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Mulberry and Non-Mulberry Silk Fibres: Structure, Properties, and Applications in Textiles, Biomedicine, and Sustainable Materials

A. Janani[1], Dr. K. M. Pachiyappan[2], Jothi Jerald[3]
[1, 3]Research Scholar, [2]Dean & Associate Professor, Department of Costume Design and Fashion, PSG College of Arts and Science, Coimbatore

Abstract: Silk is one of the oldest fibres known to man. It is an animal fibre produced by certain insects to build their cocoons and webs. Silk is primarily produced by silkworms (Bombyx mori and wild species such as Antheraea mylitta, Samia ricini, Antheraea assamensis), and its remarkable combination of mechanical, chemical and biological properties has attracted extensive scientific research. Although many insects produce silk, only the filament produced by the mulberry silk moth Bombyx mori and a few others in the same genus is used by the commercial silk industry. Silk is a natural protein fibre historically valued for its luster, drape and strength, and it has evolved from a luxury textile material to a multifunctional biopolymer with applications in biomedicine, engineering and sustainable materials. This comprehensive review explores the classification of silk fibres, structural and physicochemical characteristics, traditional textile uses, and emerging advanced applications in tissue engineering, drug delivery, smart textiles and eco-materials. With increased global emphasis on sustainable and biocompatible materials, silk stands at the interface of tradition and innovation, offering solutions from luxury fashion to cutting-edge biomedical technologies.

Keywords: Silk fibre, mulberry silk, non-mulberry silk, biomechanical properties, silk fibroin, biomedical applications, sustainable materials.

I. INTRODUCTION

Silk is a natural protein-based fibre that has been valued for centuries for its exceptional aesthetic qualities, mechanical performance, and versatility in textile and non-textile applications. Traditionally recognized as a luxury material used in apparel and decorative textiles, silk has a documented history spanning over 5,000 years. Originating in China, silk production gradually spread across Asia, Europe, and the rest of the world through the Silk Road, profoundly influencing trade, culture, and textile development. The enduring appeal of silk lies not only in its lustrous appearance and pleasant handle but also in its outstanding mechanical strength, toughness, and adaptability to diverse uses. In recent decades, silk materials have attracted significant scientific and technological interest due to their unique combination of high tensile strength, flexibility, biodegradability, and biocompatibility. Unlike many synthetic polymers that require high temperatures, toxic solvents, and energy-intensive processing, silk is produced under mild, aqueous, and environmentally benign conditions. Silkworms spin silk fibres from concentrated protein solutions at ambient temperature, using water-based systems. This natural processing mechanism has inspired extensive research into bio-inspired fibre production and sustainable material development. Among the various natural sources of silk, silkworm cocoons are the most widely recognized and commercially important. These cocoons represent a remarkable example of natural material engineering. Over time, they have evolved complex structural architectures and combinations of physical and chemical properties that enable them to withstand environmental stresses such as predators, moisture, ultraviolet radiation, and microbial attack, thereby ensuring protection of the developing pupa. A silkworm cocoon is essentially a natural silk composite material with a complex non-woven structure composed.

Continuous silk fibroin fibres bound together by a sericin matrix. The fibroin protein forms the load-bearing core of the fibre, providing strength, toughness, and elasticity, while sericin acts as a protective, adhesive coating that binds the fibres together and enhances the cocoon’s structural integrity. This hierarchical composite architecture imparts the cocoon with excellent mechanical stability, thermal insulation, and resistance to external damage.

The structure–property relationship observed in silk cocoons has inspired extensive research into silk as a high-performance biomaterial.

The hierarchical organization of silk, from the molecular arrangement of amino acids to the macroscopic cocoon structure, results in exceptional performance characteristics that are difficult to replicate synthetically. As a result, silk has transcended its traditional role as a textile fibre and is now widely explored in advanced applications such as tissue engineering scaffolds, wound dressings, drug delivery systems, biomedical devices, smart functional materials, and eco-friendly composites. Today, silk is recognized not only as one of the most prestigious natural fibres but also as a versatile and sustainable biopolymer with significant potential in modern material science and engineering. Understanding the types, structure, and properties of silk is therefore essential for both textile science and emerging technological applications.

II. MOLECULAR STRUCTURE AND COMPOSITION OF SILK

Silk is primarily composed of two proteins, fibroin and sericin, which together determine its structural and functional properties. Fibroin is the core structural protein and constitutes approximately 70–80% of the silk filament, while sericin makes up about 20–30% and surrounds the fibroin as a protective coating. Fibroin is a fibrous protein rich in glycine, alanine, and serine amino acids, which enable the formation of highly ordered β-sheet crystalline regions interspersed with amorphous domains. This unique molecular arrangement is responsible for silk’s exceptional tensile strength, elasticity, and toughness.

