

# Natural Silk – an Unusual Fibre: Origin, Processing and World Production

DOI: 10.5604/01.3001.0014.9291

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## Abstract

*The article presents the history of the development of sericulture in the world, including Poland. The advantages of natural silk which cause interest in its production and processing in many countries of the world are indicated. A brief description of mulberry silkworm breeding and the technology of silk processing into textile products are presented. The article provides information on the production of natural silk in several countries in 2015-2019. The share of silk in the world global production of fibres is about 0.2%. Over the last few years, the largest amounts of natural silk have been produced by the following countries: China, India and Uzbekistan – the total share of these countries in the world silk production is about 98%.*

**Key words:** natural silk, silkworm breeding, *Bombyx mori*, mulberry, silk technologies, history of silk.

## Introduction

Silk is a product of the larvae of several species of moths belonging to the bombycid (*Bombycidae*) and saturnid (*Saturniidae*) family. The domesticated mulberry silkworm, *Bombyx mori*, which is the most common moth used in the commercial production of silk fibres, is representative of the bombycidae family. The saturnid family includes several species living in a wild state that are suppliers of what is called wild silk [1-3]. Asia, mostly China, is the homeland of silkworms. According to Chinese records, the beginning of cultivated silk production with the mulberry silkworm *Bombyx mori* occurred around 2700 BC [1, 3].

Silk is a special fibre clearly different from all other natural fibres. Expensive silk fabrics imported from distant China have been a symbol of wealth and luxury for many centuries for Europeans. They fascinated with their lightness and softness, incomparable with any other fabrics produced in Europe at that time. The Chinese – which seems unbelievable – for many centuries successfully kept the secret of obtaining and processing silk fibres, which made them a monopoly in the production of these beautiful and very expensive fabrics. The beginning of sericulture in the Byzantine Empire and later in the countries of Southern Europe took place only in the middle of the 6th century AD. [1, 4].

Raw silk contains about 75% fibre with a triangular cross-sectional shape (formed from a protein called fibroin) and about 25% of gum (globular protein called sericin) coating the fibroin

fibres. The two fibroin filaments are held together by sericin, thus helping in the formation of a cocoon. The sericin is usually left on the silk filaments during production processes (spinning, weaving), acting as a protective layer. After manufacture, the silk fabric is subjected to the degumming process in order to remove the sericin. This process reveals the softness, sheen, hand, and colour of the silk [2, 5].

Sericin has traditionally been removed with alkali (sodium hydroxide or sodium carbonate), organic acids, or detergent [6]. However, some of these agents cause deterioration of silk fibroin fibre properties. Undesirable changes to the fibres can be manifested by a deterioration of aesthetic and physical properties, such as a decrease in tenacity, surface fibrillation, poor handle, and dull appearance [6, 7]. In recent years, a large number of studies have been devoted to degumming methods using proteolytic enzymes. The enzyme degumming processes are effective, economical and eco-friendly. Moreover, as research shows, enzymatic processes do not damage the silk fibres and allow to obtain products of high quality [5, 8].

The amino acid composition of silk fibroin differs significantly from that of keratin in wool fibres. Silk fibroin, unlike keratin fibres, lacks amino acid cystine. Fibroin is formed primarily of two amino acids; glycine and alanine constitute in total about 60% of the amino acids comprising silk fibre [2, 5].

A characteristic property of silk fibres is the relatively high tenacity, amounting to 30-50 cN/tex, and high elasticity, which

causes that silk fabrics exhibit the ability to prevent the formation of wrinkles or creases on their surface during use. Silk has a high moisture sorption capacity. If the relative humidity of the surrounding air (RH) is 65%, the silk fibre contains about 11% water (in relation to its dry weight) [4]. This feature has a very positive effect on the comfort of using silk underwear and clothing. The smoothness and softness of silk fibres make the clothes, underwear and bedding made of them have excellent parameters of sensory comfort. Silk shows high resistance to most of the organic solvents commonly used, as well as relatively good resistance to organic acids and low-concentration mineral acids. It is, however, sensitive to light. UV radiation present in the spectrum of sunlight causes the photodestruction of fibroin, which is manifested by yellowing of the products and deterioration of their mechanical parameters [2, 4].

The aim of the article is to present the history of sericulture development, as well as to provide a short description of the obtaining and processing of silk fibres and global silk production in the recent period.

## History of sericulture in the world

For centuries, natural silk has been and still is one of the most valuable fibres. Silk fibre has been a fibre of splendour and legend for several thousand years, which has fascinated people all over the world.

