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Silk Sericin Nanomaterials: A Sustainable Frontier in Advanced Biomedical and Cosmetic Applications

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Authors' contributions

This work was carried out in collaboration among all authors. Author AK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MT and BS managed the analyses of the study. Authors SD and AAS managed the literature searches. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Silk sericin, a hydrophilic protein extracted from silkworm cocoons, is increasingly recognized as a sustainable and multifunctional biomaterial with wide-ranging applications in the biomedical and cosmetic sectors. Its inherent properties—including excellent biocompatibility, biodegradability, antioxidant potential, and moisture retention—have positioned it as a promising candidate for eco-conscious innovations. The integration of sericin with nanotechnology has further amplified its utility by enhancing bioavailability, active ingredient stability, and controlled release capabilities. In

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biomedical applications, sericin-based nanomaterials have demonstrated notable efficacy in wound healing, tissue engineering, and targeted drug delivery systems, where they contribute to accelerated cellular proliferation, collagen synthesis, and precise therapeutic action. Concurrently, in the cosmetic industry, sericin nanoparticles offer substantial benefits such as improved skin hydration, elasticity, anti-aging, and whitening effects, aligning with consumer demand for natural and environmentally friendly skincare formulations. This review highlights the most recent advancements in sericin extraction methods, functional modifications, and nano-formulations, with a focus on their mechanisms of action, clinical relevance, and industrial applicability. It also critically assesses the challenges related to large-scale production, regulatory compliance, and formulation stability. By consolidating insights from both biomedical and cosmetic fields, this work underscores sericin's pivotal role as a sustainable nanomaterial capable of advancing circular bioeconomy goals and driving next-generation innovations in health and wellness industries.

Keywords: Sericin; nanotechnology; biomaterials; cosmeceuticals; drug delivery; wound healing; sustainability.

1. INTRODUCTION

Sericin is a hydrophilic, globular silk protein that constitutes approximately 20–30% of the silk cocoon and is traditionally removed during degumming in sericulture (Fig. 1) (Padamwar & Pawar, 2004; Capar et al., 2022; Mathew et al., 2024). This removal process has historically contributed to environmental pollution, yet sericin's inherent bioactivity has increasingly attracted interest for high-value biomedical and cosmetic applications (Zhaorigetu et al., 2003; Lamboni et al., 2015). Its amino acid composition, rich in serine, aspartic acid, and glycine, contributes to its excellent moisture-retention, film-forming ability, and biocompatibility (Vepari & Kaplan, 2007). Additionally, sericin possesses antioxidant, antibacterial, and anti-inflammatory properties, making it suitable for skincare and wound healing (Lamboni et al., 2015; Kurioka & Yamazaki, 2002; Mazurek et al., 2024).

Recent advances in nanotechnology have expanded sericin's potential by enabling its formulation into nanoparticles, nanofibers, and hydrogels, enhancing its stability and controlled release properties for biomedical and cosmetic applications (Stradczuk-Mazurek et al., 2025; Ma et al., 2025). In wound healing, sericin accelerates tissue repair by promoting fibroblast proliferation and collagen synthesis while reducing inflammation, making it a promising component in advanced wound dressings (Padamwar & Pawar, 2004; Lamboni et al., 2015; Mazurek et al., 2024). In drug delivery, sericin-based nanocarriers enable controlled and sustained release of therapeutic agents, improving efficacy while reducing side effects (Liu et al., 2022; Silva et al., 2022; Aad et al., 2024).

In cosmetics, sericin contributes to skin hydration, elasticity, and protection against oxidative stress, aligning with the demand for natural, biodegradable ingredients in the cosmeceutical industry (Ma et al., 2025; Mandal et al., 2009). Sericin-based formulations have been shown to enhance skin barrier function, reduce trans epidermal water loss, and improve skin smoothness, supporting its integration into premium skincare products. Moreover, sericin's anti-tyrosinase activity contributes to skin brightening, offering additional value in cosmetic formulations. Sericin nanoparticles generally range from 50–200 nm, ideal for efficient skin penetration and drug delivery (Mandal et al., 2009).

At the molecular level, sericin interacts with skin cells through hydrogen bonding and electrostatic interactions with keratin and collagen, promoting fibroblast adhesion and proliferation. This molecular affinity enhances tissue regeneration and supports extracellular matrix formation. Sericin's compatibility with other biopolymers allows it to be blended with hyaluronic acid, collagen, and chitosan for enhanced bioactivity and mechanical properties in both biomedical and cosmetic formulations, expanding its versatility for various applications (Silva et al., 2022; Suryawanshi et al., 2020).

Despite these promising attributes, challenges remain in scaling sericin extraction with consistent quality and ensuring its stability in complex formulations for nanomaterial development (Padamwar & Pawar, 2004; Mathew et al., 2024; Vaishnav & Singh, 2023). Thus, a focused review on sericin-based nanomaterials for biomedical and cosmetic applications is timely to guide further research

