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WILD SILK FIBERS: TYPES, PROPERTIES AND UTILIZATION AREAS

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Abstract

As being one of the most important textile fibers, silk has drawn attention of specialists for a long time. Fiber's extraordinary features, due to its structure, are the reasons for this. This animal fiber, commonly known as silk, is the mulberry silk produced by the silkworm called *Bombyx mori*. In addition to this, there are also different silk types which are called as "wild silk" and obtained from the cocoons of the worms that they produce for completing their metamorphosis. Although their use is not as common as Mulberry silk, utilization of wild silk fibers - generally produced in India and China - in textiles have been increasing in recent years. There are various studies about wild silk fibers which have different types such as Eri, Muga, Tasar and Tussah. Moreover, spider silk can be categorized in wild silk fiber group. In this study, wild silk types, their properties and utilization in textiles are introduced.

Key Terms

Wild silk, silkworms, eri, muga, tussah, tasar.

1. Introduction

Silk is one of the most important raw material type for textile industry thanks to its properties. This fiber type's discovery took place in China and it dates back to 3000 BC. According to Confucius, Chinese princess Xi Lin Shi invented silk reeling, so the fiber, accidentally[1]. It is believed that ancient source of this silk was *Bombyx Mandarina (Moore)* which was a wild silk moth/worm species living on white mulberry trees. However, silk demand in time, forced these insects to be domesticated and to become human dependent[2–7]. Silk demand raised from the properties of which the fiber could provide to fabrics; along with its lustrous apparel, its strength, elasticity, softness and absorbency are quite impressive[8]. Silk is produced by a wide variety of animals which are mostly in classes Insecta and Arachnida[9]. However, the most known ones are in Insecta class. Insects produce this fiber in order to build a cocoon for its protection during methamorphosis[10]. Most silks have proteinaceous character and they generally contain two types of proteins, which are called sericin and fibroin. Fibroin is the a type of protein which constitutes the filament and sericin is a viscous, glue like protein[9,11]. Two fibroin filaments leave insect's gland held together by sericin. For that reason sericin should be removed in order to obtain processable silk fibers[1,10].

Most known and commercialized silk type is produced by a special silkworm belonging to Bombycidae subclass, *Bombyx Mori*, which is domesticated for silk production. This silkworm type's diet contains mulberry leaves, thus the fiber is called "mulberry silk". This fiber can be obtained/reeled, from unharmed cocoons, in filament form up to 1600 meters in length. This fiber has high tenacity, good elasticity and permeability properties. However, amino acid composition and properties of the fiber are effected by the silkworm's diet[12,13]. Silk fibers contain; Glycine, Alanine, Valine, Leucine, Isoleucine, Phenylalanine, Aspartic acid, Glutamic acid, Lysine, Arginine, Histidine, Serine, Threonine, Tyrosine and Proline amino acids in different amounts[14]. The highest amount in these amino acids belong to glycine for mulberry fibroin.

Non-mulberry silks, or as we use in this study: wild silks, are mostly produced in India, China, Japan, Madagascar, Mexico and Botswana. However, India has the most production amount

for these fibers among these countries[5,7]. Sericultural map of India is given in Figure 1, which contains production regions for mulberry and wild silks. In this study, information about wild silks and most known types of these fibers will be given

