulk to the fabric without altering its 'hand'.

Some weavers continue to use de-gummed, non-weighted silk which is officially known as 'pure silk', whereas weighted silk is 'all silk', i.e. no other fibre is present. European legislation does not take into account the presence of such substances as weighting agents or dyeing auxiliaries in the definition of a fabric as 'silk'. What is important in the labelling of silk as '100 %' is that no other fibre is present.

1.6.5 Dyeing and printing

1.6.5.1 Dyeing

Silk has excellent dyeing affinity and is capable of rendering colours in a unique way. The silk fibre is triangular in section and when several yarns are twisted together they offer a number of facets that reflect light rather in the same way as a diamond is cut to give maximum brightness.

Yarn dyeing is the traditional method of dyeing fibres and practised throughout Asia. In Europe, yarn dyeing is still used when weaving jacquard, striped, checked or 'shot' designs.

The commonest method of dyeing, piece dyeing, was developed in Lyon in the nineteenth century. Today, silk fabrics are dyed using different types of dyestuff: acid, metallic, reactive, and vat. One of the problems facing contemporary silk dyers is the relatively small number of dyestuffs available on the market. Once again, because of the small quantities of fabrics that silk represents, it is no longer possible to find dyestuffs specifically designed for silk because they are of little interest to the dyestuffs manufacturers. Very often dyers have to substitute dyestuffs designed for other fibres, particularly wool, which is also a protein fibre. In addition, European legislation on the protection of consumers and of the environment has banned the use of certain azoic dyestuffs because they are potentially carcinogenic. Some of the brightest hues which used to characterise silk are no longer possible because these dyes have to be fixed using certain agents that contain, for example, chromium whose use is also banned.

With the decreasing number of chemical dyes available and more and more pressure from the legislator, there is increasing interest in returning to the use of natural dyes, such as indigo or madder. The difficulty in producing natural dyes is that they require large areas of land for small quantities of dyestuff, land which could more profitably be used for food production. Furthermore, natural dyes are not usually fast to washing.

1.6.5.2 Printing

One of the areas in which silk can best express its unique characteristics is in prints. Printing is a technique which has never ceased to evolve over the centuries, from block printing to screen printing. Nowadays, screen printing is the most common method of printing silk, although roller printing may be used when long runs are called for. Screen printing is a relatively long and complex process, consequently it is expensive. Some designs call for as many as 32 colours and this means preparing 32 screens.

The dyestuffs used in screen printing contain gum arabic, used to thicken the dyestuff and ensure it does not migrate outside the limits of each individual yarn to which it is applied but remains precisely within the area intended by the designer. Once the entire design has been completed, the gum is washed out, the dyestuff can penetrate the fibre and the contours of the design remain sharp.

Another printing technique, discharge printing, is also commonly used to print silk fabrics. This process consists of dyeing the fabric uniformly then removing the dyestuff within the area of the design to be printed. The fabric is then printed over the spaces left free after discharge.

Printing technology continues to change and the latest development is ink-jet printing, derived from the computer industry. It is as yet too early to say how far ink-jet printing will replace screen printing, because it remains relatively slow and expensive. Nevertheless, silk printers are all seriously studying this new possibility and there is every chance that it will find an application in printing silk each time short runs and rapid changes of colour are required.

1.6.6 Specific finishes

Various finishing treatments can be applied to silk to give it special characteristics, for example 'scroop'. Scroop is at the same time the familiar rustling sound produced by a silk fabric when it is handled and the 'crackling' handle which accompanies it. The effect is achieved by a special treatment using an organic acid such as formic, lactic, citric or acetic in a concentration of 2–4 ml/l. Other forms of treatment are intended to make the fabric crease-resistant, waterproof, spot-resistant and so forth.

The art of finishing consists of enhancing the natural suppleness and brilliance of silk without altering its 'hand'. Theoretically, it is possible to apply a finishing treatment to silk to make it more easily washable, even in a washing-machine. One such treatment consists of coating the fibres with a silicone-based product. The danger is that the resulting fabric will no longer feel like silk.

1.7 The care of silk

There is no doubt that many potential customers are afraid of buying silk because it has a reputation of being difficult to wash and iron. Silk is often described as 'delicate' or even 'fragile' with regard to its care characteristics. Part of the problem is that today's consumers are used to fabrics which are ‘easy care’ and made of fibres such as polyester that can be washed in a machine and often do not require ironing.

As we mentioned above, silk is a natural microfibre. When the silk fibre is wet, i.e. swollen with water, it becomes extremely sensitive to abrasion. Putting silk into contact with other, rougher fabrics or with the metal drum of a washing-machine will expose it and cause chafing. Many a housewife has had the disagreeable experience of washing a navy blue silk blouse in the washing-machine and discovering afterwards that it seems to be covered with white patches or streaks as if icing sugar had been spilled on it. This defect is often attributed to a loss of dyestuff when in fact it is due to chafing. The outermost layer of microfibre has been brushed up off the surface of the fibre and these fibrils reflect light. During processing, before and after printing and dyeing for example, silk is frequently exposed to water without suffering any damage. The difference between the industrial processes and domestic washing is in the quantity of water used. The drive for ‘economic’ washing cycles in a typical washing machine means that the bath ratio between the weight of laundry in the wash and the quantity of water is very low, so the silk items in the wash are not as well cushioned against abrasion as in industrial washing. It also means that the quantity of detergent in relation to the amount of water is relatively high.

Fortunately, modern washing machines are often equipped with a ‘gentle’ washing cycle, designed for wool and other delicate fibres. In this type of cycle, the temperature is low (30–40 °C) and the drum, instead of completing a full revolution is ‘rocked’ backwards and forwards. Under these conditions, many silk items can be washed in safety.

The other alternatives to machine-washing with a special gentle cycle are hand-washing and dry-cleaning. Hand-washing is recommended for silk, providing the proper precautions are taken:

- The temperature of the water must be about 30–40 °C.
- The detergent must be non-aggressive. It is recommended to use a gentle, liquid detergent as a powder may not completely dissolve in the water giving a possible risk of abrasion. Detergents designed for wool will adequately wash silk, some consumers even use shampoo but care must be taken not to produce too many suds as this could cause problems in some types of washing-machine.
- The ratio of water to fabric must be high.
- The fabrics or garments must be washed separately, i.e. not washed together with other, more abrasive items.
- The fabrics or garments must not be rubbed, screwed up into a ball or wrung in the wet state.
- Excess water should be squeezed out and the silk item dried flat.

The care method most frequently recommended by manufacturers of silk garments is dry-cleaning, which is the safest method of cleaning in comparison with hand-washing or machine-washing, unless these are conducted under optimal conditions. But dry-cleaning has other drawbacks. It is inconvenient to have to go to the dry-cleaner's and come back to pick up the goods. Dry-cleaning is also relatively expensive and the process often leaves a disagreeable odour on the garments. In addition, the traditional dry-cleaning process is destined to change for ecological reasons, in particular through the elimination of potentially harmful chemical solvents. In the near future, dry-cleaning will become 'wet-cleaning', with the gradual inclusion of more and more water in the process.

Everything points to careful hand-washing as being a sensible answer to the problem of silk care, with one notable exception. Silk ties should never be washed because of their structure, which is based on a tie-fabric, a lining and an interlining. These three fabrics are liable to behave in different ways when subjected to water and there is a serious risk of distortion if a tie is washed in water.

Modern consumers are often reluctant to wash by hand unless it is strictly necessary and this is certainly an obstacle when encouraging more people to buy silk. Attempts to add a finishing agent to silk to make it washable have always resulted in an alteration of the hand of the silk, so this is not really a step forward.

For the consumer, there has to be a trade-off between the incomparable qualities that silk offers and its lack of easy care. For the silk manufacturer, it is vital to educate the consumer in the characteristics of silk and remove his or her fears of looking after it. When ironing, it is important to know that silk should always be ironed damp, with a cool iron and on the 'wrong' side of the garment or fabric.

1.8 Sand-washed silk

As we have seen, silk always had a special place among textile fibres. It was considered *the* luxury fibre, partly because of its peerless qualities and partly because of its relative scarcity. This positioning of silk at the summit of textiles was to change radically in the late 1980s and early 1990s with the arrival of sand-washed silk. This new treatment of silk, that originated in the United States but was mainly exploited in Hong Kong and China, was a revolution in the way in which the public looked on silk. From now on, silk was to be found in places other than in up-market garments and accessories. So what exactly is 'sand-washed' silk?