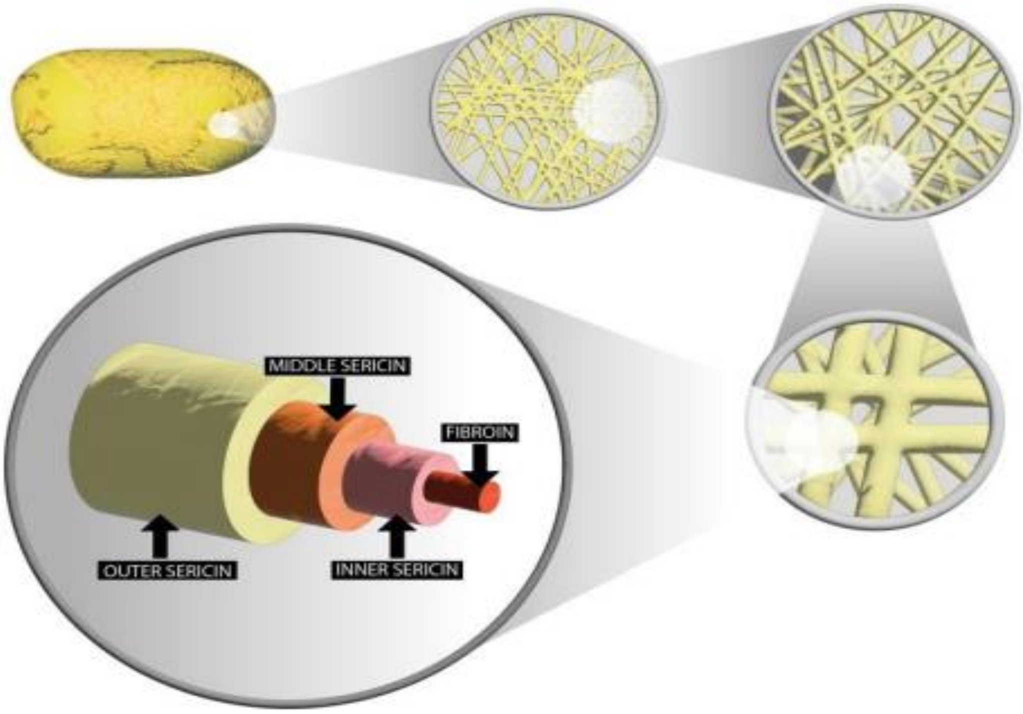

Fig. 1. Structural morphology of Bombyx mori cocoon, illustrating the transition from the intact cocoon to individual silk fibers enveloped with sericin (Chen et al., 2012; Cao & Zhang, 2016; Reis et al., 2025)

and practical application (Liu et al., 2022; Joseph et al., 2024). This review discusses recent advances, preparation strategies, functional properties, and emerging biomedical and cosmetic uses of sericin-based nanomaterials, providing insights for researchers and industry to harness sericin as a sustainable, high-value biomaterial (Aramwit et al., 2010a).

2. EXTRACTION, CHARACTERIZATION AND PROPERTIES OF SERICIN

The extraction of sericin from silk cocoons is a critical step influencing its quality, molecular weight, and functional properties (Mathew et al., 2024; Vaishnav & Singh, 2023). Conventional extraction methods involve hot water, alkaline, acidic, and enzymatic degumming, each impacting the yield and structural integrity of sericin (Padamwar & Pawar, 2004; Capar et al., 2022; Lamboni et al., 2015; Sarangi et al., 2023). *A comparative summary of these extraction methods, including their solvents, yields, molecular weight ranges, bioactivity retention, and practical considerations, is presented in* Table 1*.* Hot water extraction preserves bioactivity but may result in lower yields, while alkaline extraction provides higher yield at the cost of partial degradation of sericin chains, affecting its film-forming and moisture-retention properties (Kurioka & Yamazaki, 2002; Mandal et al., 2009; Vaishnav & Singh, 2023). Enzymatic extraction using proteases offers a milder alternative, preserving functional groups while maintaining the biocompatibility necessary for biomedical and cosmetic applications (Zhaorigetu et al., 2003; Silva et al., 2022; Sarangi et al., 2023). Sericin nanoparticles produced through these methods generally exhibit sizes ranging from 50 to 200 nm, which is ideal for efficient cellular uptake and transdermal delivery (Ma et al., 2025).

Characterization of sericin involves techniques such as Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), differential scanning calorimetry (DSC), and scanning electron microscopy (SEM) to assess structural features, thermal stability, and morphology (Stradczuk-Mazurek et al., 2025; Suryawanshi et al., 2020). The amino acid profile, dominated by serine, glycine, and aspartic acid, is responsible for its hydrophilicity and interaction with water molecules, enabling high moisture retention in cosmetic formulations (Ma et al., 2025; Padamwar et al., 2005). Sericin has been reported to retain up to 65–70% moisture, comparable to standard humectants, due to its strong hydrogen bonding with water molecules. Antioxidant activity of sericin, assessed via 2,2-Diphenyl-1-picrylhydrazyl (DPPH) and 2,2'-Azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assays, typically ranges from 60% to 90%, depending on its molecular weight and extraction technique (Aad et al., 2024; Sarangi et al., 2023; Padamwar et al., 2005). Molecular weight distribution of sericin, typically ranging between 20–400 kDa depending on extraction methods, influences its viscosity, film-forming capacity, and biological activities (Vepari & Kaplan, 2007; Vaishnav & Singh, 2023).

Sericin's bioactivity includes antioxidant, antimicrobial, anti-inflammatory, and UV-protective properties, which are critical for wound healing and cosmetic applications (Suryawanshi et al., 2020; Aramwit et al., 2010a; Aramwit et al., 2010b). Its antioxidant capacity helps in scavenging reactive oxygen species, reducing oxidative stress in skin applications, while its antimicrobial activity supports wound healing by preventing infections (Padamwar & Pawar, 2004; Veiga et al., 2024). Additionally, sericin demonstrates excellent film-forming properties, making it suitable for topical applications, providing a protective layer that aids in moisture retention and enhances skin smoothness (Mandal et al., 2009; Padamwar et al., 2005).

Recent advancements in nanotechnology have further enhanced sericin's utility by enabling its formulation into nanoparticles, nanofibers, and hydrogels, which improve its stability, bioavailability, and controlled release in biomedical and cosmetic applications (Stradczuk-Mazurek et al., 2025; Suryawanshi et al., 2020). Nanoparticle formulations of sericin have demonstrated improved cellular uptake and targeted delivery of therapeutic agents, while sericin-based hydrogels have shown promise in creating moist environments for wound healing, facilitating faster tissue regeneration (Lamboni et al., 2015; Mazurek et al., 2024; Veiga et al., 2024). Studies have shown that drug-loaded sericin nanocarriers can achieve sustained release profiles over 24 to 72 hours, depending on the encapsulation method and drug-polymer interaction**.** These properties collectively position sericin as a promising biomaterial for the development of advanced nanomaterial-based applications in the biomedical and cosmetic industries (Aad et al., 2024; Wang et al., 2024a).