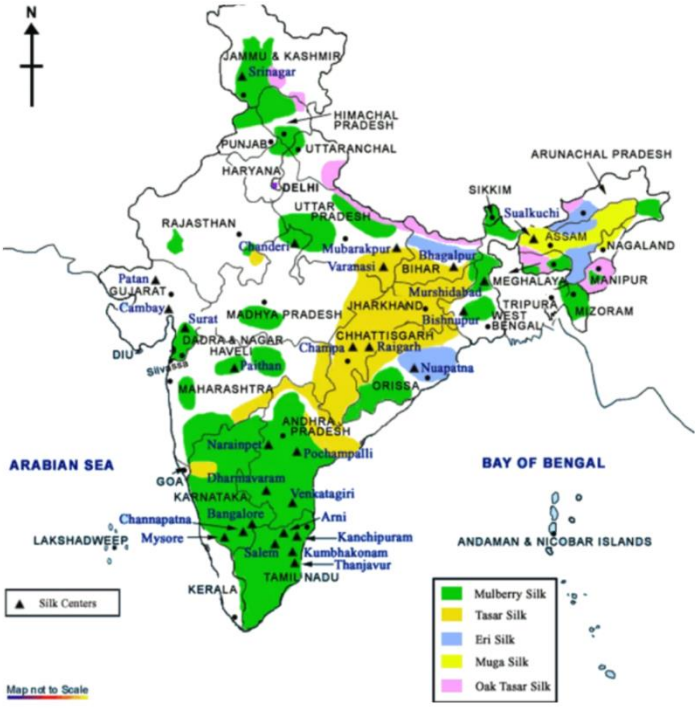

Figure 1. Sericultural map of India

2. Wild Silk

Wild silk fibers are produced mostly by lepidopterans which belong to Saturniidae family. Most known types of these fibers are eri, muga, tasar and tussah, all of which can be produced in India. According to a report prepared by Indian Ministry of Textiles, wild silk production and the prices of these fibers in period of 2017-2018 in India are given in Table 1. However, the difference between Tussah and Tasar silk should be clarified, initially. Tasar is the silk fiber type which gathered from the cocoons of *Antheraea mylitta* which is mostly found in India and the fiber is also called tropical tasar there[7,15]. Tussah, which is also spelled as "Tusser" according to Peigler, is produced by *Antheraea pernyi* that is Chinese oak silk moth. A hybrid was developed in 1970s, which was initially called as Antheraea proylei, from Antheraea roylei and Antheraea prenyi and the fiber of this silkworm is called also as oak tasar or temperate tasar[7]. In literature, Tasar and Tussah name were used together/or separately sometimes for the same fiber and in some of them the differences were specified[7,8,16–18].

Table 1. Indian silk market data[19]

Wild Silk Type	Production (metric tonnes)	Price ($/kg)*
Tasar	2988	48-52.5
Eri	6661	33.75-39
Muga	192	255-300

* according to rupee-dollar exchange rate of 19.03.2019
Source: Central Silk Board-Bangolore

There are other types of wild silk fibers produced in different parts of the world. Most of the insects which are responsible for the production of these wild silks are not belong to Saturniidae

family. Notodontidae of Western Africa, Lasiocampidae of Madagascar, Lasiocampidae of Africa are the lepidopterans which produce wild silk[7].

Silkworms produce silk in order to build cocoons that will ensure protection from environmental threats and predator attacks during their metamorphosis[20–22]. For this reason, cocoons of these silkworms should meet these expectations. It was indicated that cocoons should be considered as a porous composite which consists sericin matrix and fibroin fiber reinforcement[21,23,24]. Some properties of these "porous composites" were investigated in several studies[20,21,23–27]. According to these studies;

- Wild silk cocoons (*A. mylitta, A. pernyi and S. Cynthia*) exhibited higher level of thermal buffer than domestic cocoon (*B. mori*)[20],
- Fiber widths on outer layer is higher than fiber widths on inner layer of the cocoons (*A. mylitta, A. pernyi and S. Cynthia and B. mori)*[20],
- They have antibacterial and antifungal properties[11,25,28].
- Structure of inner layers of cocoon allow gas and vapour exchange while outer layers act like a barrier for protection. *A. pernyi* cocoons contain high amounts of calcium oxelade crystals which might increase water resistance at outer layer and allow the silkworm to withstand winter conditions for several months while hibernating[25].
- Pelades (inner layer) have better static and the dynamic properties than average properties of cocoons (conducted on *B. mori* cocoons)[21].
- According to Chen et al., cocoons of different silkworms have differences in "*the number and connectivity of layers through the cocoon wall thickness, the amount and distribution of sericin binder, the diameter and packing density of the silk fibres, the degree of orientation of the nonwoven structure, the distribution of larger holes within that structure, and the presence of calcium oxalate crystals"* (27 cocoon types were investigated)[24].
- Demineralisation was carried out to wild silk cocoons which contains mineral crystals in some studies. Kaur et al. stated that *A. assamensis* silkworm cocoons have brick shaped mineral deposits or crystals and physical (ultrasonication) or chemical (with milder concentration and pH) demineralisation can be used on these cocoons[27].