'Sand-washing' has nothing to do with sand. The term is derived from 'stone-washing', a process used to treat denim jeans in which pumice stones are used to soften the fabric and remove some of the dyestuff. The sand-washing process, based on enzyme treatment and/or mechanical abrasion, is a deliberate reproduction of the fibrillation defect to which silk is prone.

In sand-washing, a normal silk fabric is deliberately roughened to produce fibrillation over the whole surface and not just in some places where it is an accident of the washing-machine. After the individual fabrics have been treated in this way, a softening agent is added. Garments made of sand-washed silk are characterised by their soft feel, their lack of lustre and by a distinctly limp or 'distressed' appearance. For several years, sand-washed garments were very successful because:

- They were low-priced.
- They looked and felt natural.
- They were different from the lustrous, smooth and structured traditional silk garments.

Sand-washed silk garments consequently found a ready market among young consumers who had heard so much about silk but had never been able to afford it. This was particularly true for young women who had heard about silk from their mothers or grandmothers but for whom silk was something they saw in the glossy magazines. Suddenly they were able to buy silk garments at a price equal to (and sometimes lower than) the price of an equivalent polyester garment.

Before the arrival of sand-washed silk almost the only silk items men would normally wear were silk ties or the occasional dressing-gown. However, sand-washed silk opened up a large market in casual wear for men but manufacturers of these goods, in their desire to capture a mass-market through low prices, often economised on quality. The initial craze for sand-washed silk started to wear off when the consumers, women and men, began to be disappointed by the overall quality of the garment. The sand-washing treatment is a deliberate degradation of the fibre, which is consequently weakened by the abrasion of its outermost layer. If the original fabric is not strong enough, and in particular if the weave is not dense enough, the fabric itself will also be weakened. In addition, the chemical finish applied to give the sand-washed garment a soft feel wears off in the wash, and then the fabric becomes stiff and disagreeable.

In 1994 the European Union, under pressure from the silk textile industry, imposed quotas on the import of Chinese silk garments, blouses in particular, which were often made of sand-washed silk. The objections raised by the European silk industries were founded less on a question of direct competition than on a question of image. Silk, traditionally the most prestigious of all fibres, was now being offered at rock-bottom prices in supermarkets, department stores and even on street markets. It should be added that the sand-washed phenomenon was exploited by these distributors of inexpensive clothing, rather than by the traditional textile trade.

The consumer was also confused because, with no thorough knowledge of what constitutes the quality of a silk garment, it was difficult to understand the enormous price differential between an imported silk blouse sold in the local supermarket and the designer blouse in the High Street boutique. The professionals of the silk industries in Europe consider sand-washed silk as an aberration with regard to the traditional image of silk that is associated with luxury, quality and exclusivity.

In any event, independently of the European quotas, the consumer was already beginning to turn away from sand-washed silk because of quality problems. In particular, some consumers had the disagreeable experience of seeing their silk blouse literally come apart at the seams. The statistics are eloquent. In 1994, the year quotas were introduced, Europe consumed 5674 tonnes of silk garments. In 1995, the figure had dropped to 3141 tonnes and by 1998, Europe consumed only 1701 tonnes.

1.9 The market position of silk

1.9.1 The organisation of the silk industry

In terms of market positioning, silk has two characteristics which make it ill-suited to the mass-market:

– It is not only a very rare fibre (it constitutes about 0.2 % of total textile fibre production) but its production cannot be easily or quickly increased.
– It is relatively difficult to look after in terms of household care and cannot offer the convenience of synthetic fibres.

This suggests that the place of silk is to be something other than a mass-market fibre. From the most ancient times, silk has always been an inspiration for textile creation, not only artistic creation in the sense of colours and designs, but creation in a wider sense of innovation.

Although silk is not as widely used in Europe today as it was before the Second World War, it remains the inspiration for fashion designers. The top fashion designers always include a significant percentage of silk dresses in their collections, and these dresses are considered as the highlights. Fashion designers have never ceased to consider silk as the ultimate reference because of its inimitable qualities of texture, brilliance and beauty.

The areas in which silk continues to be used in the west are:

– The fashion industry: silk continues to be the ideal mode of expression of the top fashion designers.

- Lingerie: silk is still the irreplaceable fibre for luxury underwear.
- Accessories: scarves and ties are the vehicles of the most elaborate prints.
- Furnishing: silk furnishing fabrics are widely used for the most prestigious decoration. Silk can meet the most stringent non-flammable regulations.

The major silk producing and processing countries are grouped together in an international body, the International Silk Association (ISA). This association was founded in 1949, following a constituent congress held in Lyon and Paris in 1948.

Prior to the Second World War, Japan was the chief producer and supplier of raw silk, so the silk trade was totally disrupted by the hostilities. Following the end of the war, General Douglas MacArthur, as head of the provisional government of Japan, was anxious to revive the whole of Japan's industry, which had been seriously damaged by the war. He decided to begin by re-establishing the silk industry, first of all because of the important role of silk in Japanese culture and traditions and also because silk had been the basis for Japan's industrial development at the end of the nineteenth century. It was the revenue from the silk trade which had fuelled Japan's industrial revolution. With the collaboration of the French silk trade, an initial congress was held in June 1948 and the major decision of this congress was to set up an international federation of silk producers, industrialists and traders. The statutes of ISA were drawn up the following year in Zürich, and the headquarters of the Association were settled in Lyon, which at that time was the centre of the silk industry. Today, ISA counts 40 member countries, including all the major producers such as China, India, Brazil, Uzbekistan and Brazil, as well as the top silk consuming countries.

ISA is responsible for setting international standards for raw silk and trade rules for the raw silk trade. It also helps to promote silk and defend the proper use of the word 'silk' and its derivatives. It is also the only organisation which brings together every sector of silk activity, from cocoon production to the finished article.

1.10 Silk production and trade today

1.10.1 Sericulture

Silk production is often envisaged as an excellent activity to help solve the problems of developing countries because of the numerous advantages it seems to offer:

- Sericulture is first of all an agricultural activity. It could therefore be one way of halting rural exodus by offering an additional source of revenue to poor farmers.

- In countries where sericulture is well-developed, farmers can expect to receive on average $2 per kilo or more for their cocoons, which is a much higher unit price than for many other cash crops.
- In addition, sericulture is not a strenuous activity and can involve all family members, leaving the head of the household more time to look after the basic subsistence of the family.
- Sericulture is environmentally friendly because mulberry trees need little fertiliser and no insecticides can be used for fear of poisoning the silkworms which feed on the mulberry leaves.

However, this idealistic view of the value of sericulture in developing countries must be tempered by some practical considerations. One of the most tenacious misconceptions about sericultural start-ups is that silk production is a simple activity that can be undertaken with a minimum of investment. Nothing could be further from the truth. If a new sericultural venture is to be ultimately successful it must begin with a serious plan stretching over several years. This plan must start from a marketing outlook rather than from a simple production objective. It is obviously dangerous to begin by saying 'let's start by producing raw silk and then see how (or if) we can sell it on the export market'.

This plan must incorporate the precise objectives of the project. Is it designed to produce raw silk for export? Is it intended to use its raw silk production in the local textile industry? Is the ultimate objective to produce raw silk, fabrics or garments? The answers to these questions will determine the nature and the scope of the project and consequently the level of investment required.

In any event, the investments required are substantial, not only to buy and prepare the land and to purchase mulberry saplings and eggs but also for the following:

- To provide for irrigation where required.
- To set up proper grainage and selection procedures so as to produce parental strains of silkworms adapted to local conditions.
- To create training and extension services.

In general, it takes two to three years, according to the climate, for a mulberry tree to produce enough leaves to feed silkworms. There must therefore be sufficient will on the part of the authorities responsible for the project to keep going throughout the initial period when substantial investments are being made but no revenue is coming in. The experts in this field agree that a country with no sericultural tradition that decides to undertake a sericultural project will take a minimum of ten years to produce any tangible results, at least in terms of exportable products. This is a long time to wait for a return on investment.

1.10.2 World production and international trends

There are at least 50 countries producing silk throughout the world, with a production ranging from over 38 000 tonnes of raw silk in China (1999) to 20 tonnes in Turkey. The major producers, with the exception of Brazil, are all in Asia. China is the world's largest producer of raw silk, followed at some distance by India.