The potential of sericin extends beyond its intrinsic properties, as its compatibility with other natural polymers such as chitosan, collagen, and hyaluronic acid allows for the creation of composite biomaterials with enhanced functionalities (Ma et al., 2025). These composites can be engineered to possess specific mechanical properties, biodegradability, and bioactivity tailored to the intended application, whether in skin care, wound management, or drug delivery systems (Stradczuk-Mazurek et al., 2025; Kumar & Abrahamse, 2022). At the cellular level, sericin interacts with keratinocytes and fibroblasts via hydrogen bonding and electrostatic forces, enhancing adhesion, proliferation, and extracellular matrix remodeling (Veiga et al., 2024). Thus, understanding the extraction methods, structural properties, and functional

Table 1. Comparison of sericin extraction methods: process parameters and outcomes

Methods	Solvent/Conditions	Yield	Molecular weight range	Bioactivity retention	Advantages	Limitations
Hot water extraction	Boiling water (100ºC), 30-36 mins	Moderate	20–300 kDa	High	Preserves functional groups; eco-friendly	Lower yield; time-consuming
Alkaline extraction	Na_2CO_3, NaOH, pH (9-10), 60-90ºC	High	10–200 kDa	Moderate	Higher yield; faster extraction	Partial degradation of sericin; reduced bioactivity
Acidic extraction	Weak acids (citric/acetic acid), 60-90ºC	Moderate	30–250 kDa	Moderate to High	Good bioactivity retention	Corrosive; lower yield than alkaline
Enzymatic extraction	Proteases (papain, trypsin), 37-50ºC	Low to moderate	30–400 kDa	Very High	Mild conditions; excellent bioactivity retention	Expensive enzymes; lower yield
Novel methods (microwave, ultrasonication, supercritical CO_2)	Microwave: 400–600 W, 5–15 min; Ultrasonication: 40 kHz	Moderate to high	Broad (20–400 kDa)	High	Fast; energy-efficient; eco-friendly	Requires specialized equipment

Note: Data compiled and averaged from multiple studies to provide an indicative comparison of extraction methods, conditions, and outcomes for sericin processing from silk cocoons. For detailed methodologies and results, refer to (Ma et al., 2025; Suryawanshi et al., 2020; Sarangi et al., 2023, Wang et al., 2024a; Wang et al., 2024b) characteristics of sericin is essential for optimizing its application in nanomaterial development for biomedical and cosmetic uses (Suryawanshi et al., 2020; Sarangi et al., 2023; Holland et al., 2019).

3. NANOTECHNOLOGY INTEGRATION: SYNTHESIS AND CHARACTERIZATION OF SERICIN-BASED NANOMATERIALS

The integration of sericin with nanotechnology has revolutionized its application scope, enabling the development of nanoparticles, nanofibers, and hydrogels with enhanced bioavailability, stability, and targeted delivery profiles suitable for advanced biomedical and cosmetic interventions (Stradczuk-Mazurek et al., 2025; Suryawanshi et al., 2020; Mondal et al., 2007). This integration has led to the development of diverse sericin-based biomaterials for biomedical and cosmetic applications (Fig. 2).

Synthesis techniques such as desolvation, cross-linking, and self-assembly have been employed to fabricate sericin nanoparticles, with the desolvation method using ethanol being particularly effective in producing uniformly sized nanoparticles with controlled morphology (Zhaorigetu et al., 2003; Ma et al., 2025). Sericin nanoparticles fabricated via desolvation typically range between 100 and 200 nm in diameter, an optimal size for cellular uptake and enhanced skin penetration (Ma et al., 2025; Joseph et al., 2024). Cross-linking with agents such as glutaraldehyde enhances nanoparticle stability, although careful optimization is required to mitigate potential cytotoxicity and maintain biocompatibility (Aramwit et al., 2010a).