According to Confucius, the discovery of the possibility of using the cocoons

of the *Bombyx mori* mulberry silkworm to obtain perfect silk fibre took place in China in 2640 BC. Legend has it that we owe this discovery to the Chinese princess Xi Lin Shi. One day, while she was drinking tea in a mulberry garden, a cocoon fell into her cup. The hot tea partially dissolved the tight outer layer of the cocoon. The princess, taking it out of the cup, noticed that the cocoon was made of a thin fibre. As she began to pull them gently, the fibre unwound and unwound [4]. Silk turned out to be a long (continuous) fibre, with a length incomparable to any other natural fibre, several thousand times longer than cotton or wool fibres.

Most historical sources indicate that silkworms were bred from the earliest times by peoples of East Asia, mainly in China. Magnificent tapestries, bedspreads, vestments, clothing fabrics and accessories were made of silk. The splendour, the richness of patterns and colours made silk as precious as gold. That is why the Chinese emperors kept silkworm farming a secret from the world for many centuries. For the betrayal of this secret or the export of silkworm eggs (grain) from China, people were punished with death [1, 9]

The former trade route, more than 12,000 km long, connecting China with the Middle East and Europe, known as the Silk Road, played an important role for many centuries. This route was used by merchants to transport gold, precious stones, perfumes and arable crops to China. There they exchanged these goods mainly for silk, iron and paper. Silk fabrics, which appeared in the Mediterranean region for the first time in the 2nd century BC, were brought to Europe in this way [10].

The centuries-long Chinese domination of silk production was broken when Byzantine Emperor Justinian (482–565), learning that fine silk yarn was the product of caterpillars bred in China, sent several monks to China on an espionage mission. After learning about the breeding, the monks took a grain of the mulberry silkworm in pilgrim sticks from China. This gave rise to silk production in the Byzantine Empire, and then silkworm farming spread to Greece and other southern European countries. Although China lost its monopoly on silk production, beautiful Chinese fabrics continued to be imported into Europe.

In addition to China and India, many countries have participated in the development of silk production, such as Turkey, Japan, Russia, Italy, France, Spain, and America [9].

India is the second largest silk producer after China, where sericulture is not only a tradition but also a living culture [11].

In the Asian part of Turkey, in Anatolia, silkworm farming began in 552 A.D. Many years later, in the mid-16th century, silk-making developed here on a large scale. The city of Bursa became famous for its silk trade [12].

Silkworm eggs came to Japan from China via Korea. Good climatic conditions and careful breeding meant that the Japanese silk industry in the early 19th century was at a higher level than the Chinese. For many years Japan kept its secrets of the breeding and technology of obtaining fibres, thanks to which Japanese silk was of higher quality than Chinese.

In Russia, Peter the Great is considered a promoter of sericulture. Beginning in 1700, the silk industry developed, especially in the southern regions, where the best conditions for mulberry cultivation and silkworm farming prevailed. The highest development of breeding took place in 1800, when the production of cocoons amounted to approx. 10,000 tons. The following years are marked by a decline in breeding. Only in 1928 was the same production achieved as in 1800. The following years, thanks to the development of the production and cultivation of mulberry, resulted in a further increase in the production of cocoons.

Silk shipped to Rome in the 1st century A.D. cost as much gold in weight. Until the 9th century AD silk production in Italy was practically non-existent. Ready-made silk products and fabrics were imported from China, and later also from Constantinople. The first farming began in Italy in 1146 in Sicily. Several decades later, in the mid-thirteenth century, Italy became the centre of silk production in Europe.

In France, the beginnings of silk production date back to the 16th century, and in its centre – Lyon – to the middle of the 18th century, 25% of the inhabitants were involved in the cultivation of silkworms and the production of silk fabrics.

The production of silk was moved to England by the French Huguenots in the 17th century, who settled in the London area. Due to the unfavourable climate, silk production in England did not develop.

In Spain, there were positive results in the rearing of silkworms. Already in around 740 A.D, the Arabs spread breeding there. Spain became a centre for the export of silkworm grain to neighbouring countries.

The beginning of silkworm farming in America dates back to 1522, when Cortez brought mulberry trees and a grain of silkworm to Mexico. Silkworm breeding arrived in North America, in 1609. King James I of England sent mulberry seedlings and a grain of silkworm to Virginia to start breeding there. Since silkworm farming was labour-intensive and was less profitable than cotton or tobacco farming, it did not develop. However, at the beginning of the 19th century, in the northeastern regions of the USA, there was a development of silk fabric production.

Attempts to breed silkworms in Sweden, the Netherlands and Ireland were unsuccessful due to climatic conditions. Apart from the above-mentioned countries, silkworm breeding developed later in other European countries – in Hungary, Romania, Bulgaria and Poland [1, 4, 9].

