

# SERICIN AS A MULTIDIMENSIONAL SILK PROTEIN: FROM SILKWORM NUTRITION TO ANTIBACTERIAL, BIOMEDICAL AND COSMETIC RESOURCE

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## ABSTRACT

Sericin, a hydrophilic globular protein constituting the outer layer of silk fibers produced by the silkworm (*Bombyx mori*), is emerging as a multifunctional biomolecule with significant relevance to sustainable sericulture. Once discarded as an industrial waste, sericin is now recognised for its nutritional value, antioxidant capacity and antimicrobial activity. This review collates current evidence on the application of sericin as a functional feed supplement in silkworm rearing, with a particular emphasis on its dietary supplement and antibacterial properties in silkworms. Accumulating studies demonstrate that dietary or topical sericin supplementation enhances larval growth performance, cocoon and shell parameters, and survival, especially under bacterial challenge. Sericin exhibits inhibitory activity against a range of Gram-positive and Gram-negative bacteria, contributing to reduced infection burden and improved host resilience. Collectively, these findings position sericin as a value-added, eco-friendly intervention that not only enhances silkworm health and productivity but also advances circular bioeconomy approaches through the reutilization of silk industry residues.

**KEYWORDS:** *Bombyx mori*, Sericin, Dietary supplement, Antibacterial, Biomedical and Cosmetic.

## INTRODUCTION

Sericin, a natural polymer, is increasingly recognised for its multifaceted biological activities, encompassing antibacterial, antioxidant, anti-cancer and anti-tyrosinase properties, making it a valuable biomaterial with broad applicability (Vidyashree *et al.*, 2024). Specifically, its notable antioxidant capacity, attributed to its ability to inhibit lipid peroxidation and neutralise free radicals, positions sericin as a promising natural additive for various applications, including food and pharmaceuticals (Miguel *et al.*, 2020). Beyond these established benefits, the historical practice of

discarding sericin as wastewater during traditional silk processing has prompted extensive research into its potential for valorisation, particularly given its abundance in silk cocoons, where it constitutes 25-30% of the total silk protein (Zhao & Zhang, 2020). This inherent abundance, coupled with its biocompatibility and biodegradability, positions sericin as an economically viable and environmentally sound alternative to synthetic compounds across diverse industrial sectors (Singh *et al.*, 2020). Due to its amino acid profile and significant antibacterial properties, sericin has multiple applications; however, this review primarily focuses on its use as a dietary supplement for silkworms. A rich profile of amino acids found in sericin can directly promote the growth and well-being of silkworms. Its natural antibacterial properties may also lessen typical microbial problems in sericulture. Additionally, sericin's functionality and potential as a nutritional supplement are influenced by its protein composition, which consists of 18 different amino acids, most of which are polar (Miguel *et al.*, 2020). Its hydrophilic nature and high concentration of amino acids, including glycine, aspartic acid, and serine, which enhance nutritional absorption and boost immune responses, make it a more suitable inclusion in silkworm diets. This amino acid richness is particularly noteworthy, given that such proteins can act as radical-trapping devices, thereby offering antioxidant benefits to the silkworm (Michael & Subramanyam, 2014).

The distinct amino acid profiles of different sericin extracts, such as those from *Gonometa postica*, *Gonometa rufobrunnea*, and *Argema mimos*a, which exhibit distinct polar-to-non-polar ratios, indicate the possibility of species-specific optimisation of sericin supplements for silkworms. (Manesa *et al.*, 2020). Silkworm contains various amino acids, including serine, glycine, arginine, and threonine, depending on the species and extraction methods, which makes it a significant food ingredient (Endrawati *et al.*, 2023). The potential for nutritional supplementation is substantial, as 100 kg of silk yields approximately 22–30 kg of sericin protein, which is rich in 18 different types of amino acids, including roughly 30% serine, 18% aspartic acid, and 9% glycine (Boonpavanitchakul *et al.*, 2019). This makes sericin a compelling candidate for enhancing the nutritional value of silkworm feed, potentially improving their growth and silk production (M. Yang *et al.*, 2014). Besides its dietary properties, sericin itself possesses antibacterial properties attributed to its special protein structure and amino acid sequence, which enables natural defence against common ailments that threaten the health of silkworms (Manesa *et al.*, 2020; C. Yang *et al.*, 2023). In particular, it has been observed that the cytoprotective and mitogenic properties of sericin promote an increase in cell union sites and cell proliferation on various cell lines, including keratinocytes and fibroblasts, which indicate a potential increase in repair and regeneration in silkworms. (Mandal *et al.*, 2011; Prakash *et al.*, 2024). Its regeneration abilities, coupled with its known use as an antioxidant, imply a dual role for sericin in improving the nutritional status and resisting environmental and microbial challenges of silkworms. Therefore, using sericin as a feed supplement could significantly enhance the resilience and productivity of sericulture by improving nutritional status and innate immune responses (Wu *et al.*, 2024).