The crystalline β-sheet regions provide rigidity and strength, whereas the amorphous regions contribute to flexibility and energy dissipation during deformation. This balance between ordered and disordered domains allows silk to exhibit a combination of stiffness and extensibility rarely found in natural or synthetic fibres. Sericin, on the other hand, is a globular protein that acts as a natural adhesive, binding fibroin filaments together and protecting them from environmental damage.

The removal of sericin through the degumming process enhances the softness, lustre, and dyeability of silk fibres, making them suitable for textile applications. However, in biomedical applications, both fibroin and sericin have shown bioactive properties, including antioxidant activity, antimicrobial effects, and enhanced cell adhesion, further expanding the functional scope of silk materials.

III. TYPES OF SILK TYPES OF SILK

Silk fibres are broadly classified based on the species of silkworm, its degree of domestication, and the nature of the host plant consumed by the larvae. On this basis, silk is divided into two major categories, namely mulberry silk and non-mulberry (wild) silks. Each type of silk exhibits distinct structural, physical, chemical, and aesthetic characteristics, which significantly influence its end-use applications. The variations in fibre morphology, amino acid composition, crystallinity, and filament fineness arise primarily due to differences in silkworm species, environmental conditions, and feeding habits.

A. Mulberry Silk

Mulberry silk is produced by the domesticated silkworm *Bombyx mori*, which feeds exclusively on mulberry leaves (*Morus* species). This type of silk constitutes more than ninety percent of the global silk production and is considered the finest and most uniform silk variety. The domestication of *Bombyx mori* over thousands of years has resulted in controlled breeding, uniform cocoon structure, and consistent fibre quality, making mulberry silk the most commercially important silk type.

Structurally, mulberry silk fibres are composed of highly aligned fibroin chains with a relatively high degree of crystallinity. The fibroin protein consists predominantly of glycine, alanine, and serine amino acids arranged in repetitive sequences that form stable β-sheet crystalline regions. These crystalline domains are responsible for the high tensile strength and stiffness of mulberry silk, while the amorphous regions contribute to elasticity and flexibility. The average filament length of mulberry silk is exceptionally long, often ranging from 800 to 1,500 meters per cocoon, allowing for the production of smooth, continuous filaments. Mulberry silk exhibits superior lustre due to its triangular cross-section, which reflects light efficiently. It also demonstrates excellent dye affinity, moisture absorption, and thermal regulation properties. These features make it highly suitable for luxury apparel, such as sarees, dresses, scarves, and ties, as well as for home furnishings like curtains and bed linens. Beyond traditional textile applications, mulberry silk fibroin has gained extensive attention in biomedical research owing to its biocompatibility, controlled biodegradability, and minimal inflammatory response, making it suitable for sutures, tissue scaffolds, and drug delivery systems.

B. Non-Mulberry Silks (Wild Silks)

Non-mulberry silks are produced by silkworm species that are either semi-domesticated or entirely wild and feed on a variety of forest plants. These silks are collectively referred to as wild silks and differ significantly from mulberry silk in terms of texture, colour, filament structure, and mechanical behavior. The most important non-mulberry silks include tussar, eri, and muga silks, which are predominantly produced in India and parts of Southeast Asia.

C. Tussar Silk

Tussar silk, also known as tasar silk, is produced by silkworms belonging to the genus *Antheraea*, such as *Antheraea mylitta* and *Antheraea proylei*. These silkworms feed on forest trees like Arjun (*Terminalia arjuna*), Sal (*Shorea robusta*), and Oak, and are largely reared in natural or semi-wild conditions. As a result, tussar silk production is closely linked with forest ecosystems and rural livelihoods.

Tussar silk fibres are generally coarser and less uniform than mulberry silk due to variations in environmental conditions and feeding patterns. The fibres possess a natural golden to copper-brown colour, which reduces the need for extensive dyeing and enhances their appeal in eco-friendly and sustainable fashion. From a structural perspective, tussar silk exhibits lower crystallinity compared to mulberry silk, leading to slightly reduced tensile strength but improved thermal insulation properties.

The cocoon structure of tussar silk is more porous, providing better air permeability and comfort in warm climates. However, the filament length is shorter and more variable, which limits its use in producing very fine fabrics. Tussar silk is widely used in sarees, dress materials, upholstery, and handicrafts, particularly in traditional and ethnic textiles that emphasize texture and natural aesthetics. Its rustic appearance and biodegradable nature have increased its demand in sustainable and slow fashion markets.