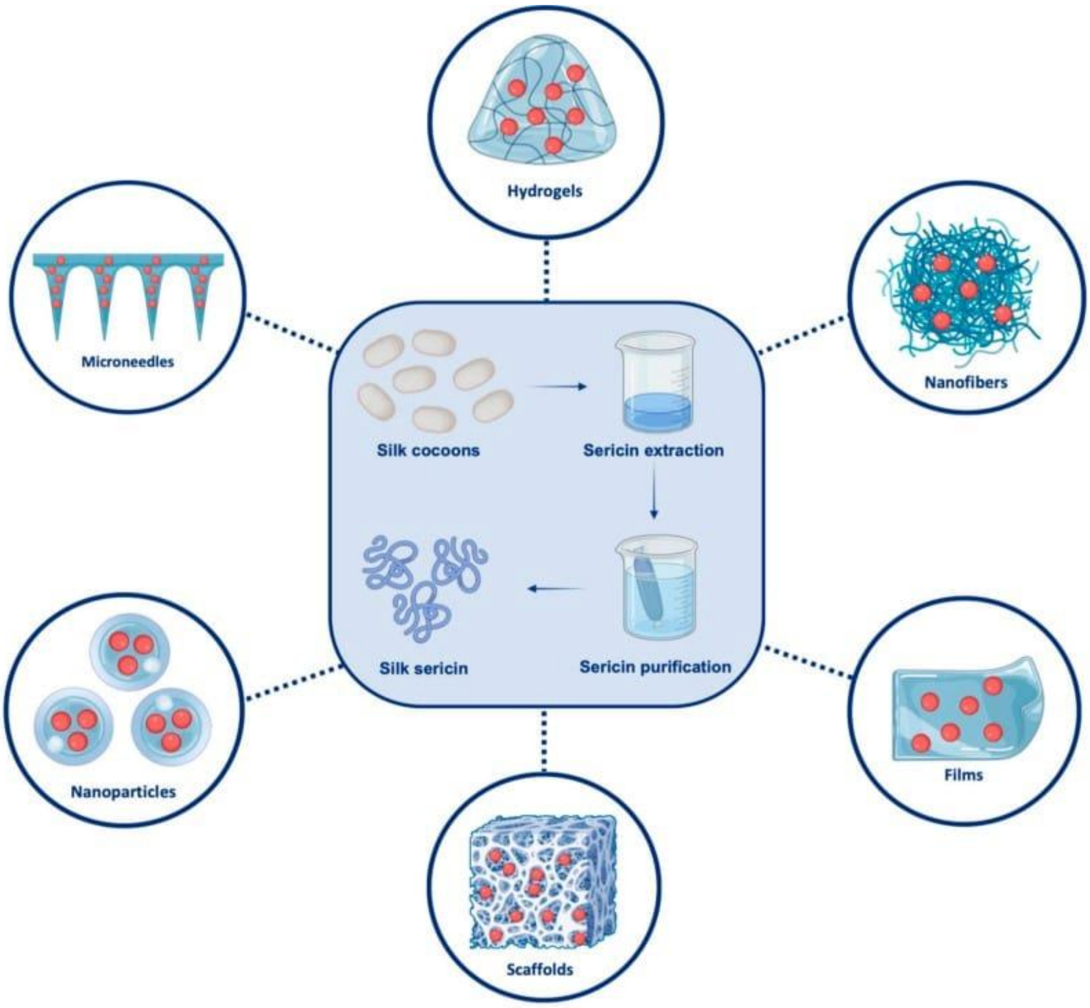

Fig. 2. Preparation and biomedical applications of sericin-based biomaterials derived from silk cocoons, highlighting their conversion into hydrogels, nanofibers, films, scaffolds, nanoparticles, and microneedles for therapeutic use (Ma et al., 2025)

Electrospinning has emerged as a promising approach for producing sericin-based nanofibers due to its capacity to generate high surface area, porous structures that mimic the extracellular matrix, thereby promoting cellular adhesion and proliferation essential for wound healing and tissue engineering applications (Lamboni et al., 2015; Vepari & Kaplan, 2007; Mazurek et al., 2024). Additionally, the fabrication of sericin-based hydrogels using physical or chemical cross-linking techniques has allowed the development of systems capable of sustained drug release while maintaining a moist environment conducive to accelerated wound healing and skin regeneration (Stradczuk-Mazurek et al., 2025; Aad et al., 2024).

Characterization of sericin-based nanomaterials employs a combination of analytical techniques including scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), dynamic light scattering (DLS), and X-ray diffraction (XRD) to confirm morphological integrity, surface properties, particle size distribution, and functional group composition (Ma et al., 2025; Suryawanshi et al., 2020). Zeta potential analysis is also commonly used to assess surface charge and colloidal stability of sericin nanoparticles, which generally show values between –20 mV to –40 mV, indicating good stability in aqueous suspensions. These characterization efforts are pivotal in ensuring that sericin-based nanomaterials meet the physicochemical and biological requirements for their intended biomedical and cosmetic applications while maintaining consistency across production batches (Stradczuk-Mazurek et al., 2025; Ma et al., 2025; Holland et al., 2019).

4. BIOMEDICAL APPLICATIONS OF SERICIN-BASED NANOMATERIALS

4.1 Wound Healing and Tissue Engineering

Sericin-based nanomaterials have gained recognition as effective wound healing agents due to their antioxidant, antimicrobial, and moisture-retaining properties. These attributes collectively support a conducive microenvironment for rapid wound closure and tissue regeneration (Padamwar & Pawar, 2004; Lamboni et al., 2015; Mazurek et al., 2024). Sericin nanoparticles and nanofibers facilitate re-epithelialization, enhance collagen deposition, and promote angiogenesis, while reducing inflammation and oxidative stress at wound sites (Stradczuk-Mazurek et al., 2025; Aramwit et al., 2010b; Veiga et al., 2024). Their nanostructured architecture enables superior cellular adhesion and migration, which is critical for effective wound healing (Liu et al., 2022; Suryawanshi et al., 2020).

In tissue engineering, silk-derived natural polymers such as fibroin and sericin are gaining attention for their biocompatibility and biodegradability. They support cell adhesion, migration, proliferation, and differentiation (Veiga et al., 2024; Wang et al., 2018; Li & Sun, 2022). Blending sericin with other biopolymers like chitosan and collagen yields composite scaffolds with enhanced mechanical stability and bioactivity. These scaffolds are suitable for applications like skin grafts, nerve regeneration, and bone tissue engineering (Lamboni et al., 2015; Vepari & Kaplan, 2007; Ding et al., 2021). The biodegradability of sericin ensures gradual resorption, aligning with the tissue regeneration timeline while avoiding adverse immune reactions. At the molecular level, sericin promotes cellular adhesion and signaling via integrin-mediated pathways and influences extracellular matrix remodeling through regulation of matrix metalloproteinases (MMPs) (Mazurek et al., 2024; Mandal et al., 2009; Zhu et al., 2025).

Recent studies have expanded sericin's role as a scaffold material. For example, Teramoto *et al.* (2005) developed sericin hydrogels using alcohol without crosslinkers, demonstrating sericin's promise as a natural biomaterial, while modifications with gelatin and crosslinkers like glutaraldehyde have enhanced sericin's mechanical properties for use in 2D and 3D scaffold systems (Lamboni et al., 2015; Mandal et al., 2009; Teramoto et al., 2005). These scaffolds support fibroblast attachment and proliferation, although higher sericin concentrations may induce cytotoxicity (Nayak et al., 2012). Nayak *et al.* (2013) developed 3D porous sericin matrices co-cultured with keratinocytes and fibroblasts for skin tissue engineering, showing successful epidermal and dermal layer formation with low inflammatory responses (Nayak et al., 2013). Similarly, collagen-sericin scaffolds enriched with hyaluronic acid and chondroitin sulfate have been used for cartilage tissue engineering, supporting adipose-derived stem cell proliferation and differentiation (Dinescu et al., 2013).