Table 1.3 shows how world raw silk production has evolved over a ten year period (all figures in tonnes). It is difficult to obtain accurate figures for raw silk production because of the areas and conditions in which it is produced. The farmer who produces a few kilos of cocoons which he sells on the local market is not necessarily recorded in official figures. This is why the figures shown are to be considered as estimates. To compare how silk production has developed, it should be noted that production in 1939 was just under 54 000 tonnes. It is clear from the figures given that overall raw silk production is declining and the causes of this decline are explained elsewhere.

Sericulture and raw silk production are notably labour intensive activities. This means that the overall economic conditions of the producer country play an important role in the way its production develops.

There are no longer any significant quantities of raw silk being produced in Europe, except in Bulgaria, which continues to produce about 60 tonnes per annum. All the other erstwhile European producers, France, Italy, Spain, Portugal and Greece stopped their production when it became uneconomic to continue. There is a distinct connection between industrialisation and the

Table 1.3 Estimated world raw silk production (tonnes), 1989–98

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
China	40 800	43 800	48 480	54 480	69 300	72 000	77 900	59 000	55 117	49 430
India**	10 020	10 800	10 800	12 600	13 200	13 200	12 884	12 927	14 048	14 500
Japan	6 060	5 700	5 520	5 100	4 200	3 900	3 240	2 580	1 920	1 080
Brazil**	1 680	1 680	2 100	2 280	2 340	2 520	2 468	2 270	2 120	1 821
Uzbekistan*	4 020	4 020	4 020	2 160	1 800	1 800	1 320	1 568	1 500	1 500
Vietnam	na	na	na	na	na	na	2 100	1 500	834	862
Thailand	na	1 503	1 612	1 589	1 229	1 377	1 313	1 144	1 039	900
Iran	na	381	385	423	427	396	750	600	500	400
North Korea	1 000	1 000	1 300	1 200	1 200	1 200	600	360	200	150
South Korea	1 200	1 200	1 000	910	840	491	346	146	72	60
Others	2 120	1 719	1 615	1 677	2 801	3 504	2 217	2 165	1 666	1 438
Total	66 900	70 983	76 732	82 419	97 337	100 388	105 138	85 192	79 590	71 727

* estimate ** silk year April/March or September.

Source: ISA National Statistic Bureaux.

decline and eventual disappearance of sericulture, and this statement can be confirmed on examining the situation of all the European countries listed above. In the latter half of the nineteenth century, competition for jobs, better working conditions and higher wages in industry as well as competition from other fibres sounded the death-knell of sericulture in France and later in Italy.

This is a universal phenomenon, not confined to Europe. An economic study of the financial aspects of sericulture made by a Korean specialist goes as far as to define the actual level of national revenue at which sericulture ceases to be economically viable. Korean raw silk production today stands at about 60 tonnes, whereas 25 years ago Korea was still producing over 6000 tonnes.

In the case of Japan, which has been an industrialised country for much longer than any other Asian nation, the same phenomenon ought to have happened a long time ago. However, sericulture is so deeply rooted in the Japanese national psyche and the traditions of the country that it has a value that goes much deeper and much further than its purely economic aspects. For this reason, the Japanese government for many years continued to support sericulture with heavy subsidies, long after it became objectively uneconomic. This well-managed but highly expensive policy enabled sericulture to go through a gentle decline rather than an abrupt downfall. However, the decrease in Japanese cocoon and raw silk production is now accelerating. Japan, as a member country of WTO, cannot continue artificially to support its sericulture. In addition, the silk farmers are generally very old and their successors are reluctant to follow in their footsteps. In 1999, raw silk production in Japan declined to just over 1000 tonnes.

Sericulture is a difficult job. It involves long hours and it is subject to the vagaries of the climate and of the overall market for cocoons. As soon as silk farmers and their children have the chance of earning a better and more reliable livelihood from other agricultural products they will abandon their cocoon production.

There is a question mark over the future of world raw silk production and it concerns the major producer, China. The standard of living of the Chinese people is rising rapidly. The Chinese farmer is increasingly independent in the choice of crops he wants to produce, so if he cannot earn as much from cocoon production as he can from food crops or raising pigs he will switch away from sericulture.

Silk is produced in the majority of China's provinces. The province with the largest production is Sichuan. The provinces with a reputation for producing the best qualities, i.e. the higher grades of raw silk that are exported to Europe and Japan, are Zhejiang and Jiangsu. These two provinces, situated in the orbit of Shanghai, are precisely those that are industrialising the most quickly. The consequences are:

– Agricultural land, including that devoted to mulberry plantations, is being built over with factories, housing, shopping-centres and highways.
– The new industries often bring added pollution that is extremely harmful to the remaining mulberry trees.
– Farmers can earn a better livelihood producing food for the enormous population of the region around and including Shanghai, and many of them are giving up sericulture.
– It is becoming increasingly difficult to find girls willing to work in the reeling mills, which is quite understandable. Instead of standing all day long with their hands in very hot water reeling cocoons, the girls now have the option of working in a clean, well-lit factory assembling television sets or portable telephones.

In other words, these two provinces of China are beginning to reproduce, in socio-economic terms, exactly the same situation that existed in the Rhône valley in the late nineteenth century.

The Chinese authorities are, of course, perfectly aware of the situation. Already they are beginning to transfer sericulture to inland areas of the country where it has not been highly developed until now. Many experts are concerned, however, about how long it will take for these new sericultural regions to reach the quantities and above all the standards of quality that the international silk market requires.

1.10.3 The international silk trade

While there are a great many countries producing silk, there are only two countries exporting any appreciable quantities of raw silk, namely China and Brazil. All the other producing countries consume their own production (Japan) and in some cases supplement their local production by imports (India). The silk processing countries are reduced to two sources of supply of raw materials, China and Brazil, which is an uncomfortable situation. The two basic conditions for exporting raw silk are quality and price.

The modern textile machinery used in Europe and Japan requires raw silk of a very high quality. In the International Silk Association's grading system, 3A is the minimum grade which can be accepted and usually 4A or 5A would be preferred. China and Brazil are, for the time being, the only two countries capable of supplying raw silk of this quality. However, with the introduction of modern textile machinery in China, this country increasingly needs its own higher qualities of raw silk.

The preoccupation of the silk processors is that production is declining in China and Brazil, while importing countries depend more and more on these two sources for their supplies, with the result that raw material supplies are being squeezed from both sides simultaneously. As was previously stated, Japan is no longer a major producing country but remains a very large consumer and is increasingly dependent on Chinese raw silk to feed its processing industries. The Republic of Korea, which has almost ceased to exist as a producer of raw silk, is obliged to import more and more from China and Brazil.

In recent years, the problem has been masked by the fact that demand for silk was also declining. The financial and economic difficulties of several Asian countries made them reduce their silk consumption. In Europe, silk gradually fell out of favour, due in part to the negative impact of cheap imports and due in part to competition from other fibres. Today, however, there are signs that demand for silk is increasing. Most Asian countries are climbing out of their economic inactivity and beginning to buy silk again. In Europe, colour is coming back into fashion after many years dominated by black and grey, the ‘grunge look’ as it was known in the UK and US. Since silk is the ideal vehicle for bright colours, silk consumption is likely to increase again.

China’s silk production has decreased for two reasons: (a) some silk farmers have turned away from cocoon production because it is not profitable enough and (b) because the Chinese government has voluntarily reduced supply in view of falling demand. Many small reeling mills were closed in 1996 and 1997 because demand was poor and the quality of their production was low. Now that demand is increasing again, there is a definite risk of lack of raw silk supplies if only because of the time it takes to increase production. Silk is not nylon or viscose. If there is a sustainable demand for either of these fibres, a new plant can be up and running in under two years. In the case of silk, the time-span is much longer. There are two cases. If the silk farmer has neglected his mulberry trees but left them standing he could resume production relatively quickly. On the other hand, if he has uprooted his trees to replace them with some other plants it will take a minimum of three years to replant new mulberry trees and have them produce leaves again.

Brazil is the only other source of quality raw silk supplies. In fact, Brazil is an exception in the world of silk in the sense that is the only remaining country which is a producer/exporter of raw material with practically none of its production used domestically. Raw silk production in Brazil, which used to stand at roughly 2200–2400 tonnes per annum, is now down to 1400–1500 tonnes. Brazilian farmers expect a higher price for their cocoons than Chinese farmers, so unless the market is very strong and prepared to pay high prices, many farmers will not continue in sericulture. This is what is already beginning to happen.

There has been, over the past 20 years or so, a considerable change in the silk trade. In the past, China was essentially an exporter of raw or semifinished materials. The European industries imported raw material and processed it through all the relevant phases up to the finished product.