## ■ Sericulture in Poland

It is difficult to determine exactly when the beginnings of silkworm breeding in Poland date. The first written records of attempts to establish silkworm breeding in Poland come from the mid-seventeenth century. It is known that in the mid-eighteenth century, silkworm farms already existed in Poland. This is evidenced by, inter alia, the works of priest Jan Krzysztof Kluk (1739–1796), an outstanding naturalist and promoter of progressive methods of plant cultivation. In a book published in 1777 entitled ‘Plant Maintenance and Reproduction’ [13], he described effective methods of obtaining good quality white mulberry leaves (*Morus alba* L.) as food for silkworms. Another book published in Poland, ‘The Practice of Silk Making’ by Jan Ferdynand Thym, contained comprehensive knowledge of the cultivation of mulberry trees, necessary for obtaining food for silkworms, as well as the princi-

**Table 1.** Production of cocoons in Poland in the years 1938-1990 (kg) [19]. Note: \*) – values in m<sup>3</sup>.

Year	Number of breeders	Cocoon production, kg	Average cocoon production per breeder, kg
1938	1322	11.130	8.4
1945	996	10.076	10.1
1947	1850	10.600	5.7
1949	3934	72.846	18.5
1954	6293	136.000	21.6
1960	3263	113.000	34.6
1970	330	442	1.34
1980	254	163	0.64
1990	246	34.4 *)	0.14*)

ples of growing mulberry silkworms, and unwinding cocoons [9, 14].

In the 18th century, silkworm farms existed in many Polish courts, where plants were also established in which silkworm cocoons were unwound and fabrics for clothing and furniture as well as wall decorations were produced. Some plants specialised in the production of kontusz sashes, which were very fashionable at that time in Poland, Lithuania and Belarus. In the factory in Słuck, founded around 1767, ornate silk sashes with silver and gold threads were produced. Beautiful silk kontusz sashes, famous for their rich design, were also manufactured by Jakub Paschalis' manufacture, established around 1791 in Warsaw [9, 15].

Despite the changing economic situation and many different adversities, in the following years other enthusiasts and propagators of silk making started their activities. Persistent work paid off. Szymon Pisulewski in his book "Botanika Popularna" [16], published in 1845, describes the plantation of several thousand white mulberry trees near Krakow. This plantation provided food for a large silkworm farm of over 30,000 caterpillars.

During this period, associations of white mulberry tree growers and silkworm breeders were established in Poland, e.g. the Warsaw Silk Society (1853) and the Krakow Silk Society (1870) [9, 14]. These organisations supported the development of silkworm farming in various ways, including publishing activities. The book "Sericulture", published in 1872 with the support of the Krakow Silk Society, was highly appreciated by Polish silkworm breeders for several decades [17].

A turning point in the history of the silk industry in Poland was the year 1924. At that time, the Central Experimental

Sericulture Station in Milanówek was established by the siblings Henryk and Stanisława Witaczek. In a relatively short time, a network of silkworm breeders was organised, thus ensuring the supply of raw material (cocoons) for the production of a wide range of silk fabrics, which found buyers in many countries around the world. The Sericulture Station in Milanówek also conducted training courses for silkworm breeders and popularised the rational principles of white mulberry cultivation [1, 18].

After World War II, from 1945, the Central Experimental Sericulture Station in Milanówek operated under new organisational conditions under the name of MILANÓWEK. In addition to the production of silk fabrics and grain, research was also carried out on silkworm breeding and the technology of obtaining and processing silk.

After 1950, there was a marked increase in the number of silkworm breeders in Poland, which resulted in an upward trend in cocoon production (*Table 1*); in the best period, in the years 1953-1954, about 600 thousand dm<sup>3</sup> of cocoons per year. Soon, due to the decline in interest in silkworm farming, the cocoon production began to decline gradually. In 1984 breeders provided only about 140 thousand dm<sup>3</sup> of cocoons [15, 19].

During this period, in addition to a small amount of domestic raw material, several dozen tons of raw silk thread and grey (undyed) silk fabrics were processed in Poland, which were mainly imported from China and Vietnam. Dyed and printed dress fabrics, scarves, shawls and ties were produced. Hand-painted silk fabrics and finished products made of these were very popular among buyers [18]. Unique silk fabrics were also produced, made to order, according to historical patterns, in-

tended for interior decoration in historic buildings, castles and palaces. These fabrics decorate, among others, the interiors of Wawel Royal Castle, the Royal Castle in Warsaw, and the Sanctuary of Our Lady of Częstochowa at Jasna Góra.