In stem cell technology, poly(L-lactic-co-ε-caprolactone)-sericin membranes have supported the proliferation and neuronal differentiation of human Wharton's jelly mesenchymal stem cells, while sericin-based hydrogels combined with collagen and hyaluronic acid have shown promise for dermal applications (Wang et al., 2018; Inthanon et al., 2016; Vulpe et al., 2018). Additionally, thermosensitive chitosan/sericin hydrogels and fibroin/sericin 3D sponges have demonstrated potential in bone tissue engineering, supporting fibroblast attachment, mineralization, and osteogenic differentiation. Sericin's particle size, typically in the range of 50–300 nm when used as a nanoparticle, significantly influences cell uptake and bioactivity, with smaller sizes enhancing cellular interaction and deeper tissue penetration (Pankongadisak & Suwantong, 2018; Siavashani et al., 2020).

4.2 Drug Delivery Systems

Sericin's inherent biocompatibility, biodegradability, and excellent film-forming ability have made it an attractive material for advanced drug delivery systems in modern biomedical applications (Kumar & Abrahamse, 2022). Its molecular structure allows the encapsulation of diverse therapeutic agents, including antibiotics, anti-inflammatory drugs, anticancer drugs, and growth factors, protecting them from premature degradation while facilitating their controlled and sustained release at the target site (Stradczuk-Mazurek et al., 2025; Aad et al., 2024).

Nanoparticle formulations of sericin can be tailored to achieve specific release kinetics by adjusting parameters such as particle size, cross-linking density, and surface modification (Silva et al., 2022; Suryawanshi et al., 2020). These controlled-release systems can reduce dosing frequency, enhance therapeutic efficacy, and minimize systemic side effects, thereby improving patient compliance. Moreover, sericin's hydrophilicity supports its integration with hydrophobic drugs, enabling enhanced solubility and bioavailability in physiological environments (Mandal et al., 2009; Kumar & Abrahamse, 2022).

Drug release studies show that sericin-based carriers can sustain release over 24–72 hours, depending on crosslinking agents and polymer blends used. The integration of sericin into transdermal drug delivery systems has opened new avenues for non-invasive therapy, particularly for managing chronic diseases and localized treatment of skin conditions (Zhaorigetu et al., 2003; Ma et al., 2025). In these systems, sericin not only acts as a carrier but also contributes to skin hydration and barrier function, facilitating enhanced permeation of drugs across the stratum corneum while maintaining skin health. Studies have demonstrated the potential of sericin-based hydrogels and nanofibers to deliver bioactive molecules efficiently while providing a moist environment conducive to healing (Stradczuk-Mazurek et al., 2025; Mandal et al., 2009).

Additionally, sericin has shown promise in the oral delivery of bio-actives, where it can protect sensitive therapeutic molecules from the harsh gastric environment, enabling targeted release in the intestines. This versatility positions sericin as a valuable material in the development of next-generation drug delivery platforms that are sustainable, effective, and patient-friendly (Ma et al., 2019).

4.3 Antioxidant and Anti-inflammatory Applications

Oxidative stress and inflammation are key contributors to various chronic diseases, including diabetes, cardiovascular disorders, and skin aging. Sericin's potent antioxidant and anti-inflammatory properties have been extensively explored for their therapeutic applications in combating oxidative damage and modulating inflammatory responses (Padamwar & Pawar, 2004; Lamboni et al., 2015).

Sericin possesses amino acids such as serine and threonine, which contribute to its reactive oxygen species (ROS) scavenging activity, thereby protecting cellular components from oxidative damage and supporting cellular homeostasis (Mandal et al., 2009; Aramwit et al., 2010a). Kato *et al.* (1998) first demonstrated sericin's capability to inhibit lipid peroxidation, a significant factor in the progression of diseases like hypertension and diabetes (Kato et al., 1998; Walter et al., 2004). Furthermore, sericin's anti-tyrosinase activity is crucial in controlling melanin biosynthesis, making it relevant in both cosmetic skin-lightening formulations and food preservation (Cavalieri et al., 2002).

Additionally, sericin modulates inflammatory cytokines such as TNF-α, IFN-γ, and IL-10, which are pivotal in inflammatory pathways, suggesting its role in managing conditions characterized by chronic inflammation (Suryawanshi et al., 2020). *In vitro* antioxidant activity assays have shown that sericin exhibits over 80% DPPH radical scavenging activity, highlighting its strong antioxidative potential. These properties make sericin a multifunctional bioactive suitable for therapeutic formulations aimed at reducing oxidative stress, managing inflammation-driven diseases, and supporting tissue regeneration while offering protective benefits in cosmeceutical products (Ma et al., 2025; Silva et al., 2022).

4.4 Antimicrobial Applications

Sericin exhibits inherent antimicrobial activity against various bacterial strains, including *Staphylococcus aureus* and *Escherichia coli*, making it a potential bioactive agent in preventing infections in wound dressings and implants (Kurioka & Yamazaki, 2002; Das et al., 2021). This property is particularly valuable in the context of rising antimicrobial resistance, where there is a critical need for safe, natural alternatives to synthetic antimicrobials in healthcare settings (Wang et al., 2024b).

The antimicrobial action of sericin is primarily attributed to its ability to disrupt bacterial cell membranes and interfere with cellular metabolism, leading to effective bacterial inhibition while maintaining non-toxicity toward human cells (Padamwar & Pawar, 2004). When sericin is incorporated into nanostructured systems such as nanoparticles, nanofibers, and hydrogels, its surface contact with microbial cells increases, further enhancing its antimicrobial efficacy in biomedical applications (Lamboni et al., 2015; Aad et al., 2024; Wang et al., 2024a; Holland et al., 2019).

In wound healing, sericin-based nanomaterials serve a dual role by supporting rapid tissue regeneration while simultaneously preventing infection at the wound site. This reduces the need for systemic antibiotic administration, thereby contributing to strategies aimed at combating antimicrobial resistance while promoting faster and safer wound healing (Das et al., 2021; Munir et al., 2023). Zone of inhibition studies have demonstrated antimicrobial activity ranging from 10–18 mm against common pathogens, depending on sericin concentration and formulation type. Additionally, sericin's compatibility with other antimicrobial agents allows for the development of synergistic composite materials, expanding its applicability in advanced wound dressings, implant coatings, and biomedical devices requiring infection prevention and bioactivity. These properties collectively position sericin as a promising, sustainable material for next-generation antimicrobial biomedical applications (Silva et al., 2022; Wang et al., 2024b; Das et al., 2021).