China is now involved in exporting silk at every stage: raw silk, thrown silk, grey fabrics, finished fabrics and garments. This is due to China's natural desire to export goods with added value. The quality of Chinese fabrics has improved, as China uses more and more up-to-date machinery such as that used in Europe. This also implies that China will increasingly need the higher grades of the raw silk it produces for its own processing industries, whereas previously the better qualities were exported. When it comes to dyeing or printing silk fabrics, it is no longer viable for European processors to buy the basic weaves they need in Europe. Providing the quality is equal, it is more profitable to import Chinese grey fabric to be used as a printing base, except when absolutely perfect quality is required or when more complicated weaves are needed.

The latest development in this sense concerns thrown yarns. Europe and Japan are importing more thrown silk yarns and less raw silk. If this trend continues, it could represent a serious threat to the future of the European throwsters.

A special mention must be made of Hong Kong, which plays a major part in world trade in silk. Hong Kong is not only a centre of silk processing, it is an important centre of trade in silk products, because of its banking facilities, its commercial dynamism and of course the fact that it is now a part of China. It is thus a centre of exchange between China and the rest of the world. In 1999, Hong Kong was the chief destination of China's overall silk exports, for a total value of US$64 million. The main destinations of re-exports of these silk goods were:

– Raw silk: India, South Korea, Italy, Japan.
– Silk fabrics: Mainland China, South Korea, Italy, Singapore.
– Made-up goods: United States, European Union, Japan.

The pattern of Hong Kong's silk trade for 1998 is as shown in Table 1.4.

1.10.4 Raw silk prices

Price is, after quality, the second consideration to be taken into account when a country exports raw silk, but the relationship between quality and price is not a simple one. Basically, if the quality is right, exporters can ask a high price for raw silk, within certain limits. On the other hand they can try to sell as cheaply as they wish, but if the quality is inadequate nobody will buy.

The silk market seems to contradict one of the basic laws of supply and demand, namely that when prices are low the customer will buy more, but this is only an apparent contradiction. No-one buys on a falling market

Table 1.4 The Hong Kong silk trade 1998 (US$ '000)

	Imports	Re-exports	Exports	Consumption or stocks released
Cocoons	0.04	7	0	7
Raw silk and dupion	1495	1667	0	(172)
Waste silk	374	294	0.06	81
Thrown silk yarns	102	236	3	(136)
Spun silk	2224	1655	1	572
Blended spun silk yarns	619	409	5	205
Fabrics	4169	3678	68	423
Finished products	9857	8293	1858	297
Total	18859	16239	1953	667

Note: Numbers in brackets show decrease in stock over the year.

unless it is a question of fulfilling outstanding orders. On the other hand, when prices are rising it is wise to buy early to build up stocks and hedge against further rises. These two reactions to market prices accentuate price fluctuations and contribute to the notorious 'textile cycle'. The ideal situation for the silk trade is one in which prices are increasing gradually and in a foreseeable way. The worst scenario is one in which prices fluctuate unpredictably, as was the case in the wake of the first oil crisis in the 1970s.

Chinese raw silk prices reached the highest level known in 1988–9 at $51 per kilo. European raw silk consumption in 1989 was 5605 tonnes. In 1998, when China's raw silk prices dropped to a level of little more than $20 per kilo, Europe's consumption was barely over 3000 tonnes. The main reason for this apparent paradox is given by the very long lead times which characterise the silk business. From the moment when orders for raw silk are placed and the finished products appear on the market several months may elapse. Silk industrialists want to be sure that their product can be sold at a price which reflects its true value so they will have confidence in the market if prices are at least steady and preferably increasing. On the other hand, if the price trend is downwards, buyers will postpone their purchases.

There is no international commodity price for silk as there is for substances such as coffee and tin because there are so few players in the field. The Chinese price is the *de facto* international price. Brazil has to align its prices in relation to the Chinese price but at a higher level because Brazilian cost prices are higher than those of China. Brazil's main outlet is Japan, which is prepared to pay a high price for Brazilian silk because it will still be cheaper than Japanese raw silk and also because two of the three Brazilian silk reelers are of Japanese origin. In Europe some raw silk users are prepared to pay a premium for Brazilian raw silk because it offers a guar-

Table 1.5 Raw silk prices 1990–2000 (US$/kg)

Year	Price
1990	51.00
1991	43.50
1992	35.00
1993	29.00
1994	24.50
1995	27.50
1996	25.50
1997	24.50
1998	27.50
1999	21.10
2000	22.20

antee of regular quality. In France, just over 50 % of raw silk imports come from Brazil, a much higher percentage than in any other European country.

In the early months of 2000, prices started to rise again, thus restoring some confidence in the market. Over the period 1990–2000 raw silk prices showed a generally declining trend, with minor fluctuations in the course of each year. The prices given in Table 1.5 are the official Chinese prices in US$ in Beijing for 2A 20/22 denier raw silk on 1 January of each year. The actual prices may vary a little according to the size of the order and to availability at the time of the contract.

1.11 Silk producing countries

1.11.1 China

China holds a pivotal position in the world silk trade. It is the largest producer country and the largest exporter. China's raw silk production at present stands at over 38 000 tonnes but 5 years ago it was 70 000 tonnes.

It was in the 1970s that China overtook Japan as the world's chief source of raw material. At that time, Japan's production was beginning its long decline and overall demand for raw silk was increasing. For many years, China exported mainly raw silk, spun silk and grey fabrics. Gradually, however, it began to export finished fabrics and after that garments. In the early 1990s, garment exports accounted for the majority of China's export earnings in silk. The value of China's total silk exports reached $2.1 billion in 1999.

The silk trade is a microcosm of what is happening in every aspect of China's current economic situation. Following Deng Xiaoping's directives that the Chinese people should strive to become more prosperous and that businesses should become more self-reliant and less dependent on state subsidies, there ensued a gradual loosening of central power.

In China, the state body in charge of the silk trade is the China National Silk Import and Export Corporation, based in Beijing. The Corporation has branch offices in the main silk producing regions of the country. When there was still a large degree of centralisation, silk prices were standard throughout the country but today the branches are increasingly independent of Beijing. They also have to be profitable in their own right. Consequently, they are in competition with each other and this competition often takes the form of price cutting. The Chinese economy is somewhere between a centrally controlled economy and a free-market one and this is nowhere more obvious than in the silk business.

In this context, it is difficult to predict how silk production will evolve in China. However, silk is such a valuable export product, with current earnings around $2.1 billion, that the Chinese authorities will certainly take the appropriate measures to safeguard their raw silk production and their industry. One thing is certain, there is no other country in a position to replace China as the major supplier of raw silk to the processing industries, so the processing countries will continue to depend on China for 80 % of their raw silk requirement for many years to come.

1.11.2 India

India has its own tradition of silk production, and it is quite possible that India knew how to exploit wild silkworms before it began to use *Bombyx mori* silk introduced from China. Indians specialise in hand-woven fabrics, those of Varanasi (Benares) being particularly famous for their rich colours and their complex designs.

Over 60 000 villages are involved in silk production in India today. Total production of *Bombyx mori* silk is almost 15 000 tonnes, mainly concentrated in the state of Karnataka. The vast majority of this *Bombyx mori* silk comes from multivoltine strains or bi/multi hybrids. These are hardy varieties well adapted to the specific climatic and rearing conditions prevalent in the sub-continent. They have some drawbacks, however. They are not very productive (400–800 metres of yarn per cocoon) and the quality of the yarn is poor compared with bivoltine *Bombyx mori* silk. One way of solving the problem is the further development of bivoltine/multivoltine hybrids. Another solution is the introduction of bivoltine strains in the north of the country, where the climate is more congenial to these varieties. In the traditional producing areas (such as Karnataka) there is a certain resistance to the introduction of bivoltine strains because in shape, size, colour and general appearance the cocoons differ so widely from the small, hairy, yellow multivoltine varieties.

Raw silk produced in India is totally consumed on the local market. The overall quality is not of international standard and, in any event, the Indian government gives priority to the export of value-added silk goods rather than raw materials.

India has several other characteristics which differentiate it from China and other countries. Although it is the second-largest producer country, India exports no raw silk, although it does export waste silk and spun silk. Several Indian manufacturers are installing modern weaving machinery, particularly for the production of high-quality furnishing fabrics aimed at the export market. Since domestically produced silk does not have such qualities as evenness required by this equipment, India is obliged to import upwards of 5000 tonnes of raw silk from China, Brazil, Vietnam and North Korea. The Indian government has recently liberalised imports of raw silk as a means of fostering silk fabric and garment exports and the effects of these measures can be seen in Chinese raw silk exports to India, which increased by 28 % from 1998 to 1999.