Currently, silkworms are no longer reared in Poland in order to obtain cocoons for industrial silk production. Only certain amounts of silk fabrics (unfinished) imported from abroad are processed, subjecting them to finishing processes, i.e. dyeing, printing, as well as manual painting. Clothing and bedding fabrics are manufactured with a modern, attractive design, as well as ready-made silk products – blouses, scarves, ties and others.

The subject of silkworm breeding and the properties of silk fibres as well as new areas of their application is still of interest to several Polish research centers [20, 21]. The Institute of Natural Fibres and Medicinal Plants in Poznań conducts conservation breeding of the mulberry silkworm. The content of bioactive substances in the leaves of white mulberry, the quality of which has a direct effect on the quality of silk produced, was also studied at this Institute [22]. At Lodz University of Technology, Faculty of Material Technologies and Textile Design, a method of manufacturing so-called *silk paper* which consists of 65% silk and 35% cotton linters was developed. The thin sheets of this paper are a valuable material for the conservation treatment of historic silk fabrics [23].

## Silkworm farming and fibre production

Silkworms are divided into two groups: farmed and wild. The first group includes the most common mulberry silkworm (*Bombyx mori*). Silkworm caterpillars hatch from the eggs after 12 days of gradual heating from 18 to 27 °C. The caterpillars are very voracious. It is possible to obtain 0.3-0.5 kg of raw silk fibre from one gram of grain. In the period of 30-33 days of their life, their weight increases by 10,000. times. Shortly after hatching, the caterpillar is 3 mm long and less than 1 mm thick. An adult individual is 40-60 mm long, 10 mm thick and weighs about 5 g.

The caterpillar moults 4 times during its rapid growth. After the last moulting, it begins to form a cocoon around itself.

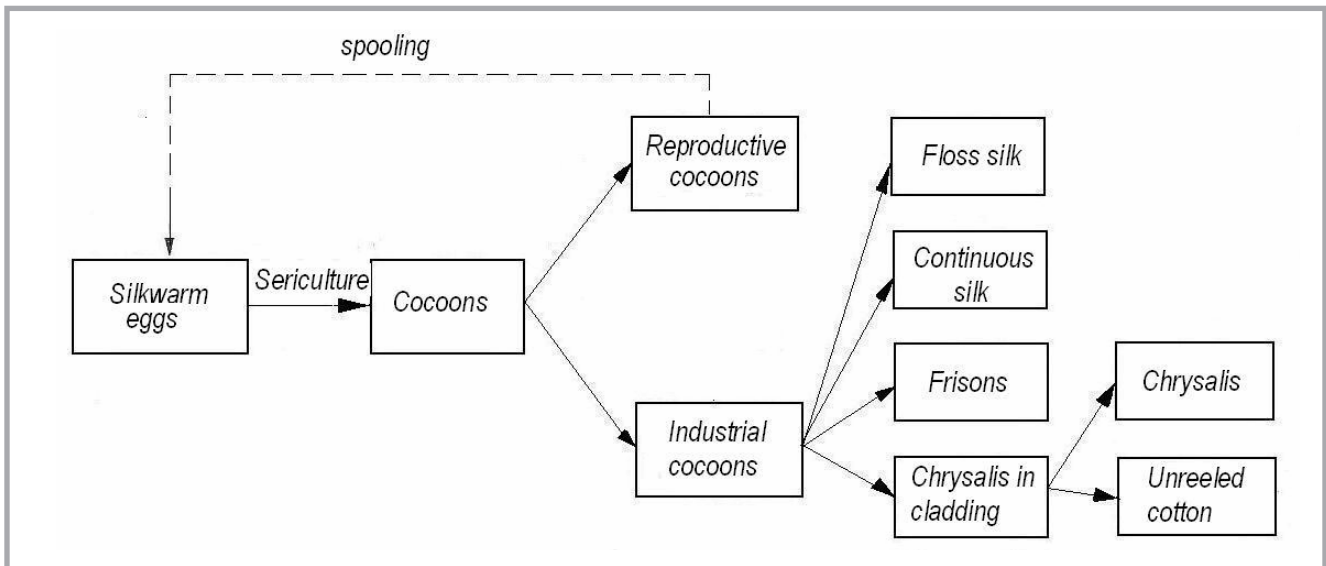


Figure 1. Technological flow chart of natural silk production.