4.5 Bone Regeneration

Emerging research highlights sericin's potential in bone tissue engineering due to its capacity to promote osteoblast adhesion, proliferation, and extracellular matrix formation when incorporated into composite scaffolds with hydroxyapatite or bioglass (Vepari & Kaplan, 2007; Suryawanshi et al., 2020). Sericin enhances mineralization and supports the deposition of calcium phosphate within scaffolds, facilitating effective bone regeneration while providing a biodegradable and biocompatible environment essential for orthopaedic and dental applications (Lamboni et al., 2015; Ding et al., 2021; Zhu et al., 2025).

Its amino acid composition aids in calcium ion chelation, stimulating hydroxyapatite crystallization and scaffold osteoconductivity (Padamwar & Pawar, 2004; Ding et al., 2021). Additionally, sericin-based composites can modulate osteogenic signalling pathways, promoting stem cell differentiation into osteogenic lineages, which is critical for bone tissue repair while ensuring biocompatibility and gradual biodegradation aligned with new tissue formation (Aramwit et al., 2010a; Li & Sun, 2022).

Studies demonstrate that the incorporation of sericin into composite scaffolds improves mechanical properties, porosity, and bioactivity, enhancing the scaffold's ability to support cell infiltration, nutrient diffusion, and vascularization, all of which are essential for successful bone regeneration (Lamboni et al., 2015; Vepari & Kaplan, 2007).

Scanning electron microscopy (SEM) and X-ray diffraction (XRD) analyses have confirmed uniform mineral deposition and crystal growth in sericin-based composites. Additionally, sericin's inherent antioxidant and antimicrobial properties further contribute to creating a favourable microenvironment for bone healing, reducing oxidative stress and infection risks at the implantation site (Veiga et al., 2024; Wang et al., 2024b). These collective attributes position sericin-based nanomaterials and composite scaffolds as promising candidates for the development of next-generation bone tissue engineering strategies, addressing current limitations in bone grafting and synthetic biomaterials while aligning with the goals of biocompatibility, biodegradability, and enhanced functional recovery in orthopaedic and dental applications (Ma et al., 2025; Waidi et al., 2024).

4.6 Sericin in Culture Media and Cryopreservation

Cryopreservation and cell culture are essential components of regenerative medicine, biobanking, and advanced cellular therapies. Traditionally, fetal bovine serum (FBS) has been used as a supplement in cell culture media; however, it poses risks of contamination and immunogenic reactions (Sasaki et al., 2005). Sericin has emerged as a safe, effective alternative to FBS, demonstrating the ability to support cell proliferation, maintain cell viability, and enhance the quality of preserved cells across various cell types. Sericin with varying molecular weights has been shown to stimulate the proliferation of hybridoma cells, with lower molecular weight sericin (5–100 kDa) being particularly effective (Terada et al., 2005). It has been successfully applied in culturing human dermal fibroblasts, keratinocytes, PC12 rat pheochromocytoma cells, and Sf9 insect cells in serum-free media, maintaining robust proliferation while reducing contamination risks (Sasaki et al., 2005).

In cryopreservation, sericin supplementation improves antioxidant stability in freezing media, maintaining membrane integrity and motility in preserved sperm cells, as demonstrated in studies with buffalo sperm (Vijyeta et al., 2024). It has also been used in culturing rat islet cells and insulinoma cell lines (Ogawa et al., 2004). Terada *et al*. (2005) showed that low concentrations of sericin (0.01–0.1%) effectively support hybridoma cell proliferation, while Verdanova *et al*. (2014) reported that 1% sericin in 10% DMSO provided effective cryoprotection for human mesenchymal stromal cells (hMSCs) (Terada et al., 2005; Verdanova et al., 2014). Sericin's protective role in cryopreservation is linked to its ability to stabilize proteins and reduce intracellular ice formation. Overall, sericin's ability to replace fetal bovine serum (FBS) in culture media while enhancing cell viability and proliferation during cryopreservation underscores its role as a sustainable, biocompatible solution in cellular engineering, regenerative medicine, and biobanking applications (Cao & Zhang, 2015; Cao & Zhang, 2017).

5. COSMETIC APPLICATIONS OF SERICIN-BASED NANOMATERIALS

5.1 Moisturization and Skin Barrier Enhancement

Sericin has emerged as a valuable component in cosmetic formulations due to its excellent moisturizing, antioxidant, and film-forming properties (Joseph et al., 2024). It forms a thin protective film on the skin, reducing transepidermal water loss and enhancing moisture retention, thereby improving skin elasticity and smoothness (Ma et al., 2025; Mandal et al., 2009). The high content of hydrophilic amino acids, including serine and aspartic acid, facilitates deep hydration, making sericin ideal for moisturizers and anti-aging products (Padamwar & Pawar, 2004; Padamwar et al., 2005).

Sericin's excellent biocompatibility, biodegradability, and wettability have led to its use in a variety of cosmetic products for skin, hair, and nails, either on its own or combined with silk fibroin. When included in lotions, creams, and ointments, sericin has been shown to enhance skin elasticity while providing anti-wrinkle and anti-aging benefits (Padamwar & Pawar, 2004; Mendoza-Muñoz et al., 2023). It is a key ingredient in moisturizers formulated to combat skin dryness by maintaining hydration in the outermost skin layers (Aad et al., 2024; Joseph et al., 2024; Padamwar et al., 2005). Moisturizers often include wetting agents such as vegetable glycerine, water, jojoba oil, vitamin E oil, and sorbitol, enhancing the hydrating capabilities of sericin-based formulations (Kirikawa et al., 2000).