Moreover, it is worth noting that the biocompatibility associated with sericin, as well as its biodegradability, reinforces its role as an eco-friendly biomaterial with advanced applications in drug delivery systems and tissue engineering scaffolds (Teramoto *et al.*, 2005). However, it has some limitations when used alone as a biomaterial due to its low inter-peptide bonding and poor mechanical strength, which necessitate the use of additional materials as a support structure to achieve desirable functions, such as morphology, biostability, and functionality relevant to biotechnological uses (Naskar *et al.*, 2014). Furthermore, the presence of some specific functional groups in the sericin molecule plays a role in making it a metal ion chelator, thus effectively nullifying its pro-oxidant properties and enhancing its

antioxidant defence system. The presence of an inherent antioxidant system in sericin not only helps sustain the internal physiological harmony among silkworms but also makes sericin a natural food preservative that resists the onset of oxidative reactions that can impair food quality and longevity (Miguel & Álvarez-López, 2020). Apart from these recorded properties, the application of sericin can help improve cellular immunity and activate detoxification functions, thereby providing resistance to organisms challenged by environmental toxins (El-Fakharany *et al.*, 2020).

It is due to this comprehensive understanding and knowledge of the molecular traits and functions of sericin that make it an extremely valuable biomaterial with immense potential for various research and commercial applications (Kunz *et al.*, 2016). The concept and exploration of hydrolysates, more specifically enzymatic hydrolysates, have also unveiled research and developments about the superior functional and antioxidant properties of sericin beyond its original form as a pure protein molecule (Omar *et al.*, 2021). These hydrolysed peptides of sericin have shown higher bioavailability and efficacy, offering significant value due to their suitability and prospects for enhancing fortified functional foods and supplementing dietary components (Miguel & Álvarez-López, 2020). Moreover, the functional capacity of sericin to act as a trace metal chelator, due to its hydroxyl groups derived from serine and threonine residues, directly contributes to its antioxidant efficacy in eliminating reactive oxygen species (Kunz *et al.*, 2016). Sericin also contains an immense number of hydroxyl groups due to these amino acids and acts as an excellent scavenger for free radicals, as it directly neutralises reactive species (Silva *et al.*, 2022). This multi-dimensional bioactivity and efficacy of sericin make it an excellent and promising compound, as it acts as a multi-dimensional bioactive compound itself. Based on all these benefits, incorporating sericin into silkworm food can be seen as a clever strategy to improve larval growth and silk production.

This review will explore the multifunctional uses and properties of sericin, focusing on recent studies that utilise sericin as a nutritional supplement in silkworms. A considerable volume of literature supports the multifunctionality of sericin, which exhibits evident antioxidant, anti-cancer, and antimicrobial properties (El-Fakharany *et al.*, 2020). Furthermore, sericin has been shown to have a strong bactericidal and antibiofilm effect on pathogenic bacteria, including *Staphylococcus aureus*, *Escherichia coli* and *Streptococcus mutans*, indicating a role in pathogenic control (Aramwit *et al.*, 2020). The role of sericin in exhibiting a strong bactericidal mechanism and antimicrobial activity can be explained by two ways in which sericin interacts with bacterial cell structures, resulting in damaged cell integrity and inhibition of basic cell functions (Matsumoto *et al.*, 2020). For example, studies have demonstrated that sericin is capable of binding with bacterial cell walls, which leads to disrupting basic functions in terms of cell permeability in bacteria (Soumya *et al.*, 2017).

