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Silkworm Sericin: A Novel Biopolymer with Multifaceted Applications

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ABSTRACT

Sericulture is an important agro-based enterprise that supports rural livelihoods, with silk valued for its superior physicochemical properties. Silk fibres consist mainly of fibroin and sericin, the latter being removed during degumming and often discarded as industrial waste, contributing to environmental pollution. Recent research, however, recognizes sericin as a valuable natural biopolymer with notable biocompatibility, biodegradability, and multifunctional properties. Structurally, it is a hydrophilic protein rich in polar amino acids, enabling diverse functional interactions. Its characteristics are influenced by extraction and purification methods, including chemical, thermal, biological, and emerging green techniques. Sericin has broad applications in biomedical, food, cosmetic, textile, and environmental sectors, including wound healing, tissue engineering, drug delivery, food packaging and skin care products. Despite its potential, challenges such as variability in extraction, limited mechanical strength, and scalability persist. This review summarizes its structure, properties, extraction methods, multidomain applications, and associated limitations, showcasing its potential role in sustainable and value-added utilization.

Keywords: Silk, Silkworm, Sericin, Antioxidant, Hydrogel, Food packaging

INTRODUCTION

Sericulture is an important, extremely profitable, and labour intensive agro-based cottage industry that is widely recognized as a viable endeavour for the socioeconomic development of rural communities like those in India. This industry provides opportunities for the sustainability of the livelihoods of rural populations in terms of valuable employment and income generation[1]. Silk, the main product of sericulture, is considered the most elegant textile in the entire world due to its unparalleled grandeur, natural sheen, elasticity, light weight, durability and high dye affinity, and is therefore regarded as the "Queen of Textiles"[2]. India ranks as the world's second-largest producer of raw silk and has the unique distinction of producing all four commercially important types of silks namely, Mulberry silk from *Bombyx mori* Linnaeus, Eri silk from *Samia ricini* (Donovan), Tasar silk from *Antheraea mylitta* Drury, and Muga or golden silk from *A. assamensis* (Helfer).3 In 2024-25, India generated 41,121 metric tons of raw silk, with Mulberry silk making up the largest share at 75.69% (31,119 MT), followed by Eri silk at 19.18% (7,886 MT), Tasar silk at 4.58% (1,884 MT), and Muga silk at 0.57% (232 MT)[4]. The silk fibre is mainly composed of two proteins: fibroin, which accounts for 65-85%, and sericin, which makes up 15-35%.[5] During the final stage of larval development, silkworms produce large amounts of these proteins, which combine to form the silk thread used in cocoon formation. These cocoons serve as a protective casing for the silkworm to undergo metamorphosis into its adult form[6].

Across the textile sector, sericin is largely eliminated from silk cocoons through degumming. After that, the remaining fibroin is processed to obtain raw silk, which is then utilized to produce various yarns and silk textiles[7]. The potential of sericin has often been overlooked over decades. Approximately 50,000 tons of sericin is dumped as waste into sewage systems each year from the 4.0 lakh tons of dried cocoons generated globally. This results in significant water pollution due to elevated levels of chemical and biological oxygen demand[8,9]. However, recent advances in sericin's conformational structure, functional characteristics, biological compatibility, and processing performance have drawn attention to its unique qualities and demonstrated its potential for application in various industries, including textiles, food, cosmetics, and healthcare[10]. It is a naturally occurring biopolymer that functions as a cementing agent, binding fibroin filaments together to form silk threads[11].This protein exhibits a range of beneficial properties,including antioxidant, moisturizing, wound-healing, antibacterial, ultraviolet protection, and antitumour activities[12]. Furthermore, sericin has also been found to be an affordable and sustainable source of edible, fat-free coating material that minimizes food weight loss during storage[13]. It also improves the colour and texture of fruits by inhibiting polyphenol oxidase activity, thereby helping to keep them fresh[14]. Therefore, this review aims to investigate the functional characteristics and potential applications of sericin obtained from silkworm cocoons across various sectors, in light of the growing demand for this protein in scientific and biomedical fields compared to other biomaterials.

Structure, Chemical Composition, and Forms of Sericin

Sericin is a globular protein that has both crystalline and amorphous regions because of its random coil and β-sheet structures. Owing to its random coil configuration, this protein has a poor mechanical strength and brittleness in the dry form[15]. The random coil form dissolves easily in hot water (≥ 50–60 °C); however, upon cooling, it changes structure to β-sheet forms, leading to gel formation[16]. γ-rays based studies have further revealed that sericin is organized into three distinct layers with varying fiber orientations; an outer layer with directional fibers, a middle layer with cross-fiber arrangement, and an inner layer with longitudinal alignment[17]. Takasu *et al.* demonstrated through chromatographic analysis that sericin within the silk gland is water-soluble; however, following spinning and drying, it becomes insoluble due to the transition to βsheet structures, which exhibit significantly lower solubility than the amorphous form[18]. Sericin's molecular weight variesbetween 10 and 400 kDa,[11] and its properties change with molecular weight distribution[10]. Generally, the random coil form is more soluble, while a higher content of β-sheets and moisture-induced aggregation leads to greater crystallinity and lower solubility.