India is also fortunate in having a buoyant domestic market for silk fabrics and garments. Silk is familiar to Indians, particularly in the form of saris. Contrary to the Japanese national dress, the kimono, which is rapidly losing ground, the demand for saris remains very strong in India. Although India is often seen as a poor country, there are approximately 80 million consumers of silk. One reason for the success of silk saris is the number of occasions when an Indian woman can wear one, notably for festive and religious events. One of silk's numerous connotations is its spiritual value, which makes it the fibre *par excellence* to be worn on the occasion of *diwali*, for example.

India exports furnishing fabrics and large quantities of dupion. Indian dupion is considered by the specialists as the most lustrous, and its most frequent application is in bridal wear. Indian fabrics are highly appreciated for their texture and colour. They are instantly recognisable, and this is one reason why they are being exported in increasing quantities. They also benefit from a demand for ethnic designs and textures, particularly in Germany and the United States. In the United Kingdom, they find an outlet among the large population there of Indians and Pakistanis. They also hold a strong market position in the Middle East.

Although silk generally is going through a relatively difficult time, in common with other textile fibres, India is in a comparatively strong position. In addition to this strong domestic market, India is enjoying increasing success with its exports of silk fabrics and garments.

1.11.3 Japan

Ever since silk was introduced to Japan from China via Korea approximately 2000 years ago, it has held a special place in Japanese culture and in the hearts of the Japanese people. Sericulture and raw silk production remained tasks essentially performed by artisans until the advent of the Meiji emperor in 1868, which marked the beginning of modern Japan. Meiji encouraged western specialists in every field (military, administrative, industrial and others) to come to Japan and help the country break with its feudal past.

In 1872 a French engineer, Paul Brunnat, was invited to build and start up the first modern silk reeling plant in Japan, at Tomioka. Brunnat was accompanied by several young women from the Ardèche region who were to instruct their Japanese counterparts in the art of producing high-quality raw silk. The Tomioka reeling mill ceased its commercial activity approximately 15 years ago, but it still stands, in immaculate condition, as a historic monument. The importance of the mill at Tomioka went far beyond its immediate function of producing raw silk. The Japanese learned how to use steam generators, similar to those used in the mill, for numerous other industrial applications. The Tomioka reeling mill can rightly be considered the starting-point of Japan's industrial revolution.

The high-quality raw silk produced by this first mill and the others which soon sprang up was exported, in particular to the United States, but also to Europe. The earnings from these exports fuelled the whole of Japan's economic and industrial development. This is another reason why Japan remains so strongly attached to silk, the starting-point of its remarkable success as a modern industrial power.

The turning-point for Japanese sericulture and silk industries was the Second World War. In 1938, Japan accounted for over two-thirds of world raw silk production, with 43 000 tonnes out of a total of 54 000 tonnes. Japan exported almost 70 % of its production, mostly to the United States. The chief end-use of silk at that time was hosiery, mainly as silk stockings. Out of seven pairs of stockings sold, six were made of silk. The invention of nylon just before the war put paid to silk as a material for stockings and at the same time almost destroyed the American silk industry. Nylon also captured another market from silk, namely that for parachutes.

If Japan owes so much to silk, it has also given much to silk. No other country has devoted so much time, ingenuity and money to improving silk quality. Japanese research on the mulberry, the silkworm and raw silk production techniques has been a trail-blazer since the beginning of this century. The most efficient parental strains of silkworm are Japanese and it is the Japanese who have gone furthest in attempting to diminish the impact of the labour intensive nature of sericulture and silk production.

The Japanese were the first to develop an automatic reeling machine, although the principles and design were first drawn up by an American engineer living in France, Edward Serrell, who registered a patent as far back as 1886. It was also in Japan that a synthetic diet for silkworms was first developed. One of the major bottlenecks in silk production is the fact that silkworms will eat only mulberry leaves. There now exists a synthetic diet which contains about 25 % mulberry leaf extract but also soya bean meal, rice flour and various proteins. Not only does this remove the need to cultivate such large areas of mulberry plantations, but also the silkworms no longer need to be fed and raised next to the fields.

The kimono still accounts for about 65 % of all uses of silk in Japan, but this proportion is diminishing steadily. The kimono is still used on ceremonial occasions, but it is increasingly rented. Young Japanese women are active and, for everyday use, the kimono is not a practical garment. On the other hand, western-style garments in silk are becoming more and more popular. Nevertheless, Japan remains a very important country in the overall silk market. It still consumes almost 20000 tonnes of silk in various forms out of a total world production of 70000 tonnes.

1.11.4 Brazil

Silk production was introduced to Brazil by Italian immigrants in the early part of the nineteenth century, but this activity did not last very long, possibly because the farmers found it more lucrative to cultivate other crops. Sericulture really began with the first Japanese immigrants in the late 1930s. Brazilian sericulture got off to the best possible start because it was founded on the finest Japanese technology and the most stringent rearing conditions. Brazilian production reached its peak in the early 1990s, with just over 2500 tonnes, of which 95 % was exported. Japan has always been the chief outlet for Brazilian raw silk, taking between 65 % and 70 % of total exports. There are only three reeling mills left in Brazil, of which two are Japanese. The third reeling mill is part of a large Brazilian agricultural co-operative, mainly involved in producing such items as cotton, coffee, soy beans and orange juice.

Brazil exports only raw and thrown silk, and a small percentage of its production is processed into fabrics in the country. Because the sector is almost totally dependent on exports, Brazilian sericulture is extremely sensitive to prices and to the economic situation of its main markets, in particular those of Japan. In 1998 and 1999, Brazilian production suffered considerably from the following factors:

- Brazil's prices were very high compared with the low prices offered by China, given that the Brazilian *real* was tied to the US dollar which was gaining in value all the time. (The *real* has been allowed to float since late 1999.)
- Japan, the main outlet, was buying fewer imports of everything, including silk from Brazil.
- There was less demand from Europe.

The Brazilian reelers were consequently obliged to offer their farmers a much lower price for their cocoons. From just over $3 per kilo three years ago, farmers are now being offered less than $2. The result is that many of them have stopped cocoon production. It is unlikely that even with a recovery in raw silk prices these farmers will return to cocoon production because many of them have moved out of agriculture altogether.

1.11.5 Thailand

There are two types of raw silk production in Thailand, white silk and native yellow silk, which is also made from *Bombyx mori* but is multivoltine rather than monovoltine. The first type of silk is used as warp for fabrics and garments for export, the latter essentially for domestic consumption. Most of Thailand's production comes from multivoltine silkworms, similar to those in India. Thailand also imports raw silk from China to supplement local production.

The Thai silk industry has a long history, but it came to international prominence after the Second World War, due to the efforts of the famous American, Jim Thompson, who almost single-handedly promoted it in the United States and then in Europe. If measured by international standards, Thai silk is of poor quality. It is coarse, uneven, imperfectly de-gummed and full of slubs. It is almost exclusively hand-woven, which contributes to its authentic appearance. But it has very good dyeing affinity and its very rustic quality makes it a highly desirable product. Much of Thai silk is exported 'invisibly', i.e. it is sold to tourists who take it out of the country. Thai silk is used for garments, furnishing fabrics and a wide range of accessories, not only clothing accessories but also such items as handbags, purses and picture frames.

At the moment, Thailand is striving to introduce more bivoltine silkworm strains in order to become self-sufficient. Bivoltine silk is needed to make a strong warp which can then be filled with a weft of Thai silk.

1.11.6 South Korea

The evolution of South Korea's sericulture in the past 15 or 20 years is a case study in how increasing prosperity can cause this type of activity to decline. From being a fairly large producer (2200 tonnes in 1980), Korea is now an importer of raw silk (1256 tonnes in 1998) while its domestic production hovers around 60 tonnes. One of the causes which accelerated the decline of Korean sericulture was the Olympic Games, held in Seoul in 1988. The construction of the facilities for the games and the creation of numerous jobs in the capital attracted thousands of country people, many of them silk farmers, who never returned to the land. This move has now apparently reversed, with the economic crisis of 1997–8 sparking off a return to the land. Paradoxically, Korean cocoon production is actually increasing, but the cocoons are not used for the silk industry. The silkworm pupa, 100 % protein, goes into the manufacture of health foods, beverages and cosmetics.