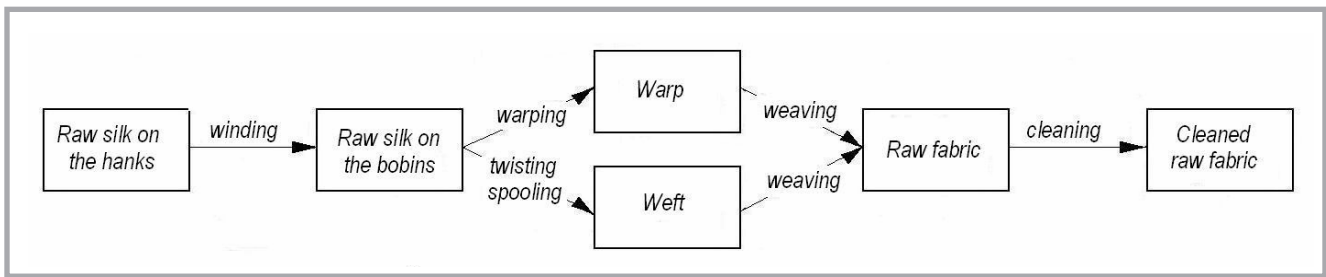


Figure 2. Technological flow chart of the processing of raw fabric.

The process of fibre formation consists in the secretion by the glands of the caterpillars of a liquid substance that is a mixture of proteins: fibroin that forms the fibre and a sticky substance – sericin, which protects the fibre naturally. The liquid substance, released at a rate of 25 cm/min, solidifies when in contact with air.

One cocoon is made of a fibre about 3,000 metres long. After creating a cocoon, the caterpillar transforms into a chrysalis, and then after a dozen or so days into a butterfly, which pierces the cocoon and gets out.

Males and females are brought together in pairs by being placed in muslin or parchment bags. After a few hours, the female lays 300-500 eggs, and then both of them die within a few days. Grain can be stored at 2-4 °C for up to 12 months. Continuous silk filament cannot be obtained from the cocoons from which the butterfly emerged. Therefore, to obtain a valuable long fibre for production purposes, most cocoons are subjected to killing the pupae inside them by hot air or steam. Such cocoons can be used to

produce continuous filament by an unwinding process.

Figure 1 shows a scheme for the production of natural silk.

The breeding of silkworms requires strict rules of conduct for the breeder in handling silkworms at every stage of their development. Thanks to proper breeding activities, optimal conditions for development and providing the right amount of food for the silkworm caterpillars, cocoons of the highest quality are obtained [1, 9].

### ■ Wild silkworms

Known for many centuries, wild silkworms are silkworms that live in the wild on trees and feed on their leaves. The most famous in this group is the silkworm called tasar or tussah, which lives in China on oak trees. The silk obtained from the cocoons of this silkworm is called tussah silk, which is thicker than mulberry silk. Another silkworm of this group is the Indian silkworm, called the tessar, which feeds on the leaves of

oak and other trees. The muga silkworm is bred in the Assam Province of India, and produces a thick and strong fibre [24].

In Asia and South America, the eria silkworm is bred, which is fed with castor leaves. The cocoons of this silkworm that cannot be unwound are intended for processing with spinning methods. Wild silkworms are farmed on trees and therefore must be protected from birds that feed on caterpillars.

The silk of wild silkworms is thicker and less even than that of mulberry. Their cultivation has little commercial importance, accounting for a few percent of the total world silk production [1, 4].

### ■ Silk (cocoons) processing

Cocoons are classified in terms of size and are subjected to the unwinding process. This process consists of infusing cocoons in hot water (softening sericin to facilitate unwinding), brushing to find the end of the fibre, and unwinding the fibre with simultaneous joining of several

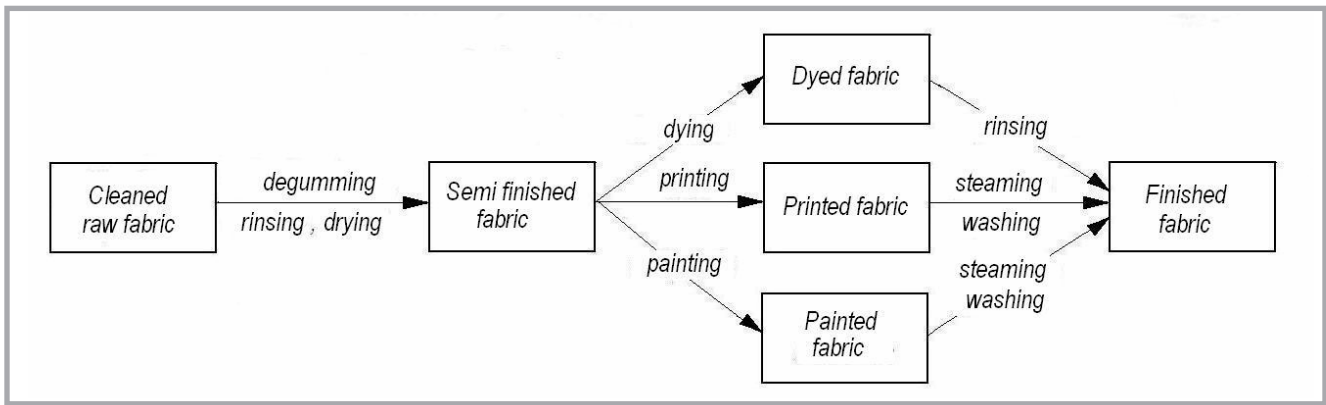


Figure 3. Flow chart of the finishing of silk fabrics.