This macromolecule comprises of 18 amino acids and is predominantly characterized by polar functional groups, including hydroxyl, amino, and carboxyl groups[19]. These functional groups facilitate hydrophilicity, crosslinking, copolymerization, and interactions with other polymers[20]. Table 1 presents the composition of amino acids present in sericin, as documented in literature. Its elemental composition includes carbon, oxygen, nitrogen, and hydrogen at approximately 46.5%, 31%, 16.5%, and 6%, respectively[21].These biochemical characters impart salient features, including biological compatibility, antioxidant potential, bacteriostatic efficiency, and moisture retention[11]. Sinohara and Asano identified glycopeptides following protease mediated breakdown of sericin, revealing the occurrence of sugars such as galactose, mannose, galactosamine, and glucosamine[22]. Furthermore, sericin from the mulberry silkworm (*B. mori*) houses two kinds of oligosaccharide units: the first is made up of two N-acetylglucosamine units and several mannose residues, of which one is associated with an asparagine residue in the protein backbone; the secondcomprises β-galactosyl (1β3)-N-acetyl galacto samine, attached to serine or threonine residues[23].

With respect to its water solubility, sericin is divided into three (A, B, and C) categories[30]. The outermost layer of the cocoon contains sericin A, which is the most soluble fraction in warm water. It contains about 17.2% nitrogen, with glycine, serine, aspartic acid, and threonine as the predominant amino acids. Beyond the amino acids contained in sericin A, sericin B, which is located in the intermediate layer, also contains tryptophan and roughly 16.8% nitrogen. The innermost fraction, sericin C, is located next to fibroin; it contains proline and displays slightly reduced nitrogen content (16.6%) and is insoluble in hot water. In addition to this classification, sericin fractions have been described by other researchers based on their dissolution behavior, using designations such as sericin I to IV, S1 to S5, and α, β, and γ forms[31].

Sericin Genes

In silkworms, sericin genes are expressed in the cells of the middle silk gland (MSG), where they direct the synthesis of sericin proteins. Multiple studies have elucidated and functionally described the key genes involved in sericin production, namely Ser1, Ser2, and Ser3. The first gene discovered, Ser1, is a single-copy gene with 9 exons and a size of about 23 kb. It is found at the Src locus on the 11th chromosome. Through alternative splicing, it generates four major mRNA transcripts (2.8, 4.0, 9.0, and 10.5 kb)[32,18]. The Ser2 gene, identified by Michaille et al.33, consists 13 exons that range in length from 28 to 2574 bp and produces two mRNA transcripts (3.1 and 5.0 to 6.4 kb) through isoform diversification. This locus is considered relatively more variable and complex compared to othersilk protein encoding genes and shows structural similarity to Ser1, particularly in the first two exons that encode N-terminal signal sequences. Ser3 is also located on chromosome 11 at the Src-2 locus.18 It is relatively smaller (~3.5 kb), with three exons and produces a single transcript of approximately 4.5 kb.

Functional Properties of Sericin

Water Solubility

Sericin dissolves easily in hot water attributable to its amino acid composition, particularly the high content of serine, threonine, glycine[34] and precipitates upon cooling. The abundance of hydroxyl-containing residues in these amino acids imparts strong hydrophilicity[16]. Structural studies using circular dichroism in sericins derived from mulberry *(B. mori)* as well as non-mulberry species (*S. ricini, A.assamensis*, and *A.mylitta*) have confirmed the relationship between structure and solubility[35]. Temperature also influences sericin conformation; it remains in a soluble random coil form at higher temperatures but transitions to βsheet structures upon cooling, leading to gel formation, a property advantageous for biomaterial applications[15].

Gelation

Temperature, pH, and concentration are some of the variables that affect sericin's gelation property.Studies on *B. mori* sericin indicate that gelation occurs more rapidly at higher concentrations and elevated temperatures (around 40 °C), andvice versa atlower temperatures. Gelation is faster at pH 6 and slows down as pH rises. Sericin exhibits reduced surface tension and increased strength during gel formation, along with a conformational change from a random coil configuration to β-sheet structure, indicating a thermo-reversible process[15]. This property has been utilized in biomaterial development through cross-linking with biopolymers like cellulose[36], synthetic polymers such as polyvinyl alcohol[25], and in the formation of hydrogels[37].

Thermal Stability

By monitoring changes in mass with temperature and time, thermogravimetric analysis assesses the thermal stability of sericin. Studies on sericin from mulberry (*B. mori*) and non-mulberry (*S. ricini, A. mylitta,* and *A. assamensis*) silkworms shows that non-mulberry sericins are more thermally stable, with *S. ricini*, the eri silkworm, exhibiting the highest stability[35]. These differences reflect structural and compositional variations among sericins from different species.