The speciality of the Korean silk industry today is printing. Korean printers have a reputation for being highly skilled, and their products are less expensive than their European or Japanese equivalents. Korean fabrics are especially appreciated in the United States and in Japan.

1.11.7 Other producer countries

Raw silk is produced in many other countries, mostly for local use. However, if the quality of these countries' raw materials improved, they could export the product.

1.11.7.1 Vietnam

This country is a case in point. Here there is a very long sericultural tradition, but production was interrupted by many years of war. Since peace was restored to Vietnam, it has relaunched its silk production, which today stands at about 1300 tonnes. Some of the silk produced is exported to countries where the highest quality levels are not necessary, but Vietnam is making serious efforts to raise its standards so as to reach international grade 3A or 4A and thus gain access to the raw silk markets in Europe and Japan. Vietnamese raw silk is also processed into fabrics and garments through joint ventures with Japanese and Italian companies.

Vietnam is a country which has considerable advantages as a potential producer/exporter of high-quality raw silk.

- It has a silk tradition, giving it a big advantage over complete newcomers to the business.
- It has good climatic conditions.
- It benefits from an educated and skilled workforce.
- Its government has the will to continue developing sericulture.

For the time being, it seems to be that certain organisational problems are the only obstacle to progress. Because of the need to protect the farmers and guarantee a reasonable level of income from cocoons, Vietnam was not competitive during the period when raw silk prices were at their lowest. The fact that prices are increasing again is a good sign for Vietnam, providing this increase is sustainable.

1.11.7.2 Uzbekistan

Silk production in the former Soviet Union reached about 4000 tonnes per annum in the 1980s. Most of this production came from Uzbekistan and the rest from such places as Ukraine, Tajikistan and Azerbaijan. Production was strictly controlled in terms of quantity and price, in common with all agricultural products. Trade in silk was almost entirely conducted within the Union.

Since the break up of the Soviet Union, Uzbekistan has remained the largest producer in central Asia, but the quantities obtained are at present only about 1500 tonnes of raw silk per annum. Now that Uzbekistan is independent, it is seeking outlets for its production on foreign markets. However, raw silk produced in Uzbekistan is not yet of international standard. In the old Soviet system, as in many centralised economies, it was quantity, not quality, that was rewarded. The result is that the quality of Uzbek cocoons is low, although strong efforts are being made to remedy this. On the other hand, Uzbekistan is a major source of cocoons for producing silk waste and then spun silk.

1.11.7.3 Iran

Apart from clothing, another application of silk is in carpets, the speciality of Iran. Production of raw silk in Iran is about 600 tonnes, used to manufacture the famous Persian rugs and carpets. Silk carpets are also manufactured in India, Turkey, Morocco and Egypt.

1.12 Silk consuming countries

As has been noted, there is no longer a sharp distinction between producer countries and consuming countries, with the possible exception of Brazil. Naturally, there are some countries, the United States for example, which have never been raw material producers but which are very large consumers.

Traditional producers such as China, India, Japan and Korea both produce and consume large quantities of silk. As the Chinese people's standard of living rises, they can be expected to consume increasing quantities of silk goods. Silk plays as important a role in Chinese traditions as it does in Japan. At present, domestic consumption of silk in China is estimated at about 28 000 tonnes. India and Japan are producers, importers and consumers.

The United States has always been and still is a very large consumer of silk. Whereas this consumption was based on stockings and knitted goods, today's consumption is in two different market segments. On the one hand, there are imports of silk fabrics from Asia and Europe and, on the other, imports of ready-made garments. These two markets represent a total value of over $2 billion.

1.12.1 Supply

World raw silk production has been falling steadily since 1995 with an overall drop of about 30 %. Silk production is closely linked to the standard of living of rural populations. Silk is often described as a fibre produced by the poor for the rich to wear and it is true that the farmers who produce silk have usually been poor farmers.

For a farmer to undertake or develop his production he has to be sure of a reasonable and steady income. However, silk is not a reliable product. It is subject, like all other agricultural crops, to the whims of the weather. One of the reasons for the decline in Brazilian raw silk production in 1998 was a series of meteorological setbacks: drought, followed by frost, followed by hail. Another factor of uncertainty for the farmer is the fact that demand for silk is conditioned to a certain extent by the demands of fashion. If silk is in fashion, cocoon prices will be high, but there is no guarantee that prices will remain at a high level over a long period.

In certain countries, silk has been envisaged as an alternative crop to coca production ('cocoons not cocaine'). It is a sad fact, however, that the market for drugs is more reliable than the market for cocoons.

1.12.2 Demand

The overall demand for silk has also been going through a period of decline. European silk consumption, all products included, has dropped from 16 601 tonnes in 1995 to 11 658 tonnes in 1998.

There are many reasons for the decline in silk consumption:

- *Low raw-material prices* which have discouraged producers and to a certain extent demoralised processors. In Europe, for example, there are no weavers specialised in weaving silk. Modern textile machines, notably weaving machines, are extremely versatile in the yarns they can process. A weaver can thus easily switch from weaving silk to weaving viscose or polyester for example. If weavers are convinced that they can earn money weaving silk they will continue to do so, but if low prices devalue the product as they have tended to do, weavers will give up.
- *Competition from other fibres*. Silk used to be considered as above competition, but many of the new microfibres offer comparable qualities in terms of feel and appearance, with the added benefit of being easier to

maintain. In addition, these new fibres, being synthetic, are constantly being developed to give them new characteristics.

– Whatever its qualities, silk is *not particularly convenient* for the working person because of its care properties.
– *The image of silk has been damaged* not only by cheap garments which do not correspond to silk's traditional image of luxury, but also because the silk products being manufactured in Europe no longer appeal to the consumers, who often find them old-fashioned.
– *Fashion has to a certain extent turned away from prints*, one of the major applications of silk. Printed silk ties, for example, which were a mainstay of the processing industries in Italy in particular, have lost ground in favour of jacquard ties using dyed yarns.
– *Silk cannot be dissociated from textiles in general*, and one of the trends of recent years is that people are dressing more casually. Consumers are adopting clothes in which they feel comfortable and seem less interested in dressing smartly. In many situations men no longer feel obliged to wear a tie, much less a silk tie.

Table 1.6 shows how silk consumption has evolved in Europe over the ten-year period from 1989 to 1998, not only in absolute terms but also in relation to the different product categories. The impact of protectionist legislation on imports of silk garments as well as decreasing consumer interest in these products are clearly brought out by the figures after 1994.

The same trend is obvious to a slightly lesser extent in the United States as shown in Table 1.7. The United States is a major importer of silk garments which also sought to limit its imports.

Table 1.6 European consumption of all silk products, 1989–98

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Raw materials	8935	6031	6010	5412	6739	13359	7393	6753	8319	6396
Fabrics	4170	4058	3726	4638	4728	6791	5563	5391	3649	2884
Garments	2301	2623	3700	4771	5250	5674	3141	2747	2139	1701
Accessories	111	204	225	440	655	1033	505	538	960	678
TOTAL	15517	12916	13661	15260	17371	26857	16601	15429	15067	11658

Table 1.7 US imports of silk garments (tonnes)

	1994	1995	1996	1997	1998
Garments	35111	24583	23888	24476	20519

1.12.3 Possible evolution of supply and demand

Today, supply and demand are roughly in balance. For example, as overall demand has declined, for a variety of reasons, China has cut back production to take this into account. Chinese production is also declining for other, socio-economic reasons.

The question silk professionals are asking themselves today is 'what will happen if there is a sudden increase in demand?'. Demand is much more volatile than supply, so the fragile balance between raw silk supplies and final consumption could be broken.

It is extremely difficult to make reliable forecasts about how the situation is likely to evolve in the silk market. In 1989, when raw silk was at $51 per kilo, who would have forecast that it would have dropped to less than half that price within the space of 5 or 6 years? In the same way, to go back to the 1940s, many observers considered that nylon and other synthetic fibres would eliminate silk production. This has patently not been the case and in 1995 almost twice as much silk was produced as in 1938.

1.12.4 Production in relation to demand

The fear of many western silk professionals is a shortage of raw material supply. If we take a look at the possible development of production, we can begin by stating with a fair amount of certainty that some of the traditional producers such as Japan and Korea will never be able to restart their production. The Chinese situation is less clear, because it is still too early to know whether or not China has already entered the critical point in its economic development at which sericulture enters an inevitable decline. There is every likelihood that India will continue to be a major producer for many years to come, but its needs on the domestic and export markets will have to be increasingly met by imports.