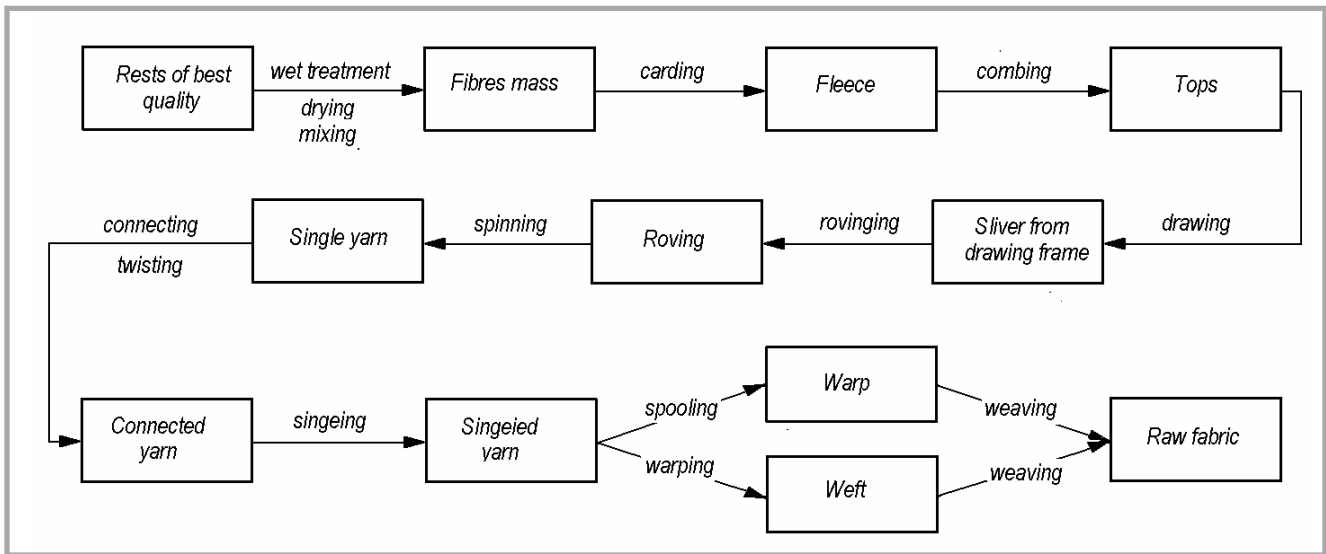


Figure 4. Flow chart of the processing of best quality rests.

fibres from separate cocoons, depending on the desired thickness of the resulting silk yarn [1].

As a result of the process of cocoon unwinding, 800-1000 m of continuous fibre are obtained, which is about 30% of the total cocoon mass. The remaining parts of the cocoon are processed in a similar way to the non-unwinding cocoons of wild silkworms.

The conditions for the boiling process are set depending on the breed of cocoons and even the region they come from. The typical thickness of the raw silk thread obtained is 2.2-2.5 tex (20-22 denier) with a fibre thickness of 0.22-0.28 tex (2-2.5 denier).

The raw silk thread obtained in the unwinding process, being in the form of hanks, is the starting material for further production. The production process of raw fabrics is shown in Figure 2.

The grey fabrics obtained and waste fibres can be finished according to the scheme shown in Figure 3. The basic technological finishing operations are as follows: removing sericin (degumming), rinsing, drying, printing, dyeing or painting.

In the process of cocoon unwinding, waste is obtained too, from which, as a result of boiling in washing agents, so-called unreeled cotton is obtained.

Waste also includes yarn waste from the warp and weft preparation processes, as well as from the weaving process. The fibres from non-unfolding (non-unwinding) and reproductive cocoons are also important.

A diagram of waste processing according to Chinese technology is shown in Figure 4. An important product made of the waste is bourette yarn, fabrics made of which are characterised by excellent

moisture absorption and are successfully used, among others, for summer clothing.

## Natural silk production in the world

Table 2 shows world silk production compared to other textile fibres. The statistical data covers the period of 20 years of the 20th century (1975-1995). The silk production during this period was about 0.2% of the total fibre production.