Adhesion Properties and Electrostatic Interaction

An essential component of silkworm development is sericin's adhesive quality, which allows it to bind fibroin fibers and secure the cocoon to substrates through the peduncle during cocoon formation. Studies on crude form of Ser2 proteins from the anterior middle silk gland indicate an adhesion strength of approximately 120 ± 30 N/cm^2 on wooden surfaces, which is greater than starch-based adhesives (42±20 N/cm^2) whereas lower (502±132 N/cm^2) than animal glue. This adhesive behavior arises from the elevated proportion of charged amino acids in Ser2, which facilitates electrostatic interactions with the substrate[38].

Biochemical Activity

Sericin demonstrates a variety of biochemical activities, such as antioxidant, anti-tyrosinase, anti-elastase, and anti-lipid peroxidation. Sericin extracted from *B. mori* has been shown to exhibit anti-tyrosinase activity, which is relevant to the regulation of melanogenesis. The effectiveness of this activity is influenced by the silkworm strain, diet, cocoon pigmentation, and extraction technique[39]. In general, urea-extracted sericin exhibits greater inhibitory activity[40], and because of related bioactive compounds, pigmented cocoons amplify this effect[25]. Additionally, sericin has anti-elastase activity, which aids in preventing the breakdown of elastin, especially when exposed to UV stress[41,39]. Both mulberry and vanya silkworm sericins, have been found to have this characteristic[29]. Furthermore, several in vitro tests have demonstrated sericin's strong antioxidant activity, with pigmented cocoon varieties showing greater activity[42,43]. Additionally, it exhibits anti-lipid peroxidation properties that prevent oxidative damage in biological systems[24,29]. These properties collectively support its potential in biological and cosmetic applications.

Immunogenicity

Immunogenicity is a critical biochemical property of sericin that has been extensively studied to assess its ability to induce immune responses such as inflammation, fibrosis, or material rejection. Earlier reports suggested that sericin could elicit immunogenic reactions in vivo; however, subsequent studies have clarified that such effects are mainly associated with sericin when bound to fibroin. In contrast, purified sericin exhibits negligible immunogenicity along with favourable attributes, including physicochemical stability, biocompatibility, biodegradability, and extended shelf life[44]. Recent studies have also demonstrated the immunomodulatory capacity of sericin in regulating immune responses.45 Its non-toxic nature, low immunogenicity, and high biocompatibility further support its suitability for biomedical use. Additionally, its low immunogenic profile allows prolonged implantation without the need for immunosuppressive interventions[46].These characteristics make sericin well-suited for uses like wound repair, drug delivery, artificial tissue fabrication, and regenerative medicine, where it promotes cell adhesion and proliferation, highlighting its potential as a promising biomaterial in biomedical applications[9].

Sericin Extraction Methods

Conventional Methods

The sericin layer, a hydrophilic protein surrounding silk fibroin fibers, is removed through degumming[7]. Traditionally, this process involves boiling silk in surfactantmixtures, particularly olive oil derived Marseille soap. The alkaline conditions generated during soap hydrolysis facilitate the breakdown and solubilisation of sericin, while the soap aids in dispersing it into the aqueous medium. Degumming with Marseille soap is typically carried out at boiling temperature for 90 to 120 minutes to achieve effective sericin removal. However, this method has several limitations, including high chemical consumption, sensitivity to water hardness, and potential adverse effects on silk quality. Additionally, the large volume of soap required contributes to environmental concerns[25]. To improve efficiency, combinations of soap and alkali have been explored. Alkalis such as sodium silicate and sodium carbonate help maintain alkaline conditions and enhance sericin removal. Nevertheless, these methods remain sensitive to water quality and complicate sericin recovery from the degumming solution. The resulting wastewater, containing sericin, residual soap, and salts, requires extensive treatment, prompting the development of alternative extraction techniques[9].

Chemical Methods

Chemical procedures that exclude the use of Marseille soap are widely employed in industrial degumming processes. These approaches utilize acids (e.g., tartaric, citric, and succinic acids) or bases (e.g., sodium silicate, phosphate, carbonate, and hydrosulphite) to facilitate sericin removal. Such reagents hydrolyze peptide bonds within the protein, rendering sericin soluble under acidic or alkaline conditions. However, both acid- and alkali-based treatments are associated with substantial protein degradation[44]. In contrast, urea-based extraction, often combined with 2-mercaptoethanol, is considered less detrimental to sericin integrity and can recover up to 95% of sericin without significant structural alteration. Although effective, this approach is limited by elevated costs and extended processing duration. Moreover, urea-derived sericin demonstrates considerable cytotoxicity, thereby limiting its applicability in biological fields. Residual chemicals from these processes may further compromise sericin purity, while the discharge of chemically laden effluents poses environmental concerns, highlighting the need for more sustainable extraction strategies[10].