## 1. SERICIN AS A NUTRITIONAL SUPPLEMENT

Sericin is considered a byproduct of the silk industry, boasts a unique amino acid composition and bioactive properties that make it a compelling candidate for nutritional supplementation. The high amount of serine within sericin, along with glycine and aspartic acid provides reason for its potential use as a functional food ingredient. These amino acids are responsible for establishing antioxidant, anti-inflammatory, and cryoprotective effects making sericin a valuable asset for enhancing cellular health and resistance. This protein's unique profile, characterised by hydrophilic amino acids, contributes to excellent moisture retention capabilities, which is beneficial in various physiological functions. Moreover, sericin has already demonstrated promising applications in regulating metabolic processes, which have the potential to influence nutrient absorption and energy utilisation due to its specific peptide sequences. This makes it

highly relevant for the diet of *Bombyx mori* larvae in particular, where optimised nutrient uptake directly correlates with silk production efficiency and overall silkworm health. Given that enormous amounts of sericin are discarded annually from textile industries, approximately 50,000 tons worldwide, re-purposing this valuable byproduct as a silkworm feed supplement is an economically and ecologically sound solution that not only mitigates waste but also simultaneously enhances sericulture yields. The application of sericin as a feed additive enhances its intrinsic value, improving larval growth, cocoon quality, and disease resistance, thereby addressing three critical issues necessary for sustainable sericulture. It has been indicated that adding sericin to silkworm diets can enhance physiological parameters, such as increased larval body weight, silk gland weight, and improved cocoon and shell copolymerization. This productivity increase is beneficial, as it enhances nutrient assimilation and strengthens the silkworms' immune responses, thereby reducing their susceptibility to pathogens. These multifarious bioactivities position sericin not only as a valuable component for advanced biomedical applications but also as a potent dietary supplement to enhance the growth and disease resistance of *Bombyx mori*.

Nutritional supplementation with various feed additives, such as amino acids and vitamin substances, can significantly improve economic traits and silk conversion rates, which is believed to enhance benefits for the silk industry. This approach aligns with a broader effort to fortify mulberry leaves with a range of nutrient supplements, including carbohydrates, proteins, and vitamins, to enhance the health and productivity of silkworms. This strategic improvement in the feeding diet not only optimises the growth and silk production of *Bombyx mori* but also provides a further sustainable pathway for the valorisation of an important industrial byproduct. This innovative sourcing method could circumvent the drawbacks of conventional sericin extraction, which often involves severe chemical treatments that can degrade its bioactive compounds. Consequently, incorporating sericin as a food additive for silkworms presents a multifaceted approach to strengthening sericulture, utilising both the nutritional completeness and protective attributes that it offers. This use may significantly enhance the health and productivity of silkworms, thereby improving the economic feasibility and sustainability of silk production. Furthermore, the application of sericin in the diet of the silkworm articulates with the general efforts in sericulture towards the improvement of the resilience and productivity of silkworms through bioactive additives. This includes additives from silkworm faeces and other organic sources. Ismayilova *et al.* state that all these promise a new frontier for sericulture, characterised by high productivity with minimal environmental impact. Mulberry leaves, the exclusive diet of *Bombyx mori* are highly influential on larval growth and development and consequently on silk yield and quality. Therefore, their enrichment with supplementary nutrients, such as sericin, either as a feed ingredient or applied topically, becomes a vital approach toward optimising the performance of silkworms and silk yield.

Thirumalaisamy *et al.* and Dhar have pointed out that fresh mulberry leaves, which are normally fed to the worms, have changed over time due to industrial pollution and labour shortages in traditional sericulture regions. Hence, innovative feeding strategies need to be developed beyond merely fresh mulberry leaves. Indeed, sericin is considered a functional feed additive, moving beyond mere nutritional supplementation to active health management of the silkworm through its antibacterial and antioxidant properties, among others. Such studies will facilitate the formulation of standardised sericin-enriched diets that result in consistent enhancement of larval development, disease resistance, and overall silk production efficiency. Moreover, a proper understanding of sericin's specific role in modulating the silkworm gut microbiome and subsequently affecting nutrient absorption pathways is needed to further refine its application as a dietary supplement. By attaining a full understanding, one can optimise silkworm health and silk yields, in addition to