If the traditional producer countries are unable to maintain or increase their production, what are the chances of new producers filling the gap?

In the present state of sericultural technology, silk production is associated with countries that have abundant and cheap labour. When the other requirements for successful silk production are taken into account (e.g. soil, climate, proper technology, investment, training) there are not many countries which offer the possibility of becoming major producers.

There is no lack of projects, or even of some new production on a limited scale. Indonesia, Cambodia, Laos, Myanmar, Colombia, Paraguay and other Latin American countries have the potential, but their contribution to world silk supply will take many years to reach significant proportions. Several African countries are also doing their best to introduce sericulture.

They include the Central African Republic, Egypt, Ivory Coast, Kenya, Nigeria, Uganda, Zambia and Zimbabwe.

1.12.5 Consumption

Silk has been known for over 5000 years. It has had its ups and downs throughout the ages and, in particular, it has survived the invention of synthetic fibres. Obviously, silk must be offering something other than pure performance for it to remain a desirable fibre. We can therefore imagine that it will continue to be in demand, although the real need for it is difficult to quantify. The two crucial elements in its survival will be, once again, quality and price.

First of all, the quality of the raw material must be so high as to allow it to be processed on modern equipment. There are no raw silk newcomers as yet capable of providing this level of quality. Secondly, the price must be acceptable. This does not mean necessarily low, because as we have seen even at $51 per kilo silk was selling better than at $25. However, the price is not infinitely elastic. It must always be remembered that silk (0.2 % of world fibre production) is a luxury, not a necessity as are cotton (55 %), synthetic fibres, mainly polyester (40 %) or wool (about 4 %). There will always be a small number of clients prepared to pay a higher price for silk than for other fibres, but within certain limits.

Consumption is likely to be influenced much more by products than by price. Although silk still benefits from a very strong image as a fibre, silk products are, at least in Europe, losing some of their appeal. Silk has so far failed to capture a sizeable market share among younger customers, if we except the sand-washed phenomenon. The demand for sand-washed silk ceased partly because it was a contradiction: the world's most prestigious fibre was offered in the form of cheap, down-market garments. It was also a nonsense in marketing terms: how is it possible to sell silk (0.2 % of total fibre production) more cheaply than polyester (40 %)?

Part of the explanation for silk's slump in the past two or three years lies in the overall financial difficulties of some major Asian users, Korea, Japan and Thailand. As these countries slowly recover, they will presumably resume their consumption of silk products.

Today, silk seems to be enjoying a partial recovery in Europe also. Designers are looking at silk again, attracted by its naturalness and its various textures. There is more and more interest in ethnic looks, which helps to explain the increasing success of Indian designs and fabrics on western markets. In addition, colour is coming back into fashion after years of minimalist blacks and greys. As silk is considered an ideal vehicle for colour, this ought to trigger increased consumption.

Everything considered, the signs are relatively promising for more consumption. In traditional silk countries such as China and India, improved living standards will surely lead to more people buying silk. There is not the same need to promote silk in China and India as in the west, because it is much closer to people's everyday life and therefore more familiar. The fundamental question for the future is how to balance supply and demand, given that production is declining but consumption appears to be rising again.

1.13 What about the future?

1.13.1 Supply

In every attempt to estimate the future of raw silk supply it has to be recognised that world production is declining, perhaps irrevocably. Total production in 1998 was the same as in 1990, just over 70000 tonnes, after reaching a peak of 104000 tonnes in 1995. The drop was particularly marked in the chief producer country, China, while the second main producer, India, is increasing its production very slowly.

It has also been noted that initiating or developing raw silk production in new countries, with or without a sericultural tradition, takes a number of years, so it is vain to hope that in the near future there will be new sources of large quantities of raw silk, especially raw silk of internationally tradable quality.

Does this mean that silk is doomed to disappear? If the present situation continues unchanged, the answer to this question is probably 'yes'. The critical factor lies in the word 'unchanged'.

Silk as a fibre has always shown remarkable resilience, literally and figuratively. If it has managed to survive for over 5000 years it is because:

- It has succeeded in adapting to new conditions. From the initial work carried out by the Chinese and then the Japanese in domesticating the silkworm, silk production has constantly been the object of intensive research. Improved strains of mulberry, scientific selection of parental strains of silkworm and more efficient rearing methods have all contributed to the survival of silk over the centuries.
- When nylon was invented, silk could have disappeared completely. It did not because silk possesses a certain number of qualities that make it precious to a given segment of the overall textiles market.

There is no doubt, however, that if the present situation continues exactly as it is, there is a real threat to the future of raw silk production.

1.13.2 Technical and scientific developments

However, another scenario is now possible. The present context is not frozen in time. Many new developments are feasible in technical, scientific, industrial and commercial areas:

– Japanese researchers have for a long time been involved in trying to remove the bottlenecks in the silk production chain. One of these bottlenecks is the need to bring fresh mulberry leaves to the silkworms at regular intervals, especially in the early stages of their development. Japan has experimented with a different principle, namely bringing the silkworms to the mulberry leaves by a system of conveyor belts.
– Another factor which adds to the cost of silk production is the need for research. Improved strains of mulberry, scientific selection of parental strains of silkworm and more efficient rearing methods have all contributed to the survival of silk over the centuries.
– The *Bombyx mori* silkworm is capable of eating only one thing, mulberry leaves. But in Japan, and now in Italy, an artificial diet is available to feed the silkworms. This diet is based on other protein-rich ingredients as well as a certain proportion of mulberry leaves. The advantages of this type of feeding are numerous. For one thing, the area planted with mulberry trees can be much smaller, thus sparing land for food crops. Secondly, it is possible to feed the worms all the year round, as they are no longer totally dependent on freshly picked mulberry leaves. Thirdly, artificial feeding means that it is no longer necessary to rear the silkworms close to the places where the leaves are grown. It is theoretically possible to rear silkworms in any premises, provided they are clean, disinfected, temperature-controlled and have the other correct conditions.

For the time being, the possibilities of these new technologies are limited because they are expensive, but if they prove to be viable under real conditions they will be adopted in an increasing number of places and their price will inevitably start to decrease. It can therefore be expected that the silk process still leaves room for a large degree of rationalisation, without altering the natural characteristics of the silk thread.

Meanwhile, science has not been standing still. One of the fields in which research is the most active is that of genetic engineering, and the silkworm is in this respect one of the organisms that interest scientists in several countries. The silkworm is an animal which presents some highly promising characteristics independently of its capacity to produce a continuous filament of textile fibre. This alone would be enough to establish its uniqueness, but there are other interesting factors.

The silkworm produces a fibre made of protein, i.e. it is a protein-producing organism. If it is capable of producing the groups of proteins present in its fibroin and sericin, it ought to be capable, through genetic engineering, of producing other proteins. For some years now, scientists have been looking at the possibilities of the silkworm as an animal which could produce proteins useful to medicine. First among these is natural insulin. Diabetics are dependent on synthetic insulin which they have to take at regular intervals. It is obvious that the natural insulin, in which their bodies are deficient, would be much better. Similarly, interferon is used as a means of fighting certain types of cancer; to produce interferon naturally would be a great step forward.

In January 2000, a major scientific breakthrough was achieved by research teams working together in France, Japan and the United States, who perfected the mechanism of transgenesis of the silkworm. In other words, scientists now know how to transplant certain genes onto the silkworm's DNA.

Apart from the possible applications in terms of medicine and pharmaceuticals, this technique opens up vast new horizons for the animal's silk-producing functions. The two main lines of research which have now been made possible are:

- Enabling the silkworm to become resistant to the endemic diseases that, despite all the precautions taken, can still ravage production, especially in countries where proper conditions of hygiene are not always respected.
- Increasing the productivity of the silkworm. At present, *Bombyx mori* can produce 1600 metres of silk thread per cocoon. Research will be directed towards increasing this capacity.
- Finally, it ought to be possible to produce not only more quantity of silk thread but better quality, through a judicious selection of the genetic factors which enter into the production of fine silk yarn.

The development of alternative technologies, artificial diet and the results of genetic research in terms of greater productivity of the silkworm, improved disease resistance and better quality could together lead to a large-scale increase in raw silk production without planting one extra hectare of mulberry. Due to better selection of silkworm strains through genetic research, any new producing country could achieve production of good quality raw silk much more quickly than before. Obviously, the achievement of these objectives will require a considerable amount of investment, but if it is clear that the market is still capable of absorbing enough quantities of silk, it will be worth the effort.