Biological Methods

Enzymatic degumming is considered an energy saving method for removal of sericin from silk. This process hydrolyzes sericin using proteolytic enzymes like cocoonase, papain, trypsin, and microbial peptidases. Because of the elevated levels of arginine and lysine residues in sericin, trypsin selectively breaks peptide bonds at these residues[47], whereas papain's broad substrate specificity allows for efficient degumming[48]. Fungal proteases and commercial enzymes like alcalase provide economical and safe substitutes for chemical processes[9]. The efficiency of enzymatic degumming depends on parameters such as enzyme type, concentration, and treatment duration, which also influence the properties of the resulting sericin peptides. Although enzymatic methods are relatively expensive, they require lower energy input and are considered more sustainable. Combined approaches, including the use of ultrasound with enzymes like alcalase and savinase, have been explored to enhance degumming efficiency, though the molecular confirmation of the recovered sericin remains uncertain[49]. Furthermore, it has been demonstrated that *Bacillus sp*. extracellular proteases can break down sericin into peptides with a size of roughly 10–12 kDa while maintaining fibroin structure in mildly alkaline environments[50]. Serine protease with thermostability and alkaline activity, derived from *B. halodurans*, has also shown better degumming efficiency than commercial alcalase[51].

Thermal Methods

Thermal extraction, involving boiling of cocoons in aqueous media, is widely used because of its operational ease and minimal chemical requirement. This process has gained considerable attention and is typically conducted under high atmospheric pressure at 80° to 100°C[52]. Degumming techniques have been further expanded through the use of laboratory autoclaves for high-pressure extraction. Impurity-free sericin recovery is made possible by boiling in water at room pressure or higher, which frequently removes the need for dialysis. Although partial degradation may occur at higher temperatures or prolonged exposure, thermal extraction remains preferred as it retains most functional properties of sericin. The molecular weight of extracted sericin is influenced by temperature, pressure, and duration, and can be regulated by optimizing these parameters for specific applications[44].

Modern Methods

New technologies have led to more efficient and sustainable extraction of sericin from fibroin. These methods involve microwave treatment, infrared heating, steam processing, ultrasonication and carbon dioxide supercritical fluid extraction[52,53,54,55]. Such approaches minimize water use and help achieve sustainability targets. On the other hand, the molecular weight of extracted sericin is affected by processing conditions (temperature and time).Infrared heating enables complete sericin removal from raw silk and yields better quality protein compared to conventional methods by directly transferring energy and enhancing solubility. Microwave-assisted degumming decreases energy consumption, extraction time, andusage of chemical. These techniques are generally more efficient and environmentally favourable than acid, alkali, or high-temperature methods, producing sericin with greater purity due to their minimal chemical input. Spectroscopic analyses indicate that infrared methods cause less degradation than autoclave-based extraction, thereby preserving protein integrity[53]. Pressurized steam treatment offers a chemical-free alternative that minimizes water pollution while maintaining physicochemical properties of sericin and reducing operational costs. Carbon dioxide supercritical fluid extraction provides impurity-free recovery, making it an environmentally benign option. Ultrasonic-assisted extraction further enhances degumming efficiency and fibre quality at lower temperatures, representing an eco-friendly alternative to conventional thermal processes[56].

Environmental and Economic Feasibility of Sericin Isolation Techniques

Various approaches to sericin extraction offer distinct benefits, with their comparative performance summarized in Table 2. Despite their effectiveness, chemical methods often significantly degrade sericin's structure, which results in functional impairment and the need for subsequent refinement to get rid of any remaining chemicals[57]. Additionally, these methods produce hazardous effluents, which raise environmental issues and raises treatment expenses.Similar limitations apply to urea-based extraction due to its high cost and lengthy processing time[25].On the other hand, because of its ease of use and minimal environmental impact, thermal extraction using hot distilled water continues to be the most popular technique[58]. Although there may be partial protein degradation, particularly at high temperatures for long periods of time[54], the lack of additive chemicals makes it cost effective and appropriate for widespread use. Enzymatic approaches are expensive but environmentally sustainable. More recently, sustainable alternatives includinginfrared heating, supercritical CO_2 extraction, and ultrasonic-assisted techniques have been evaluated[59]. These methodologies mitigate the use of dangerous chemicals and enhance environmental compatibility;however, they necessitate specialized instrumentation, that raises the upfront cost and prevents wide-scale implementation until cost-effectiveness is proven.

Purification of Sericin

To acquire highly purified sericin following degumming, further fractionation and refinement steps are necessary (Figure 1).