2.1. Tasar silk

The word "Tasar" comes from Sanskrit word trasara or tassara which means shuttle, according to Peigler. There are two different types of tasar silk which are called: temperate tasar (or oak tasar) and tropical tasar[7]. Tropical tasar is produced by *A. mylitta* silkworm while *A. proylei* silkworm is responsible for oak tasar production[8,18,29]. Tropical tasar (Figure 2) has copperish colour and coarse fibers (in comparison with mulberry silk)[8,30]. Silkworm diet contains trees *Terminalia tomentosa* (asan tree), *T. arjuna* (arjun tree) and *Shorea robusta* (shala tree)[31]. The shape of the cocoon is oval like the rest of the wild silks, its colour is brown, it has a wall thickness of 0.38±0.02 mm wall thickness and nominal density of 804±33 kg/m^3 [24]. Average length of this fiber is 700 m, density is 1.3 g/cm^3-1.34 g/cm^3 (outer layer-inner layer) and its moisture regain is 10.76% - 10.27% (outer layer-inner layer)[32]. Non-broken filament length, which is an important cocoon quality parameter that effects reeling speed, for this type of silk is around 150 m (average)[33]. Average tenacity, elongation and initial modulus values of the fiber are; 4.50 g/d, 26.5% and 84 g/d, respectively[34]. It was also stated by Sen and Babu that dye uptake of tasar fiber is lower than mulberry fibers but higher than other two wild silk type used in their study (Eri and Muga) for acid and disperse dyes[35]. Chattopahyay et al. investigated the commercial types of yarns, which are thigh-reeled, machine reeled, single twisted (tram) and double twisted (organzine), and stated that tenacity reached highest value with double-twisted yarns. Moreover, they have found that IPI values varied between 42.60/125m (single twisted) to 71.60/125m (machine-reeled)[16].

Figure 2. silkworm(a), moth (b) and cocoon (c) of tasar silk (*A. mylitta*)

Oak tasar is produced by the hybrid of Chinese tussah silkworm *A. pernyi* and *A. roylei* and called *A. proylei*[7,8,30]. These silkworms' diet contains – as can be understood from the fibers name- oak trees. Density of the fiber is 1.345 g/cm3 for male and 1.344 g/cm3 for the female insect. Crystallinity percentages of fibers of the same insects are 44.6 and 41.8, respectively[30]. This fiber is produced in Manipur, Himachal Pradesh, Uttar Pradesh, Assam, Meghalaya, Jammu and Kashmir states of India[8].

2.2. Tussah silk

The word "Tussah" (can also be spelled as Tusser, tussor and tussore) is derived from "Tasar"[7,36]. This silk type is produced by A. pernyi silkworm which is native to China (Hunan, Zhejiang, Shandong and Liaoning)[37]. The first document about artificial rearing of this silkworm was written in 1651 by Sun Yanquan and in it says "*The cocoon it produces is about 6 cm in length with a brown colour unlike mulberry silkworm cocoon that is yellow or white. The cocoons like hen egg in size are hanging on the tree*"[37]. Silkworm diet contains oak leaves and this gives the fiber its ecru to dark brown colour[36]. Cocoon is oval, its wall thickness is 0.43±0.07mm (it was 387±31 in study of Zhang et al), and the nominal density is 624±47 kg/m^3 [23,24]. Tensile strength of this fiber is around 28.6 cN/tex while its breaking elongation is approximately 21%. Linear density of the fiber is 5.5 denier, which is approximately twice the mulberry silk fiber's size[38].