Sericin gels containing hydroxyproline have been found to increase epidermal thickness and reduce skin impedance, reflecting its superior moisturizing capacity (Padamwar et al., 2005; Hari & Kandasubramanian, 2024). *In vivo* studies have confirmed that sericin increases hydroxyproline levels, hydrates epidermal cells, and reduces skin impedance, with the proline content aiding collagen production while limiting transepidermal water loss to prevent dryness (Padamwar et al., 2005; Mendoza-Muñoz et al., 2023). By retaining moisture within the stratum corneum, sericin helps keep the skin smooth and plump, making it a highly effective component in moisturizing skincare formulations (Joseph et al., 2024; Hari & Kandasubramanian, 2024).

In skin conditions like atopic dermatitis and ichthyosis, which reduce free amino acids in the stratum corneum and cause dryness, sericin has shown therapeutic promise. Kim *et al.* (2012) demonstrated that a 1% sericin application effectively alleviates skin dryness in atopic dermatitis, while dietary sericin intake enhances hydration by increasing filaggrin and free amino acids in the stratum corneum, inducing gene expressions critical for skin barrier function, such as PPARγ, PAD3, and caspase-14, thus establishing its role in dry skin management (Stradczuk-Mazurek et al., 2025; Kim et al., 2012).

Sericin is highly hygroscopic and inhibits melanin synthesis in the skin's cortical layers, making it valuable for skin-brightening cosmetic applications. The molecular weight of sericin influences its application: 12,000–17,000 Da for haircare and 5,000–70,000 Da for skin-care products (Joseph et al., 2024; Hari & Kandasubramanian, 2024; Sheng et al., 2013). Its amino acid composition closely resembles the natural moisturizing factors in the stratum corneum, which maintain skin hydration (Aad et al., 2024; Hari & Kandasubramanian, 2024; Kim et al., 2012). Combining 1% sericin with 4% D-glucose in lotions provides effective hydration and conditioning benefits (Joseph et al., 2024; Mendoza-Muñoz et al., 2023). Sericin-based creams exhibit enhanced cleansing with reduced skin irritation (Joseph et al., 2024; Sheng et al., 2013) while its addition to sunscreen formulations boosts the light-screening effects of UV filters like triazines and cinnamic acid esters (Joseph et al., 2024).

Additionally, sericin helps absorb sweat and sebum, contributing to cleaner, healthier skin (Joseph et al., 2024). Sericin's antioxidant activity neutralizes reactive oxygen species, reducing oxidative stress and preventing premature aging due to UV radiation and pollution (Lamboni et al., 2015). It also supports collagen synthesis while inhibiting matrix metalloproteinases, enhancing skin firmness and reducing fine lines and wrinkles (Suryawanshi et al., 2020). Furthermore, its film-forming ability reinforces the skin barrier against pollutants while maintaining hydration, making it highly suitable for sensitive and dry skin formulations (Ma et al., 2025).

5.2 Anti-Aging and Skin Rejuvenation

Sericin has shown remarkable potential in anti-aging formulations due to its fibroblast-stimulating and collagen synthesis-enhancing properties, which help maintain skin elasticity and structure, reducing the visibility of fine lines and wrinkles (Vepari & Kaplan, 2007; Ma et al., 2025). By inhibiting collagenase activity, sericin preserves existing collagen networks while promoting the formation of new collagen fibers, critical for maintaining skin firmness and resilience (Lamboni et al., 2015; Suryawanshi et al., 2020). Additionally, sericin's antioxidant capabilities counteract reactive oxygen species generated by UV exposure and environmental pollutants, thereby reducing oxidative stress-induced skin aging and photoaging effects (Stradczuk-Mazurek et al., 2025; Mandal et al., 2009).

Studies indicate that sericin, when incorporated into creams and serums, can improve skin texture, hydration, and radiance, making it a valuable ingredient in advanced skincare regimes (Ma et al., 2025; Joseph et al., 2024). Its compatibility with other anti-aging agents like hyaluronic acid and vitamin E further enhances sericin's ability to support skin rejuvenation while maintaining moisture and barrier function, aligning with the demand for multifunctional cosmeceutical products (Lamboni et al., 2015; Aad et al., 2024). This multifaceted approach positions sericin as a sustainable, bioactive component for next-generation anti-aging skincare formulations.

5.3 Skin Brightening and Anti-Hyperpigmentation

Sericin demonstrates anti-tyrosinase activity, which helps regulate melanin synthesis, providing an effective and natural approach to managing hyperpigmentation and promoting a brighter, more even skin tone (Zhaorigetu et al., 2003; Suryawanshi et al., 2020). By inhibiting excessive melanin production, sericin-based skincare formulations address conditions such as melasma, age spots, and post-inflammatory hyperpigmentation without the harsh side effects often associated with synthetic brightening agents (Lamboni et al., 2015; Ma et al., 2025). Moreover, sericin's antioxidant properties further contribute to skin brightening by neutralizing oxidative stress that can trigger pigmentation pathways, thereby reduce the recurrence of dark spots and promote skin clarity (Mandal et al., 2009; Das et al., 2021).

Recent studies have shown that combining sericin with vitamin C, niacinamide, or botanical extracts enhances the skin-brightening effect synergistically while providing hydration and anti-inflammatory benefits, supporting comprehensive skin tone improvement (Lamboni et al., 2015; Suryawanshi et al., 2020). The biocompatibility and mild nature of sericin make it ideal for sensitive skin types, providing effective brightening without irritation, which is crucial in consumer-friendly brightening formulations (Stradczuk-Mazurek et al., 2025; Joseph et al., 2024).

5.4 Sericin-Based Nanocarriers for Active Ingredient Delivery

The application of sericin as a nanocarrier system represents a significant advancement in cosmeceuticals, enhancing the delivery and stability of active ingredients such as vitamins, peptides, botanical antioxidants, and coenzymes used in skincare (Lamboni et al., 2015; Suryawanshi et al., 2020; Joseph et al., 2024; Das et al., 2021). Sericin-based nanoparticles and nanofibers encapsulate these actives, protecting them from environmental degradation and enzymatic breakdown while ensuring controlled and targeted delivery into deeper skin layers (Stradczuk-Mazurek et al., 2025; Aad et al., 2024).