The isolated sericin extract is typically purified by paper filtration to remove undissolved fibroin fraction, with subsequent centrifugation to eliminate residual impurities. Acidification, chemical coagulation, salting out, and organic solvent precipitation are examples of precipitation-based techniques that are frequently used[41]. To extract

Table 1: The amino acid spectrum of sericin from various studies

Amino acid	Composition in Mol (%)							
	24	25	26	27	21	8	28	29
Alanine	3.80	4.10	5.71	6.47	NA	5.30	NA	3.28
Arginine	3.90	2.87	4.45	9.75	5~15	1.80	11.95	4.71
Aspartic acid	17.80	15.64	NA	3.82	7~10	1.80	14.00	11.52
Glutamic acid	4.40	4.61	NA	6.90	4~6	4.60	3.30	2.92
Glycine	19.10	15.03	12.17	12.24	10~20	15.70	23.20	12.60
Histidine	1.00	NA	0.00	3.50	3~6	1.30	1.13	2.05
Cysteine	NA	0.44	<0.05	NA	NA	NA	<0.05	0.07
Isoleucine	0.40	0.56	1.48	4.23	NA	0.70	0.91	0.34
Leucine	0.80	1.00	2.03	2.85	NA	1.10	2.08	1.05
Lysine	2.70	2.35	0.60	4.76	20~30	2.50	3.18	2.33
Methionine	<0.05	3.39	0.00	1.56	NA	<0.05	0.77	0.13
Phenylalanine	0.20	0.28	NA	7.89	NA	0.40	1.29	0.53
Serine	31.00	33.63	32.55	7.01	7~16	32.20	21.56	40.51
Threonine	8.00	8.16	7.48	7.24	3~10	8.40	7.04	8.45
Tryptophan	<0.05	NA	NA	6.36	NA	0.20	NA	NA
Tyrosine	3.30	3.45	3.69	8.58	4~6	3.70	6.23	5.42
Proline	0.40	0.54	2.38	NA	NA	0.60	NA	0.59
Valine	3.10	2.88	6.31	6.88	NA	3.60	3.36	3.56

NA = data not available

sericin from the solution, these techniques use freeze-thaw cycles or the addition of precipitating agents. Dialysis is frequently used as an additional purification step when chemical degumming agents like urea, sodium carbonate, or citric acid are used. Membrane filtration helps eliminate finer contaminants, while gel chromatography may further fractionate sericin protein according to molecular size. However, there are drawbacks to precipitation techniques, including a comparatively low recovery rate (about 40%) and the possibility of secondary pollution from the use of chemicals[60]. In order to obtain a stable product, sericin is typically recovered in solution form following purification and then dried. Lyophilization and spray drying are common drying methods that are both efficient at eliminating moisture. Although widely applied, achievement of an ideal balance between yield and purity continues to be difficult[9]. Membrane-based separation techniques, in particular nanofiltration and ultrafiltration, have drawn interest as viable choices in this regard because they offer increased recovery performance (above 80%) and improved purity[61].

Applications of Sericin Across Diverse Domains

Sericin has emerged as a promising, sustainable biomaterial with varied applications across healthcare, industrial, textile and food sectors (Figure 2). Its unique physicochemical properties, enable its integration into advanced systems such as therapeutic drug delivery platforms, engineered tissue scaffolds, wound repair, anticancer therapy, functional foods, skin care products, fabrics, cryopreservation systems, and anti-frost coatings.

Table 2: Comparative performance of various sericin isolation methods

Method	Approach	Yield	Suitability for use	Environmental impact	Reference
Conventional (Soap-based)	Boiling Marseille soap in water for 90-120 minutes	Moderate	Limited (residual impurities, inconsistent quality)	High (soap waste, water use)	25
Chemical	Carboxylic organic acids ($C_4H_6O_4$/ $C_4H_6O_6$/ $C_6H_8O_7$); industrial sodium salts (Na_2CO_3/ Na_3PO_4/ Na_2SiO_3/ $Na_2S_2O_4$; urea + β-mercaptoethanol	As high as 95 %	Limited (cytotoxicity low biocompati bility)	High (chemical pollutants)	44
Enzymatic or Biological	Serine and cysteine proteases; Bacillussourced enzymes under slightly alkaline conditions	Moderatel y high	High (minimal degradatio n, bioactive)	Low (ecofriendly)	51
Thermal	Hot water (80 °C-100°C); pressurized steam;autoclaving;	Average	Significant (limited chemical usage)	Moderate	10
New technologies	Microwave treatment; radiant heating; ultrasonic processing;supercriti cal CO_2	High	High (pure, bioactive, scalable)	Negligible (green methods)	56, 9

Biomedical Applications

Nano-structured Sericin for Drug Delivery Applications

This protein has become a flexible biomaterial for delivering drugs, and it can be used with a wide range of bioactive compounds, such as therapeutic drugs and small molecules[62]. It has both polar side chains and hydrophobic domains, which

Table 3: Nutrient Composition and Digestive Aspects of Sericin

S. No.	Sericin Characteristics	Remarks	Reference
1.	Constitutes approximately 18–25% (w/w) of the total weight of cocoon and exhibits antioxidant, antihypertensive, and immuno-modulatory properties	Contains bioactive peptides, released during gastrointestinal digestion	75
2.	Rich in essential amino acids like leucine, lysine, valine, phenyl alanine, etc	High nutritional value	76
3.	The molecular weight ranges between 10 and 400 kDa, subject to the extraction technique applied	Effective digestibility and intestinal uptake	77
4.	pH sensitive and highly soluble in hot water	Enables application in enteral and oral formulations	78
5.	Relatively low-to-intermediate calorific value, varying with formulation and processing conditions	Appropriate for incorporation into nutraceutical formulations and health-promoting dietary products	79
6.	Non-toxic, non-allergenic	Food additive potential	80