D. Eri Silk

Eri silk is produced by the silkworm *Samia ricini*, which feeds primarily on castor leaves (*Ricinus communis*). Unlike other silk varieties, eri silk is commonly referred to as “peace silk” or “ahimsa silk” because the silk is harvested after the moth emerges from the cocoon, ensuring that the life cycle of the silkworm is not interrupted. This ethical aspect has significantly increased the popularity of eri silk in environmentally conscious and ethical textile industries.

Eri silk fibres are staple-like rather than continuous filaments, resulting in a soft, bulky, and wool-like texture. The fibres exhibit excellent moisture absorption and thermal insulation properties, making eri silk particularly suitable for colder climates. The fibroin structure of eri silk contains a higher proportion of amorphous regions, which contributes to its softness and flexibility but results in comparatively lower tensile strength than mulberry silk.

Eri silk fabrics are known for their comfort, breathability, and hypoallergenic nature. They are widely used in shawls, blankets, sweaters, baby garments, and winter clothing. In addition, eri silk has gained attention in biomedical applications due to its slow biodegradation rate and compatibility with human tissues. Its ability to blend easily with cotton, wool, and other natural fibres further enhances its versatility in textile production.

E. Muga Silk

Muga silk is one of the rarest and most prestigious silk varieties in the world and is produced exclusively in the Assam region of India by the silkworm *Antheraea assamensis*. The silkworm feeds on specific host plants such as Som (*Persea bombycina*) and Soalu (*Litsea polyantha*), which grow naturally in the Brahmaputra valley. Due to its limited geographical distribution and labor-intensive production process, muga silk is considered a heritage fibre and holds immense cultural significance.

Muga silk is renowned for its natural golden-yellow colour and exceptional durability. Unlike other silk varieties, muga silk does not require dyeing and becomes shinier with age and repeated washing. The fibre exhibits high tensile strength, resistance to moisture, and excellent ultraviolet stability, making it one of the most durable natural fibres known.

Structurally, muga silk fibroin shows a unique balance between crystalline and amorphous regions, contributing to its long service life and resistance to environmental degradation. Muga silk is primarily used in traditional Assamese garments, ceremonial attire, and high-value textiles. Its superior longevity and natural lustre make it particularly suitable for heirloom textiles passed down through generations.

F. Comparative Significance of Silk Types

The diversity of silk types reflects the adaptability of silkworm species to different ecological conditions and highlights the influence of biological and environmental factors on fibre properties. Mulberry silk dominates industrial and biomedical applications due to its uniformity and superior mechanical properties, while non-mulberry silks contribute significantly to sustainable fashion, traditional textiles, and ethical production systems.

The structural and functional differences among silk types offer vast opportunities for targeted applications in textiles, composites, and bio-based materials.

IV. APPLICATIONS AND USES OF SILK

The exceptional combination of mechanical strength, flexibility, aesthetic appeal, and biocompatibility has enabled silk to remain a highly valued material across a wide range of applications. While silk has traditionally been associated with luxury textiles and apparel, advancements in material science and biotechnology have significantly expanded its functional scope. The unique molecular structure of silk proteins, coupled with environmentally benign processing conditions, has positioned silk as a sustainable and high-performance material suitable for both conventional and advanced technological applications.

A. Textile and Apparel Applications

Silk has been extensively used in the textile and apparel industry due to its natural lustre, smooth texture, excellent drape, and superior comfort properties. The triangular cross-section of silk fibres enables efficient light reflection, imparting a characteristic sheen that distinguishes silk fabrics from other natural fibres. Silk exhibits high moisture absorbency while remaining dry to the touch, which enhances wearer comfort in both warm and cool climates. Its low thermal conductivity allows silk garments to provide insulation in cold conditions while maintaining breathability in hot environments.

In apparel, silk is widely used for sarees, dresses, blouses, scarves, ties, lingerie, and evening wear. Its excellent dye affinity enables vibrant coloration and intricate design patterns, making it suitable for high-fashion and couture garments. Silk also demonstrates good elasticity and crease recovery, contributing to its elegant appearance and durability in wearable applications. In addition, silk is often blended with fibres such as cotton, wool, and synthetic fibres to improve fabric performance, reduce cost, and enhance functional characteristics.

B. Home Textiles and Furnishing Applications

Beyond apparel, silk finds extensive use in home textiles and interior furnishings where aesthetic appeal and functional performance are equally important. Silk fabrics are commonly used in curtains, draperies, upholstery, cushion covers, bed linens, and wall hangings. The natural sheen and rich texture of silk enhance the visual appeal of interior spaces, while its strength and durability contribute to long service life when properly maintained.