This targeted delivery enhances the bioavailability and efficacy of actives, allowing lower concentrations to achieve desired effects while reducing potential irritation (Ma et al., 2025; Mandal et al., 2009). For example, sericin-based nanocarriers delivering vitamin C can improve collagen synthesis and brightening effects while maintaining stability, which is often a challenge in conventional formulations (Ma et al., 2025; Liu et al., 2022).

Additionally, sericin's inherent film-forming and hydrophilic properties aid in prolonged skin contact and moisture retention, further boosting the functionality of active ingredients delivered through these nanocarriers (Lamboni et al., 2015; Ma et al., 2025). As consumer demand grows for high-performance, targeted, and sustainable skincare, sericin-based nanocarriers align well with industry trends, supporting the development of innovative, clean-label cosmetic products (Joseph et al., 2024; Das et al., 2021).

5.5 Scalp and Hair Care Applications

In hair care, sericin's moisture-retaining and film-forming abilities make it valuable for improving hair hydration, reducing frizz, and enhancing shine and smoothness in shampoos, conditioners, and hair masks (Padamwar & Pawar, 2004; Suryawanshi et al., 2020; Joseph et al., 2024). By forming a protective layer around the hair shaft, sericin reduces hair breakage and split ends caused by mechanical stress and environmental damage while preserving hair structure (Lamboni et al., 2015; Vepari & Kaplan, 2007). Sericin's antioxidant properties also contribute to scalp health by reducing oxidative stress, which can impact hair follicle vitality and contribute to hair thinning and loss (Ma et al., 2025; Mandal et al., 2009).

Incorporating sericin into scalp treatments and serums can help maintain scalp hydration and protect against UV and pollution-induced damage, promoting a healthier scalp environment conducive to hair growth (Hari & Kandasubramanian, 2024; Ristić et al., 2022). Additionally, sericin's biodegradability and compatibility with botanical extracts and vitamins enhance the performance of hair care formulations, making them suitable for sensitive scalps and environmentally conscious consumers (Ma et al., 2025; Suryawanshi et al., 2020). These properties collectively position sericin as a multifunctional, sustainable ingredient for next-generation hair and scalp care innovations.

6. MECHANISMS UNDERPINNING BIOMEDICAL AND COSMETIC EFFICACY

The multifunctionality of sericin in biomedical and cosmetic applications is primarily driven by its amino acid composition, molecular structure, and bioactivity (Holland et al., 2019). The high content of hydrophilic amino acids facilitates moisture retention, which is crucial for maintaining skin hydration and creating a moist environment for wound healing, promoting cell proliferation and tissue regeneration (Padamwar & Pawar, 2004; Vepari & Kaplan, 2007). Sericin's antioxidant properties, derived from its ability to scavenge reactive oxygen species, play a pivotal role in reducing oxidative stress, thereby protecting skin from environmental damage and accelerating wound healing (Lamboni et al., 2015; Suryawanshi et al., 2020; Veiga et al., 2024).

Biodegradability is another essential property, ensuring that sericin and its nanostructures degrade into non-toxic byproducts within the body, minimizing adverse immune responses and supporting safe biomedical use (Stradczuk-Mazurek et al., 2025; Mandal et al., 2009). The integration of sericin into nanomaterials further enhances its stability and facilitates targeted delivery, improving its therapeutic outcomes in drug delivery and skincare formulations (Ma et al., 2025; Aramwit et al., 2010b). These mechanisms collectively position sericin-based nanomaterials as effective and versatile tools in the development of sustainable healthcare and cosmetic products (Silva et al., 2022).

7. CHALLENGES AND FUTURE PROSPECTS

Despite its promising potential, the widespread application of sericin-based nanomaterials faces several challenges that require systematic attention. Variability in extraction methods leads to differences in molecular weight and bioactivity of sericin, necessitating standardization to ensure consistency in product performance across batches (Zhaorigetu et al., 2003; Suryawanshi et al., 2020; Vaishnav & Singh, 2023; Sarangi et al., 2023). Stability issues during storage, including nanoparticle aggregation and degradation, require the development of effective stabilization strategies to maintain the functional properties of sericin-based formulations (Ma et al., 2025; Aad et al., 2024).

Regulatory hurdles remain a significant challenge, particularly for clinical applications of sericin-based biomedical products, necessitating comprehensive toxicological and efficacy studies to secure approvals (Mazurek et al., 2024; Das et al., 2021). In the cosmetic industry, regulatory compliance with safety standards is essential to ensure consumer acceptance and trust in sericin-based skincare formulations (Lamboni et al., 2015; Suryawanshi et al., 2020).

Future directions should focus on optimizing extraction and purification processes for scalable production, exploring novel composite materials integrating sericin with other biopolymers, and developing stimuli-responsive nanocarriers for precision therapy and targeted skincare applications (Vepari & Kaplan, 2007; Mandal et al., 2009). Advanced techniques such as 3D bioprinting, bioelectronics integration, and functionalization of sericin with therapeutic molecules hold promise for expanding the application landscape of sericin-based nanomaterials, positioning them as next-generation sustainable solutions in healthcare and cosmetic industries (Lamboni et al., 2015; Stradczuk-Mazurek et al., 2025).

8. CONCLUSION

Sericin has transitioned from being a discarded by-product of the silk industry to a high-value biomaterial with broad applications in the biomedical and cosmetic sectors. Its inherent biocompatibility, biodegradability, antioxidant, and moisture-retention properties align well with the demands of modern healthcare and skincare products aimed at promoting wellness while maintaining environmental sustainability. The integration of sericin with nanotechnology has further amplified its utility, facilitating the development of innovative wound dressings, drug delivery systems, and advanced skincare formulations with enhanced efficacy and stability. Addressing current challenges related to standardization, stability, and regulatory compliance will be essential to translating laboratory advancements into commercially viable products. Continued interdisciplinary research focusing on the functionalization and application of sericin-based nanomaterials will contribute significantly to developing sustainable, effective, and consumer-friendly healthcare and cosmetic products, firmly positioning sericin as a critical biomaterial in the advancement of next-generation bio-based industries.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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