Table 4: Prebiotic and Metabolic Effects of Sericin

Sericin Form Utilized	Model/ System	Key Outcome	Reference
Sericin-derived oligopeptides	Human gut microbiota (in vitro)	Exerts prebiotic effects through selective stimulation of Bifidobacterium and *Lactobacillus* species	82
Dietary sericin supplement	Mouse model of high fat diet (in vivo)	Modulated gut microbiota, improved lipid profile, and reduced inflammation	83
Oral sericin extract	Obese rat model (in vivo)	Improved lipid regulation by lowering cholesterol and serum triglycerides	84
Sericin supplementation	Streptozotocin induced diabetic rat	Antioxidant and anti-diabetic properties helped to reduce pancreatic inflammation and hyperglycaemia	85
Sericin hydrolysate	Caco-2 cell line	Anti-inflammatory and antioxidant properties reduced oxidative stress and improved gut barrier integrity	86

makes it amphiphilic and allows it to interact and bind well with charged molecules[63]. Additionally, its prolonged in vivo half-life, resulting from diminished renal clearance, accompanied by significant water uptake and release characteristics, accentuates its appropriateness as a delivery vehicle[64]. Crosslink formation, chemical derivatization, phase precipitation, or polymer blending are all common ways to make sericin-based delivery systems into hydrogels. These hydrogels are good matrices for holding therapeutic agents letting them be released in a controlled way and over a long period of time, and targeting specific tissues or cells. Additionally, structural changes make drugs more effective, compatible with living things, and stable[10]. Films, sponges, scaffolds, particles, and mats are made out of sericin-based biomaterials showing their usefulness in biomedical settings[8]. Recent methodologies incorporate nanoparticles, especially silver-based systems, to augment the antibacterial

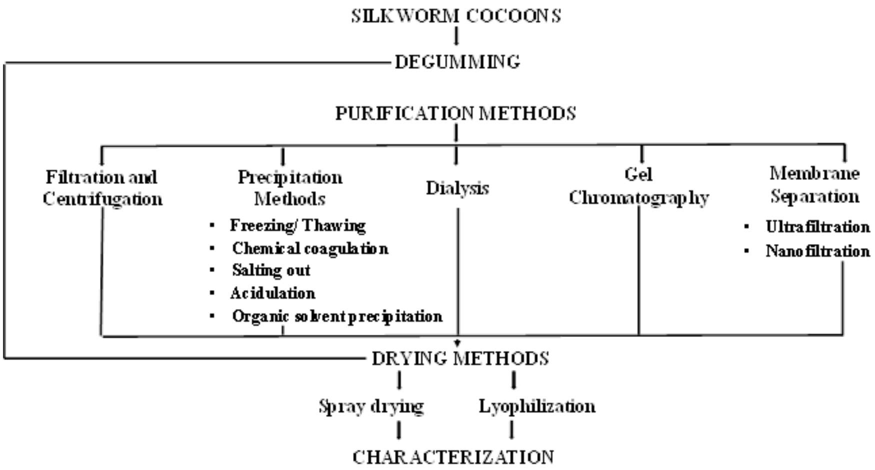

Fig. 1: Overview of the Sericin Purification Process

Fig. 2: Multidomain Applications of Silkworm Sericin

efficacy of sericin-based hydrogels[9]. Additionally, techniques such as desolvation have been explored to produce stabilized sericin nanoparticles, including pluronic-encapsulated crocetin systems, thereby improving the effectiveness of nano-enabled drug delivery platforms[14].

Wound Healing

Sericin has strong antioxidant properties,which helps in healing wounds by speeding up the growth of keratinocytes and fibroblasts along with the synthesis of collagen. It can be used as a wound dressing or topical treatment to stop infections, treat burns, reduce scars, and prevent microbial invasion. Sericin-based materials also help to heal the chronic wounds faster and reduce inflammation, which helps them move into the proliferative phase. Their porous, three-dimensional structure is cheap and works well for dressing wounds[65]. The therapeutic efficacy of sericin can be enhanced by the incorporation of naturally derived bioactive compounds, especially those derived from plants. Research indicates that human fibroblasts cultured in sericin-enriched media (400 kDa, sericin M) demonstrate proliferation rates of up to 250% within 72 hours[66]. This enhanced cellular response is attributed to improved cell–media interactions mediated by the repetitive serine-rich domains present in sericin.