Silk-based furnishing fabrics exhibit good resistance to dust accumulation and possess natural hypoallergenic properties, making them suitable for households with allergy-sensitive occupants. In addition, silk carpets and rugs, particularly those produced using traditional weaving techniques, are valued for their intricate designs, durability, and cultural significance. The use of silk in home textiles reflects its ability to combine luxury with functional performance.

C. Medical and Biomedical Applications

One of the most significant modern applications of silk is in the field of biomedical engineering and healthcare. Silk fibroin has been extensively studied for medical use due to its excellent biocompatibility, controlled biodegradability, minimal inflammatory response, and ability to be processed into various forms such as films, fibres, sponges, and hydrogels. Historically, silk sutures were among the earliest biomedical applications of silk, valued for their strength and ease of handling.

In contemporary medicine, silk fibroin is used in wound dressings, tissue engineering scaffolds, and regenerative medicine. Silk-based wound dressings promote faster healing by maintaining a moist environment, supporting cell adhesion, and preventing bacterial infection. In tissue engineering, silk scaffolds are employed for bone, cartilage, skin, and vascular tissue regeneration due to their mechanical stability and ability to support cell growth and differentiation.

Silk has also been explored for controlled drug delivery systems, where its tunable degradation rate allows for sustained release of therapeutic agents. Furthermore, sericin, once considered a waste product in silk processing, has demonstrated antioxidant, antimicrobial, and moisturizing properties, leading to its use in biomedical coatings and pharmaceutical formulations.

D. Cosmetic and Personal Care Applications

Silk proteins, particularly sericin and fibroin, are widely used in cosmetic and personal care products due to their skin-friendly properties. Sericin exhibits excellent moisture-retention capacity and forms a protective film on the skin and hair, reducing water loss and improving smoothness. As a result, silk-derived ingredients are incorporated into creams, lotions, shampoos, conditioners, and facial masks. In hair care products, silk proteins enhance shine, reduce friction, and improve manageability by forming a smooth coating on hair fibres. In skincare formulations, silk peptides contribute to improved skin elasticity, softness, and protection against environmental damage. The natural origin and biocompatibility of silk proteins align well with the growing consumer demand for eco-friendly and bio-based cosmetic products.

E. Industrial and Engineering Applications

Silk has also found applications in industrial and engineering fields where lightweight, high-strength, and flexible materials are required. Silk fibres have been explored as reinforcement materials in polymer composites due to their good tensile strength and biodegradability. Silk-reinforced composites are particularly attractive for applications requiring sustainability and reduced environmental impact.

In addition, silk-based films and coatings are being developed for use in flexible electronics, sensors, and optical devices. The optical transparency, mechanical flexibility, and thermal stability of silk fibroin make it suitable for biodegradable electronic substrates and wearable devices. Silk materials have also been investigated for filtration systems, protective textiles, and eco-friendly packaging materials.

F. Traditional, Cultural, and Handicraft Uses

Silk holds immense cultural and traditional significance, particularly in Asian countries such as India, China, and Japan. Silk fabrics are integral to religious ceremonies, weddings, and cultural festivals. Traditional silk weaving and embroidery techniques represent valuable intangible cultural heritage and provide livelihoods to millions of artisans and rural communities.

Handcrafted silk products, including sarees, shawls, tapestries, and decorative textiles, are highly valued for their craftsmanship and artistic expression. The use of non-mulberry silks such as tussar, eri, and muga supports sustainable forest-based livelihoods and preserves traditional knowledge systems. These applications highlight silk's role not only as a material but also as a cultural symbol and economic resource.

G. Emerging Sustainable and Smart Textile Applications

With increasing emphasis on sustainability and smart materials, silk is gaining attention as a renewable and biodegradable alternative to synthetic fibres. Silk-based smart textiles incorporating conductive materials, sensors, and functional finishes are being developed for health monitoring, temperature regulation, and protective clothing. The ability of silk to be functionalized without compromising its mechanical properties makes it a promising platform for future textile innovations.

Silk's low environmental footprint, combined with its multifunctional properties, positions it as a key material in the transition toward sustainable and circular textile systems. Ongoing research continues to explore novel processing techniques and hybrid materials that further enhance the performance and application range of silk.

V. CONCLUSION

Silk is a multifunctional natural fibre that seamlessly bridges traditional textile heritage and modern material science. Its unique molecular structure, hierarchical organization, and sustainable production process contribute to a rare combination of mechanical strength, flexibility, comfort, and environmental compatibility. The diversity of silk types, including mulberry and non-mulberry varieties, provides a wide range of properties suitable for both conventional and advanced applications. With growing interest in sustainable and bio-based materials, silk continues to hold immense potential for innovation in textiles, biomedical engineering, and eco-friendly material development.

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