From an industrial point of view, the increasing use of computer-aided design and manufacture offer new possibilities in the realm of silk weaving.

Increasingly complex designs are being realised on fabrics and it is also possible to change weave structures in the course of the process, without having to reinstall the machine each time. At this particular moment when printing is temporarily out of favour, computer-aided design allows for the production of a greater variety of jacquard fabrics.

There are two areas in which the use of silk could be developed more than it is today. The first area is in blends. Silk blends easily with other fibres, especially with other natural fibres. Silk–wool, silk–cashmere, silk–cotton, silk–linen blends are easier to dye than blends of silk and synthetic fibres. In addition, these blends are mutually enhancing. Silk benefits from the specific qualities of the other fibre it is blended with, while the addition of silk adds prestige and value to the blend. While blends are already used frequently in clothing fabrics, their use could be developed and diversified, both by developing new fabrics based on fibre/fibre ('intimate') blends of silk with wool, linen, cotton or polyester and by the use of yarn/yarn blends.

Knitted silk fabrics are another possible avenue of development. The chief advantage of knits is that they reduce one of the perceived drawbacks of silk, i.e. its tendency to crease. Silk in itself is not naturally prone to creasing, providing there is enough volume in the fabric, but its use in knits makes it virtually crease resistant without the need for chemical finishing. Silk knits have probably not been used more widely because its users expect to find a smooth, lustrous appearance as in satin, but those consumers who have experienced silk jersey are won over by its specific qualities of comfort, handle, drape and appearance.

Still in the industrial context, the development of ink-jet printing will make it possible to undertake short runs with much greater flexibility, and even to offer customised silk articles. Printing a special silk scarf for promotional or commemorative purposes becomes a real possibility.

1.13.3 Spider silk

So far, we have been talking almost exclusively of silkworms, in particular the *Bombyx mori* family, but have said almost nothing about another silk producing animal, namely the spider. The spider's web has always held a certain fascination for people, not only because of its inherent beauty, especially when it is sprinkled with dewdrops, but also because of its strength. The spider's capacity to produce silk has been exploited by humans in countries such as Madagascar where laces were commonly manufactured from spider silk. It has so far not been possible to domesticate the spider in the same way as the Chinese domesticated the silkworm. Anyone who has ever seen trays containing thousands of silkworms happily gorging themselves on mulberry leaves in total indifference to their neighbours will recognise that the same type of rearing is impossible for spiders. Attempts have been made to extract the silk from spiders, notably in the last century, when a French priest working in Madagascar invented a tiny reeling machine designed to 'milk' three or four spiders of their silk. It has never been possible to extend the scope of this kind of device.

Spider silk possesses some extraordinary physical properties, notably its capacity to absorb a large amount of energy without breaking and then gradually to recover its shape. This is the basic principle of the spider's web. Scientists know how to reproduce the 'recipe' for making spider silk in its semi-liquid form. It is already used in certain applications such as bullet-proof vests, precisely because of its energy-absorbing capacity. Until now, however, no-one has discovered how to spin this semi-liquid silk into a filament. Only the spider and *Bombyx mori* know how to do that.

Another possible consequence of the latest discovery in terms of gene transplantation is that *Bombyx mori* could be modified to manufacture spider silk instead of mulberry silk. This is by no means in the realm of science fiction. Generally speaking, as soon as somebody says 'genetically modified organism' all sorts of fears are raised about the possible consequences if the modified genes 'escaped' into nature. In principle, there is no danger in the case of genetic manipulation of the silkworm, because it is, as already stated, totally captive and incapable of surviving without human intervention. So if we come back to our basic question about the future of silk production, the possibilities are not quite so bleak as they initially appear. Appendix 2 by Joyce Dalton gives further details about spider silk.

1.13.4 Developments in international trade

The next few years should see an increase in silk exchanges all over the world. The ultimate objective of the World Trade Organisation (WTO) is to liberalise world trade and in particular to remove quotas. Textiles are no exception and WTO textiles are governed by a special arrangement known as the Agreement on Textiles and Clothing (ATC).

The ATC is designed to assimilate the previous multilateral textile system, the Multi-Fibre Arrangement (MFA) into the WTO. This MFA was initiated in 1974 as a means of giving the textile and clothing industries of developed countries a number of years' breathing space to enable them to adapt to competition from developing countries. MFA was in that respect an exception to the existing GATT rules. Although the initial life-span of MFA was intended to be 4 years, it was periodically renewed and instead of lasting 4 years it lasted for 21. Now that GATT has been replaced by WTO, the products covered by MFA will be 'integrated' into WTO, and be covered by the same rules as every other product. This period of integration is due to last until 31 December 2004, by which time all existing quotas on the import of textiles and clothing should disappear. (ATC does not provide for the removal of tariffs, only for the removal of quotas).

The implications for silk are considerable. Silk goods from Asia will be able to enter the European Union and the United States in unlimited quantities. In the meantime, the developing countries will have to open their frontiers to increased imports. Countries such as India and China still have high levels of import duties on the import of silk goods from the west. The level of these tariffs will inevitably have to come down. There is undoubtedly a market for western-designed silk goods in India and China. Western designer labels combined with high-quality silk garments and accessories are considered as highly desirable by the more affluent Asian consumers who already have a keen appreciation of silk.

In trade terms, European manufacturers of silk goods have certain advantages over their Asian competitors. Because they are physically closer to the centres where fashion is decided (Paris, Milan, London, New York) they can react more quickly to change. In addition, they are constantly driven towards greater creativity and the best possible quality so as to appeal to a market segment that is always looking for innovation. These same features, creativity and quality, are also appreciated in Asia and there is no doubt that the western countries' competitive advantage will not last indefinitely, as designers in Hong Kong, Korea, China and India are becoming increasingly aware of the needs of the market. For the European silk professionals it is a race to keep ahead of the competition by the exploitation of their own specific knowledge of design and marketing.

Silk's tiny share of overall textile production is at the same time an advantage and a handicap. The advantage is the exclusiveness that silk enjoys. The handicap is that the funds available for the promotion of silk are limited, compared with those available for wool and man-made fibres. Given that there is no agreement between silk producers and silk processors on the need for promotion or on the means of financing it, it may be better to talk about 'education' rather than promotion.

The younger generation knows little or nothing about silk, unlike their mothers or grandmothers, who were much more likely to own at least one item made of the fabric. As consumers, the young have no means of distinguishing between the properties of different textile fibres if they have received no training in doing so. In today's context, the criterion for textiles is increasingly 'performance'. The major retailers draw up specifications running into tens of pages and their suppliers must meet these requirements, which become ever more stringent.

Silk has its own specific properties, but they cannot be measured in the same way as those of man-made fibres. The obvious danger for silk is that consumers (i.e. retailers or end-users) will measure silk against these performance criteria. If they expect silk to offer the same performance as the most recent polyester microfibres they will find it wanting. The qualities of silk are more subjective, more emotional. It is an illusion to try to evaluate silk in purely scientific or practical terms. The way colour is expressed by a silk fabric can best be appreciated by the human eye and not by a laboratory instrument. The way a silk garment feels next to the skin is quite different from the evaluation made by a system such as Kawabata, which attempts to give objective values to an essentially personal sensation. It is as much an illusion to attempt to evaluate silk in terms of 'performance' as it is to discuss a Van Gogh painting in terms of the chemical composition of the paints used, or to describe a Beethoven symphony in a purely mathematical way.

There is no ambition for silk to replace man-made fibres in quantitative terms and there never could be. It is not fighting in the same arena, despite the persistent claims of certain synthetic fibres to be 'silk-like'. Even in a world obsessed with performance, work-rate and productivity there is still a space available for a fibre charged with history, emotion, magic, naturalness, sensuality. This is what silk is offering and this is how it has to be judged, with its incomparable qualities which far outweigh its shortcomings. As textiles tend to become more 'consumable', more disposable, when consumers increasingly buy cheap garments because they can replace them easily, silk has to make a stand for quality, for durability, for value rather than price.

Appreciation of silk will not happen spontaneously. There is an urgent need for consumer education, about fibres in general and silk in particular. Even among sales staff there is a serious lack of knowledge about the characteristics of a silk garment. The message that must be conveyed is that silk is different and should be cherished for its difference.

For a fibre to be used uninterruptedly for over 5000 years, it must have something unique. It is up to the silk professionals to communicate this individuality and make sure that in another 5000 years silk will still reign supreme as the Queen of Fibres.

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