Tissue Engineering and Bone Grafting

Biocompatibility and high affinity of sericin for biological tissues render it a promising material for scaffold fabrication intended for tissue regeneration. Scaffolds made of sericin, repairs damaged or diseased tissues by creating a microenvironment favorable for cell adhesion, growth, and differentiation[67]. Moreover, it is suitable for tissue engineering applications because of its ability to modulate cellular responses and promote angiogenesis. In bone grafting, the compatibility of the graft material with host tissue is important. Sericin is a good choice for bone regeneration because of its proteinaceous nature and excellent biocompatibility, supporting cellular adhesion and proliferation.68 It's biodegradable nature further allows gradual degradation and replacement by native tissue, thereby minimizing persistent foreign body responses. Furthermore, sericin includes amino acids like glutamic acid and aspartic acid, which are very important for the nucleation and growth of hydroxyapatite (HAp) crystals. These residues can bind calcium and phosphate ions that enhance local super saturation and create favorable conditions for HAp formation. Evidence indicates that sericin facilitates HAp crystallization and augments osteoblast differentiation within bone marrow-derived stem cells, underscoring its potential in bone tissue engineering and transplantation[69].

Anticancer Therapy

Sericin is gaining attention for its potential anticancer properties, along with its well-known antioxidant effects. Studies report its efficacy in models of breast, colon, colorectal, lung, cervical, and prostate cancers[70]. Treatment with sericin leads to a concentration-dependent decline in cancer cell viability. In particular, self-assembled silk sericin nanoparticles have been found to trigger apoptosis in MCF-7 breast cancer cells, highlighting their ability to selectively target and kill cancerous cells.71 Additionally, sericin has been observed to inhibit carcinogenic compounds such as 1,2-dimethylhydrazine, known to promote tumor formation. Suppression of such cancer-causing agents lowers the risk of colorectal cancer[14].

Food Preservation and Functional Health Products

The food sector has progressively focused on fabrication of alternative packaging solutions to overcome limitations associated with conventional materials[72]. A key research priority is the development of cost-effective, edible coatings capable of protecting food products frommoisture and oxygen permeation[73]. These coatings function as efficient protective layers that limit oxidative reactions, reduce water loss, and regulate respiratory activity, ultimately extending the storage life of packaged food products[73]. Due to its strong compatibility with biological systems and inherent degradability, sericin has gained attention as a potential material for advanced functional food packaging applications. Research findings have demonstrated that sericin-derived edible films can extend the postharvest shelf life of fruits and vegetables by suppressing polyphenol oxidase activity[10]. Importantly, regulatory approval by the US health regulatory agency (FDA) indicates that sericin and its modified forms are safe for oral consumption, non-allergenic, and non-cytotoxic[9]. In preservation applications, sericin-based coatings combined with additives such as chitosan, aloe vera, and glycerol have shown significant potential in prolongingthe storage stability of highly degradable commodities such as tomatoes[13]. Moreover, glucose-mediated sericin coatings help regulate oxidative processes, thereby enhancing storage stability[74]. These technological developments highlight the potential of sericin-based materials as sustainable and efficient solutions for modern food packaging challenges.

Sericin serves as a functional food ingredient and nutraceutical because of its rich amino acid composition and favorable digestibility, making it suitable for nutritional and functional food applications. Table 3 summarizes its key nutritional components along with properties related to digestibility and dietary health. Moreover, sericin demonstrates significant bio-functional roles, such as influencing intestinal microbial balance, enhancing carbohydrate and lipid metabolic regulation, and reducing oxidative burden across gastrointestinal and systemic systems.

Table 4 summarizes the findings demonstrating its contribution to metabolic regulation and its developing function as a prebiotic compound. Beyond these applications, sericin has been incorporated into bakery products such as bread to enhance their functional value. It has also been utilized in the formulation of jelly-based desserts, where a sustainable product was developed using depectinized apple juice, pectin, sericin, lactoferrin, and stevia. Owing to its low energy value, sericin glycoprotein is particularly beneficial for individuals with dysphagia[81].

Textile Industry

Sericin utilization offers a dual benefit by converting textile industry waste into value-added products while harnessing its inherent biocompatibility, antimicrobial effects, and tissue-repair capabilities for textile-related applications[10]. When applied to fibre surfaces, sericin enhances several functional attributes, including electrical resistance, water retention, moisture absorption, and antibacterial performance, while also reducing skin irritation. Blending sericin with polyester reduces hydrophobicity, improves UV protection, and enhances radical scavenging activity[87] Bhandari *et al.* standardized processing parameters to enhance cotton coloration and observed that treating the fabric with 0.5% sericin, 4% citric acid, and 1% sodium hypophosphite, followed by drying for 4 minutes at 70 °C and curing for 2 minutes at 160 °C, significantly improved dye absorption and color intensity. They further suggested the use of this protein as an eco-friendly option to metallic mordents in cotton coloration, thereby reducing water pollution while imparting antimicrobial and UV-protective properties[88]. In another study, sericin-coated fabrics exhibited enhanced wicking ability, reactive oxygen species (ROS) scavenging activity, and moisture regain, making them suitable for direct skin contact, particularly in applications involving dermatological conditions[89].