Table 3 shows world silk production from 1978 to 1996 in the six countries that accounted for the largest share thereof. In five countries (except Japan) in the period 1978-1993, there was an increase in silk production (production doubled). In the period 1993-1996 there was a decrease in silk production by 18 thousand tons. In 1978, China had the largest share of silk production – 42%, and next Japan – 35.5% (together 77.5% of world production). On the other hand, in 1996, China

had the largest share of silk production – 72%, and next India – 16% [25].

**Table 4** shows the world silk production in 19 countries in the years (2015-2019). The largest producers of natural silk during this period were China, India and Uzbekistan. Their total production in 2019 amounted to 106.2 thousand tons, which accounted for 97.5% of the total world production. The world production of silk in 2019 was almost half compared to 2015. Such a significant decrease in silk production was caused by a significant decrease in production in China. In the rest of the world, except for Brazil, Japan and Turkey, production increased. A graphic image of world silk production in 2015-2019 is shown in **Figure 5**. **Figure 6** shows the global silk production of other countries (excluding China). Production in these countries has a current tendency to increase; from 32.1 thousand tons in 2015 up to 40.3 thousand tons in 2019 [26].

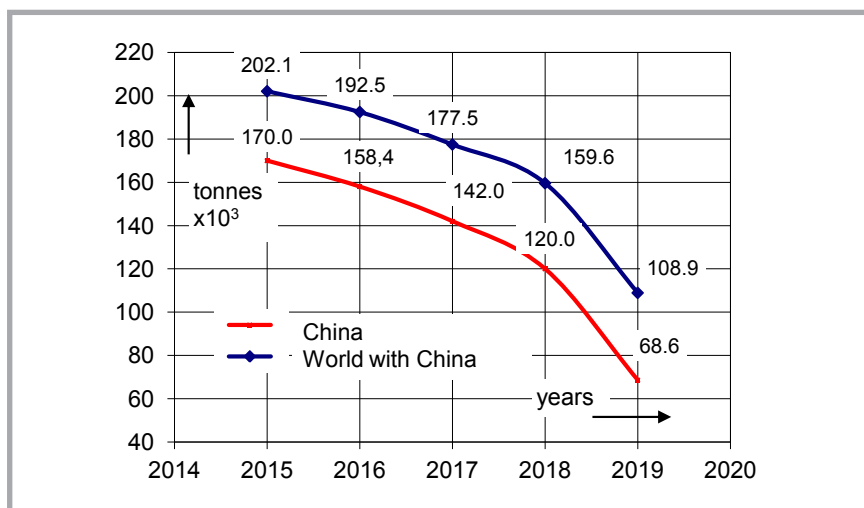
**Figure 7** shows the percentage share in the production of natural silk of China and other countries (excluding China). The share of China in world silk production decreased from 84.1% in 2015 to 63% in 2019, while that of other countries increased from 15.9% in 2015 to 37% in 2019 [26].

## Summary

China remains the main silk producer. In the 1980s, over 10 million Chinese farmers raised silkworms. In 1982, China exported 36,000 tons of silk, i.e. more than half of world production. Currently, 35-40 countries are involved in silkworm farming, and world production of raw silk in 2019 was around 108,000 tons, which is only 0.2% of the world production of textile raw materials [26].

According to data from 2019, the largest producers of natural silk are three countries: China, India and Uzbekistan. The total production of silk in these countries accounts for over 97% of the world's production of this fibre.

Various analyses and feasibility studies carried out by FAO experts indicate that not only countries in the East Asian region, but also in Eastern Europe, Central Asia, Latin America and Africa have great potential for the development of silkworm farming and silk processing. This is supported by both socio-economic and agro-climatic conditions.



**Figure 5.** World production of natural silk in the years 2015 through 2019.

**Table 2.** World silk production in comparison with other textile fibres (thousand tons) [25].

Year	Cotton	Synthetics	Cellulosic fibres	Wool	Silk	Total	% of total
1975	11.809	7.346	2.959	1.502	49	23.665	0.21
1985	17.540	12.515	2.999	1.672	57	34.785	0.16
1995	19.200	20.200	3.000	1.600	100	44.100	0.23

**Table 3.** World silk production by country (tons) [25].

Year	China	India	CIS countries	Brazil	Japan	Others	Total
1978	19.000	3.475	3.240	1.250	15.960	2.200	45.125
1985	32.000	7.029	3.990	1.458	9.582	2.748	56.807
1993	71.845	14.000	4.000	2.326	4.254	3.750	100.175
1996	59.000	13.000	2.600	2.360	2.250	2.500	81.710