overcoming some traditional rearing challenges and environmental stressors associated with sericulture production (Micheal & Subramanyam, 2014). In addition, the concept of genetically engineered silkworms to produce improved variants of sericin or those with enhanced efficiency in sericin use introduces a whole new frontier for further work in this area of research (Fatima *et al.*, 2024). This would therefore present opportunities for a new generation of sericultural practices that are both sustainable and highly productive, yielding considerable economic benefits to communities whose economic livelihoods depend on sericulture. In a recent study, dietary supplementation of sericin through mulberry leaves significantly improved cocoon and pupal parameters in *Bombyx mori* compared to the control group. Feeding 0.50% sericin at the chawki stage resulted in a 23.91% increase in cocoon yield per 100 DFLs, indicating optimal enhancement of productivity. Sericin supplementation during the entire larval period increased dry cocoon weight by up to 46.1% and pupal weight by 37.5%, depending on concentration and feeding stage. Although fecundity showed no significant variation among treatments, the hatching percentage was markedly higher in the sericin-treated groups compared to the control. Overall, the study demonstrates that low to moderate sericin concentrations function as an effective nutritional supplement, improving silkworm growth, survival, and economic traits in a sustainable manner (Hossain *et al.*, 2022).

The multifunctional nature of sericin, due to its affinity for human skin and hair, its induction of apatite nucleation, and promotion of fibroblast attachment, underlines the many ways it can be utilised beyond silkworm nutrition as a valuable biomaterial. Despite its great potential, the study of sericin in its native form has been limited due to its easy degradation, which frequently occurs during heat or alkaline treatments during extraction processes (Teramoto *et al.*, 2005). Such denaturation often results in the loss of structural integrity and functional properties, thereby limiting a proper understanding of the full biological value and subsequent applications that are possible (Teramoto *et al.*, 2005). Consequently, there is a dire need for more advanced, gentle methods of extraction that would preserve the native structure and maximise therapeutic and nutritional effectiveness for various applications (Teramoto *et al.*, 2005). Thus, there is a specific need for innovative, mild extraction techniques that protect the intricate protein structure and bioactive components of sericin, which in turn could permit more accurate assessment of its intrinsic properties and wider utilisation (Kurmi *et al.*, 2023). Such methods are crucial not only for biomedical applications, where the biocompatibility and regenerative capabilities of sericin are decisive, but also for its use as a food supplement, where the full amino acid profile and antibacterial efficacy must be retained. The application of such refined extraction techniques may unlock a wider spectrum of sericin's capabilities, promoting its integration into advanced biomaterials, nutraceuticals, and pharmaceuticals.

Sericin, for example, contains a higher content of hydrophilic amino acids than silk fibroin, which contributes to its hydrophilicity and thus enhances its performance in chemical modification for various applications. This trait makes sericin highly attractive for the development of biocompatible materials, particularly in tissue engineering and drug delivery systems, where interaction with the aqueous physiological environment is a crucial factor. This superior hydrophilicity contributes to sericin's remarkable moisture-absorbing and dispersing properties, making it valuable in cosmetic and textile applications. The molecular weight of sericin can vary from 10 to over 400 kDa, depending on the conditions under which it is subjected to extraction, including temperature, pH, and the duration of processing. For example, sericin A, M, and P have molecular weights ranging from 150 to 400 kDa, which are the main polypeptides. However, sericin often yields a molecular weight below 20 kDa at the end of conventional extraction processes, which include high alkali, enzymatic solutions, or high-pressure and temperature conditions. Such degradation may

significantly alter biological properties, such as antioxidant and photoprotective activity, since the amino acid composition and molecular weight bear an intrinsic relationship with functional efficacy. It is thus essential to tightly regulate the extraction parameters to preserve the native molecular weight distribution and conformational integrity of sericin, thereby maximising its bioactivity and application potential. It has been demonstrated by Nishida *et al.* that sericin, with a high content of polar side chains, significantly contributes to its complex three-dimensional structure and functional versatility. Indeed, such a rich amino acid composition, with serine, aspartic acid, glycine, and threonine as the most dominant amino acids, endows sericin with beneficial features, including UV resistance, antioxidation, and moisture absorption, which are highly valued in numerous industries.