Cosmetics and Skincare Products

Silk sericin is widely utilized in cosmetic formulations due to its beneficial effects on skin and hair. It exhibits excellent moisturizing and skin-whitening properties, with studies showing that a 3% sericin solution can achieve hygroscopicity comparable to 60% glycerol, indicating superior moisture retention at lower concentrations. Unlike glycerol, sericin possesses a lower molecular weight, which facilitates better skin absorption and helps reduce fine wrinkles without causing pore blockage or irritation. Sericin also enhances hair strength and elasticity through effective absorption[90]. In addition, it demonstrates strong tyrosinase inhibition; even at 1% concentration, it significantly reduces enzyme activity, thereby limiting melanin synthesis and promoting skin lightening[91]. Furthermore, sericin inhibits apoptosis and stimulates type I collagen synthesis, improving skin elasticity and imparting anti-aging effects[4]. At concentrations ranging from 0.02% to 20%, it also prevents chapping and brittleness while enhancing nail gloss, supporting its application in nail care products.

Cryopreservation and In-vitro Fertilization

Sericin is widely used in cell cryopreservation, often combined with bovine serum albumin (BSA) and about 10% dimethyl sulfoxide (C_2H_6OS), depending on type of tissue being preserved.92 It has also been explored as a component of serum-free culture media and even as a partial alternative to DMSO in certain cell types, such as osteoblasts (SaOS-2 cell line) and human mesenchymal stromal cells[93]. In addition, studies have shown improved survival of cryopreserved SaOS-2 cells when sericin-based hydrogels are combined with gelatin–carrageenan composites. More recently, sericin has found applications in reproductive biology as well, where it is used as a supplementary protein in controlled cell culture and maturation systems for the fertilization of sheep oocytes[94].

Paints and Coatings

Sericin is also used in pigment production and improves the durability along with weather resistance of coating materials. Moreover, its anti-frosting property, allows it to form protective films on surfaces like deep freezers, refrigerators, and refrigerated transport vehicles, helping to reduce frost buildup[9].

Bottlenecks in Sericin Utilization and Future Prospects

Despite its promising attributes, several limitations restrict the standalone application of sericin. These include poor mechanical strength, sensitivity to pH, thermal degradation, and variability in molecular weight arising from non-uniform extraction methods[8]. The lack of standardized extraction protocols further affects consistency across studies[9]. Its hydrophobic nature also limits its performance in water-based systems, especially in the food sector. Because of this, sericin is often combined with other polymers or crosslinking agents to improve its stability and usability[10]. At the same time, sericin has strong potential from a sustainability perspective. As a by-product of the silk industry, using it supports a circular bioeconomy, by reducing waste and improving resource use[95]. Its applications in cosmetics, food, textiles, and medicine can promote more sustainable products and open new opportunities. It also shows promise as a bio-based alternative to petroleum-based plastics, making it relevant for future eco-friendly materials[14]. Continued researchesare therefore essential to optimize its properties and expand its practical applications.

CONCLUSION

Overall, sericin has become a very promising biomaterial that can be used in many fields, such as medicine, food, textiles, cosmetics, and industry. Once considered as simply a waste product of the silk industry, is now valued for its unique properties, such as being biocompatible, biodegradable, and having antioxidant potential. Recent improvements in extraction and purification methods have made it possible to get sericin of higher quality and utility, rendering its application in high-value areas like drug delivery, tissue engineering, wound healing, functional foods and eco-friendly packaging. It also helps to improve the textile performance and shows promising role in cosmetic industry further highlighting its wide industrial usefulness. Nevertheless, the broad scale use of sericin is still restricted by some constraints, including variations in molecular weight, low mechanical strength, sensitivity to environmental conditions, and the lack of standardized extraction methods. To vanquish these drawbacks, sericin needs to be modified, and get combined with other polymers in order to develop better and environment-friendly extraction techniques. Using sericin is an important step toward a circular bioeconomy because it turns waste from the silk industry into useful products, which helps lessen the damage to the environment and make better use of resources. For future plan of work, more experiment is necessary on scalable processing, standardization, and exploring new applications especially for bio-based plastics and advanced biomedical systems. With continued innovation, sericin has strong potential to become a sustainable and widely used biomaterial.

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Conflict of Interest

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Authors' Contributions

SC:Conceptualization, comprehensive literature review, and drafting of the manuscript; SB: Preparation of tables, figures and critical revision of the manuscript; NP, SE, AKV: Collection of relevant literature and manuscript revision for application aspects of sericin; KR: Manuscript editing; SS: Conceptualization, supervision, and manuscript editing; SK: Supervision, and manuscript revision.

Data Availability Statement

All data presented in this review are obtained from previously published studies, all of which are included in the reference section.

Ethical Approval Statement

This study is a systematic review of previously published literature. Since all analysed data are secondary and publicly available, ethical approval was not required.

Informed Consent Statement

This review uses only previously published literature and contains no identifiable patient data; hence, informed consent was not required.

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