**Table 4.** World silk production (tons) [26].

Item	Countries	2015	2016	2017	2018	2019
1	China	170,000.00	158,400.00	142,000.00	120,000.00	68,600.00
2	India	28,523.00	30,348.00	31,905.00	35,261.00	35,820.00
3	Uzbekistan	1,200.00	1,256.00	1,200.00	1,800.00	2,037.00
4	Vietnam	450.00	523.00	520.00	680.00	795.00
5	Thailand	698.00	712.00	680.00	680.00	700.00
6	Brazil	600.00	650.00	600.00	650.00	469.00
7	North Korea	350.00	365.00	365.00	350.00	370.00
8	Iran	120.00	125.00	120.00	110.00	227.00
9	Bangladesh	44.00	44.00	41.00	41.00	41.00
10	Japan	30.00	32.00	20.00	20.00	16.00
11	Turkey	30.00	32.00	30.00	30.00	5.00
12	Bulgaria	8.00	9.00	10.00	10.00	10.00
13	Madagascar	5.00	6.00	7.00	7.00	7.50
14	Indonesia	8.00	4.00	2.50	2.50	2.50
15	Tunisia	3.00	2.00	2.00	2.00	2.00
16	Philippines	1.20	1.82	1.50	2.00	2.00
17	Egypt	0.83	1.20	1.10	1.25	1.50
18	South Korea	1.00	1.00	1.00	1.00	1.00
19	Syria	0.30	0.25	0.25	0.25	0.50
	<b>Total</b>	<b>202,072.33</b>	<b>192,512.27</b>	<b>177,507.35</b>	<b>159,648.00</b>	<b>108,870.00</b>

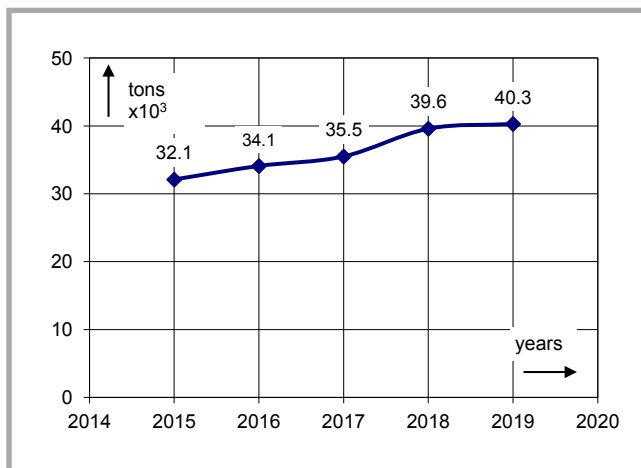


Figure 6. World production of natural silk without China.

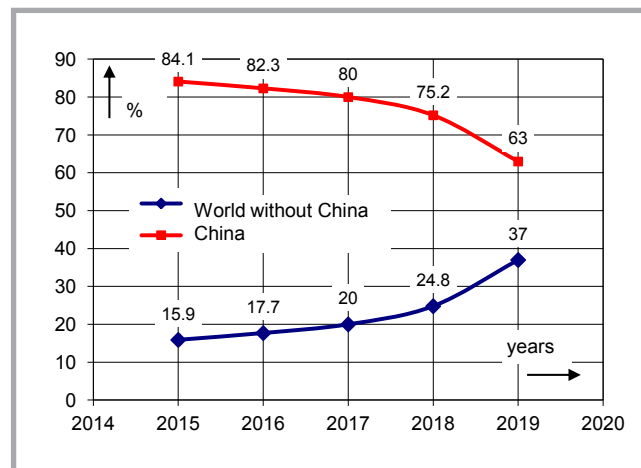


Figure 7. Percentage of world production of natural silk in China and other countries without China.

In Poland, the greatest development of silk production took place in the 1950s. In 1954, 6,300 silkworm farmers produced 136 tons of cocoons. At present, there are no longer any silkworm farms providing cocoons for the industrial production of silk. In Poland, certain amounts of silk fabrics imported from abroad are dyed and printed.

The annual Chinese silk fair is visited by traders from all over the world. Crowned heads still wear silk, and it adorns temples, palaces and historic buildings, as well as adding splendour to many shows. As the New York fashion designer Oskar de la Renta said, "Silk is to the body what a diamond is to a hand."

We owe all the benefits and properties of silk to small caterpillars and people who learned how to use them centuries ago to produce this wonderful fibre.

## Acknowledgements

This work was partially supported by statutory research funds of the Institute of Material Science of Textiles and Polymer Composites, Lodz University of Technology, Poland, no. 142/501/4-42-1-1.

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Received 07.12.2020 Reviewed 07.04.2021