## 2. SERICIN AS AN ANTIBACTERIAL

Recent studies have demonstrated the strong antibacterial properties of sericin against both Gram-positive and Gram-negative bacteria, which can be attributed to its distinctive polypeptide structure and composition. As a naturally occurring antimicrobial agent, sericin can be considered an effective alternative to synthetic antimicrobials in various application domains, including biomedicine and food preservation (Manesa *et al.*, 2020). The exact mechanism of sericin's antibacterial properties remains unknown. It involves various complex pathways, including cell membrane disruption, metal ion chelation, and the inhibition of enzyme activity, which are critical for the survival of microorganisms in nature. For example, intact sericin with a high molecular weight has shown promising results in exhibiting a strong growth-inhibitory effect on Gram-negative bacteria, indicating that these microorganisms require the intact amino acid sequence and structure of sericin to effectively exhibit their antimicrobial properties (Matsumoto *et al.*, 2020). In contrast, using enzymatic hydrolysis for some improvements, such as increased antioxidant properties, can decrease sericin's molecular weight, consequently reducing its inherent direct antibacterial properties against individual bacterial strains successfully (Omar *et al.*, 2021; Meerasri *et al.*, 2022). Nonetheless, the antimicrobial properties of sericin are concentration-dependent, with increased concentrations of sericin showing better effects due to enhanced interaction with the microorganisms' cell surfaces (Saha *et al.*, 2019). For instance, sericin has been shown to possess substantial antibacterial properties against food-origin bacteria such as *Escherichia coli* and *Listeria monocytogenes*, which are comparable to synthetic antimicrobial compounds available on the market (Seo *et al.*, 2022). Additionally, sericin's antibacterial properties have been largely attributed to its positive charge from individual amino acid side chains in an acidic medium, which has an affinity for protonating carboxylic acids during interaction with the negatively charged cell membranes of *Listeria* bacteria (Li *et al.*, 2023). Moreover the presence of distinct amino acids such as serine and aspartic acid in sericin, which comprises a considerable fraction of this macromolecule, have demonstrated an increased capacity in intervening in bacterial cell wall production and microbial metabolic pathways to achieve either bacteriostatic or bactericidal effects successfully in nature (Jassim & Al-Saree, 2010; Matsumoto *et al.*, 2020). Further studies have further clarified that the minimum inhibitory concentration and minimum bactericidal concentration of sericin extracts can vary from 0.0625 to 1.0 mg/mL, which underlines its strong antimicrobial potential for various industrial applications (Seo *et al.*, 2022).

The antimicrobial activity of sericin is not limited to native sericin. However, it can be found in modified sericin, such as sericin/silver nanocomposites, which maintain their antimicrobial potential against *Escherichia coli* and *Staphylococcus aureus* despite rigorous washing cycles, confirming their strong antimicrobial potential (Gökçe *et al.*, 2020). In fact, Eri sericin has already demonstrated membrane dysfunction in bacteria, which underlies its antimicrobial potential against *Escherichia coli* and *Staphylococcus aureus* (Senakoon *et al.*, 2009). Evidently, this membrane

dysfunction can be identified through the observation of abnormally shaped bacterial membranes using scanning electron microscopy after contact with Eri sericin (Senakoon *et al.*, 2009). Such morphologies suggest that Eri sericin exhibits a bactericidal effect, capable of compromising the integrity of bacterial cell envelopes, which results in the leakage of cellular contents and ultimately leads to cell death (Senakoon *et al.*, 2009). Such evidence has further been confirmed by the increased membrane permeability and efflux of intracellular materials, such as nucleic acids and proteins, observed after contact with sericin (Aramwit *et al.*, 2020). The presence of cysteine residues in sericin composition, which can be identified based on the presence of their sulfhydryl groups, is hypothesised to underlie sericin's antimicrobial potential based on weak hydrogen bonding, which inhibits enzyme reactions and other metabolic processes essential for microorganisms' survival (Silva *et al.*, 2022). The other antibacterial mechanism involves the ability of sericin to chelate metal ions essential for bacterial cell growth and biopolymer production, thereby impairing bacterial cell growth and survival (Senakoon *et al.*, 2009). This confirms that sericin possesses antibacterial properties not only due to its bactericidal effects but also due to its role in controlling or regulating bacterial cell growth dynamics, which is a crucial attribute in food preservation and medicine, where inhibiting bacterial cell growth is essential (Matsumoto *et al.*, 2020).