Along with textile applications, there are various studies in the literature about their applications in biomedical field[39–41]. Minoura et al studied attachment and growth of fibroblast cells on both Bombyx mori and A. pernyi silk fibroins and gathered better attachment and more growth on tussah silk fibroin[40]. Li et al. blended mulberry and tussah silk fibroins in order to produce biomaterials with desired properties[41]. Tussah fibroin scaffolds were used for nerve regeneration and tendon tissue engineering[42].

Figure 3. silkworm(a), moth (b) and cocoon (c) of tussah silk (*A. pernyi*)

2.3. Muga silk

A. assamensis is a semi-domesticated silkworm which is responsible for the production of muga silk and native to Assam state of India[27,30]. Fiber of this insect is called muga (mooga, moonga) which is derived from an old Sanskrit word that means amber. This silk type is also referred as "Pride of India" and it was used by nobles and kings of Assam in the past[7]. Silkworms consume aromatic leaves of som and soalo plants[8]. Cocoon of A. assamensis has

an oval shape and golden yellow colour with a wall thickness of 277±29 μm[23,32]. Average filament length of the fiber is 450 m and non-broken filament length of muga silk is around 180 m (average), while it is 520 m for mulberry silk. Fiber density is 1.332 g/cm^3- 1.348 g/cm^3 (outer layer-inner layer) and moisture regain of the fiber is 10.76%-10.27 (outer layer-inner layer) [32,33]. Tenacity of the fiber is 4.35 g/d and breaking elongation is 22.3%[34]. Talukdar et al enhanced tenacity by applying methanol and phenol[43]. Muga fibers have linear density of 4.5-5 denier, it is coarser than mulberry silk but finer than tussah silk. Dyeing of this fiber type is comparatively higher than both mulberry and tussah silk fibers[38]. Applications of muga silk fibroin in biomedical field were investigated[44,45].

Figure 4. silkworm(a), moth (b) and cocoon (c) of muga silk (*A. assamensis*)

2.4. Eri silk

Fiber of Samia Ricini, which is called eri silk is the only silk fiber that can be reeled without harming pupa. For this reason, the fiber is also called as "peace silk" or "vegan silk"[46]. The silkworm's homeland is northeast India[7,47]. It is produced in a small part of the country, but most produced wild silk fiber in India is eri silk with 6661 tonnes (Table 1). Its price is lower compared to tasar and muga silk. The silkworm feeds with castor oil plants and were domesticated[30,48]. Cocoons are oval and has a creamish white colour. Average filament length that can be reeled from the cocoon is 450 m, fineness of the fiber is between 2.3 denier- 3.6 denier and has a density between 1.28 g/cm^3- 1.29 g/cm^3 [32]. Its tenacity is 3.7 g/d and breaking elongation is 20.8%[34]. This fiber cannot be reeled as other silk fibers, cocoons are collected after moth leaves them, so it can be utilized in textile industry after processes like cotton fiber[49]. Kumar and Ramachandran studied eri silk knitted fabrics and indicated that these fabrics can be suitable for inner garments and thermal wear[50]. Chollakup et al blended eri silk fibers with cotton and produced ring-spun yarns and woven fabrics. They stated that blending eri silk fibers which are longer and stronger than cotton enhanced physical properties of yarns and fabrics[49].

2.5. Fagara, Tensan and *Gonometa postica* silks

Fagara silk is produced by *Attacus atlas*, which has one of the largest moths in the world, and their cocoons have light brown colour[7,30]. Cocoons of this insect has 0.28±0.08 mm thickness and 619±16 kg/m^3 nominal density[24]. Peigler indicated that fibers of *Samia cynthia* is sometimes called as fagsara silk[7]. Another wild silk type, tensan silk, is produced by Antheraea yamamai and native to Japan. Cocoons of this silkworm, which feeds with ok leaves, has a green or yellow colour[7]. Wall thickness of tensan silk cocoon is 0.17±0.01 mm and its nominal density is 779±27 kg/m^3 [24]. Moreover, silk fiber which is produced by *Gonometa postica* has been the subject of some studies[26,51].

4. Conclusions

In this study, literature about wild silk fibers were investigated in terms of their sources, production, characteristics and utilization for the use of textile specialists.

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