The broad-spectrum antimicrobial properties of sericin, which are effective in destroying both Gram-positive and Gram-negative bacteria, make it an excellent natural and renewable antimicrobial substance in place of conventional synthetic antimicrobials in various contexts owing to their effectiveness both in Gram-positive and Gram-negative bacteria, which have different cell wall structures and functions in various biological pathways, including those in bacteria (Jassim & Al-Saree, 2010; Senakoon *et al.*, 2009). This confirms that sericin can be an important biomaterial with desired antimicrobial properties in various contexts, including the design of medical implants to promote wound healing with enhanced biocompatibility in medical implant technology (Ghalei & Handa, 2021; Patil *et al.*, 2020). In fact, silk fibroin, a byproduct of sericin with higher concentrations of sericin, exhibits weak bactericidal properties and is therefore utilised in the design of wound dressing materials due to its excellent properties in terms of both biological and mechanical qualities in medical technology (Patil *et al.*, 2020). The indication of a mixed synergism in using sericin and fibroin for designing medical implant devices in wound healing confirms a multifaceted approach to handling infection and regeneration in medical technology, particularly when developing advanced medical devices, where controlling both infection and regeneration is crucial (Ghalei & Handa, 2021; Pollini & Paladini, 2020). In addition to its antimicrobial properties in medical technology, sericin can also be utilised in medicine as a nanomaterial with anti-inflammatory properties, aiding wound healing through various immune responses (Jaiswal *et al.*, 2020). With its potent antimicrobial properties, wound-healing, and regenerative abilities, sericin finds application as a versatile biomaterial suitable for advanced medical therapies and preventive approaches (Çalamak *et al.*, 2014; Munir *et al.*, 2023; Sarangi *et al.*, 2023).

Studies have shown specific blend films of silk fibroin to possess antibacterial properties against *E. coli* and *Staphylococcus epidermidis* bacteria (El-Fakharany *et al.*, 2020). In fact, a combination of sericin with other antibacterial drugs, such as amoxicillin and/or propolis in nanoparticle form, has been shown to have a positive impact on improving wound healing and significantly reducing bacteria in infected wounds (Diab *et al.*, 2022). Moreover, these combinations demonstrate sericin's capacity to enhance the efficacy of existing medications, thereby providing a promising alternative for overcoming antibiotic resistance (Bernardes *et al.*, 2024). Aside from sericin's direct antibacterial effects, these materials can be processed into various forms, such as films, hydrogels, and nanofibers,

thereby enhancing their utility in a wide range of medical applications (Silva *et al.*, 2022). Moreover, sericin's natural biocompatibility and biodegradability make this material an excellent candidate for developing a biodegradable drug delivery system, ensuring a controlled release of drugs with a minimal negative impact on patients' health (Bernardes *et al.*, 2024). Moreover, sericin can be successfully incorporated into various medical devices, such as wound dressings, artificial skin, and tissue engineering scaffolds, thereby playing a significant role in regenerative medicine due to sericin's medicinal properties in epithelial corneal regeneration (Sarangi *et al.*, 2023).

Considering the role of sericin in generating stable hydrogels and films, sericin holds immense future potential in developing advanced wound dressing products and tissue engineering scaffolds (Chouhan & Mandal, 2019; Sarangi *et al.*, 2023). The ease with which sericin can be processed into scaffolds, films, hydrogels, microspheres, and nanoparticles greatly increases its utility in a wide array of medical disciplines, including wound dressing (Tian *et al.*, 2025; Wani *et al.*, 2022). Its fast swelling rate in hydrogels is an additional attribute, which is greatly beneficial in controlled drug delivery systems (Li *et al.*, 2023). Additionally, considering the wide array of sericin properties, including its antioxidant and anti-apoptotic properties, hydrophilicity, cell attachment, and cell proliferation, it greatly expands its utility in developing advanced medical-grade materials (Sahu *et al.*, 2016). Sericin's role in accelerating cell proliferation in serum-free cell culture systems further strengthens its utility in a wide array of medical applications, including its use as an alternative to serum in islet cell culture and as a cell cryopreservation agent for various cell lines (Sahu *et al.*, 2016). Its wide array of medical applications, including wound healing and tissue regeneration, cell culture, and cell cryopreservation, further confirms sericin's status as a "highly promising natural polymer" (Li *et al.*, 2023; Liu *et al.*, 2022). In addition to this, its natural biodegradability and biocompatibility make it an important candidate for developing eco-friendly biomaterials (Jaiswal *et al.*, 2020; Wang *et al.*, 2014). The reuse of sericin, which otherwise gets disposed of in textile industries, not only resolves any environmental hazards but is of immense "scientific & commercial significance because of their unique physicochemical properties" as well (Kunz *et al.*, 2016). Traditionally, sericin has been recognised as a byproduct of textile processing; however, recent breakthroughs in medicine have revealed its rich amino acid structure and a wide array of biological and pharmacological properties (Li *et al.*, 2022; Veiga *et al.*, 2024). The presence of a high amount of amino acids, primarily glycine, serine, aspartic acid, and threonine, makes sericin a versatile biopolymer with a wide range of applications in various formulations (Das *et al.*, 2021). Apart from being used in fabricating bioprofiling materials, its excellent antioxidant properties make it an ideal cytoprotector in shielding cells from damage triggered by oxidative stress (Jassim & Al-Saree, 2010). The main contributors to this antioxidant property are the hydroxyl radicals of serine and threonine residues, which have a strong affinity for metal ions such as copper, iron, and zinc, thereby diminishing reactive oxygen species (Das *et al.*, 2021). Moreover, this capacity can be crucial in protecting biological samples, offering a non-toxic and biodegradable material for cell preservation that mitigates the toxicity associated with storage in existing microcontainers (Soumya *et al.*, 2017).

The capacity of sericin to form strong composites, especially with fibroin, makes it feasible to fabricate materials with enhanced mechanical properties for various medical applications (Wang *et al.*, 2020). Additionally, the presence of polyphenols and flavonoids in sericin significantly contributes to its antioxidant properties, thereby enhancing its effectiveness in combating oxidative stress in biological systems (Kunz *et al.*, 2016; Micheal & Subramanyam, 2014). Apart from these qualities, sericin's capacity to enhance the activities of endogenous antioxidant enzymes, such as superoxide dismutase, catalase, and glutathione peroxidase, further reinforces its effectiveness in protecting against

cell damage in biological systems (Silva *et al.*, 2022). Moreover, sericin has been shown to possess the capacity to inhibit both lipid peroxidation and tyrosinase activity, thereby acting as an antioxidant with multiple functions in medicine and food preservation (Miguel & Álvarez-López, 2020). The role of sericin in scavenging free radicals and sequestering metal ions in biological systems further highlights its potential as a natural food preservative with a life-extending capability in preserved food products, as it counteracts their oxidative degradation (Sinha *et al.*, 2022). Apart from being an antioxidant with broad antimicrobial capabilities, sericin is an antibacterial compound with a wide capacity to inhibit and interfere with biochemical reactions leading to biofilm formation, especially when obtained through different methods, such as the degradation of urea in sericin (Silva *et al.*, 2022). Such broad antimicrobial activity, especially against Gram-positive bacteria, implies different application capabilities in various programs, such as medical device coatings and food packaging, and is vital in preventing these microorganisms from invading these programs. Additionally, sericin's role in inhibiting lipid peroxidation and the tyrosinase enzyme further enhances its capabilities, thereby exhibiting prospects in improved food preservation and medical applications (Gamboa *et al.*, 2016). With its diverse capabilities as an antioxidant, antibacterial and cell protector in chronic cold, sericin is a highly versatile cell product with numerous prospects in various industries worldwide (El-Fakharany *et al.*, 2020; Sarangi *et al.*, 2023).

**Table 1: Comparative table on sericin supplementation effects on silkworm productivity and antibacterial activity.**

Study and ear	Sericin Source	Silkworm Productivity Improvement	Antibacterial Activity (Zone of Inhibition)	Experimental Duration / Conditions
Zhao & Zhang (2020)	Layered sericin peptides (degummed cocoon)	+18% cocoon yield, +22% shell weight	<i>E. coli</i> : 17.2 mm, <i>S. aureus</i> : 15.4 mm	5th instar larvae, 10-day feeding
Shaw <i>et al.</i> (2024)	Sericin–Ag nanocomposite	+15% silk gland protein content	<i>E. coli</i> : 22.6 mm, <i>B. subtilis</i> : 21.3 mm	Artificial diet coating, 7-day exposure
Wang <i>et al.</i> (2025)	Extracted native sericin powder	+10% larval growth rate	<i>S. aureus</i> : 16.5 mm	3-week rearing period
Ren <i>et al.</i> (2025)	Probiotic-sericin enriched diet	+25% silk gland amino acid efficiency	<i>E. coli</i> : 19.8 mm	Larval stage IV–V, 12 days
Seo <i>et al.</i> (2023)	Aqueous extracted sericin (degummed)	+12% total silk output	<i>B. cereus</i> : 14.9 mm	5th instar larvae, 7-day feeding
Reis <i>et al.</i> (2025)	Regional sericin (Portugal cocoons)	+14% cocoon shell ratio	<i>E. coli</i> : 18.2 mm, <i>P. aeruginosa</i> : 16.4 mm	Controlled temperature 26°C, 12 days
Nalawade & Momin (2023)	Sericin + symbiotics blend	+27% enzyme activity (protease/amylase)	<i>B. subtilis</i> : 13.8 mm	Full larval cycle, 21 days
Aznar-Cervantes <i>et al.</i> (2021)	Fibroin-sericin supplement	+8% body weight, +11% silk yield	<i>S. aureus</i> : 15.2 mm	Short-term feeding, 14 days
Zhu <i>et al.</i> (2020)	Seroiin proteins from cocoon sericin	+9% larval survival rate	<i>E. coli</i> : 14.5 mm	In vitro + in vivo tests, 8 days
Jaiswal & Banerjee (2021)	Sericin by-product (post-reeling waste)	+13% fiber quality index	<i>E. coli</i> : 12.8 mm	Cocoon post-processing evaluation

### 3. SERICIN IN THE BIOMEDICAL FIELD

The various forms of sericin have made it an excellent biomaterial, boasting properties of biocompatibility, biodegradability, and diverse material structures, including hydrogels, films, and sponges, for a wide range of biomedical and pharmaceutical applications. More specifically, sericin has proven to be effective in accomplishing

these goals due to its facilitating role in re-epithelialisation, facilitated by the antibacterial properties of sericin. Therefore, with such broad-spectrum antibacterial activity against both Gram-positive and Gram-negative bacteria, sericin is considered one of the important components in bionanomaterials for controlling microbial growth and infections. For instance, Eri sericin was found to display bactericidal action against *Escherichia coli* and *Staphylococcus aureus*, indicating its robust potential as an antimicrobial agent. The extent of this antibacterial activity has also been supported by studies that have proven sericin hydrogels, particularly when combined with silver nanoparticles, to show much greater inhibition of *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa*, offering superior properties for wound care. Sericin possesses antibacterial properties, but it also has a major role in cell adhesion and proliferation. Sericin is therefore a biocompatible and commercially feasible substance for a range of biological applications. Additionally, the highly hydrophilic nature of sericin, along with its numerous polar functional groups, enables the formation of blends through cross-linking or copolymerisation with other polymers, thereby tuning the mechanical resistance and performance of sericin-based biomaterials. Enhanced properties render sericin-based composites particularly suitable for advanced wound dressings and artificial skin applications, where biocompatibility, mechanical strength, and especially antimicrobial efficacy are essential. For example, sericin-methacrylate hydrogel nano formulations have been demonstrated to promote skin regeneration by inducing angiogenesis and regulating growth factors, including TGF- $\beta$ 1 and  $\beta$ 3. Such a capacity for regeneration makes sericin a highly promising molecule for use in new strategies for wound healing, particularly in cases that are particularly challenging to heal, such as diabetic ulcers. These characteristics make sericin a highly attractive biomolecule for application in novel strategies for wound healing, particularly in particularly challenging cases, such as diabetic ulcers, and in functionalized silk matrices loaded with bioactive molecules and antimicrobial compounds.

This is further emphasised by the use of sericin in bio-nanotextiles, where silk fibroin, often in combination with sericin, provides a biocompatible and antimicrobial barrier that promotes wound healing. Furthermore, sericin-based silver nanoparticles demonstrated high antimicrobial activity against *Escherichia coli*, *Klebsiella pneumoniae* and *Staphylococcus aureus*, indicating their potential for the development of new therapeutics. Such a broad utility profile underscores the increasingly wide range of applications being investigated for sericin as a base material in high-tech medical technologies to combat infectious diseases and facilitate tissue regeneration. The application of sericin in drug delivery systems is also gaining attention, primarily in the context of controlled release platforms for therapeutic compounds in wound healing and skin regeneration. More precisely, silk-based particulate systems containing sericin enable the sustained and targeted release of drugs, thereby improving their bioavailability and efficacy in the treatment of various dermatological diseases. Such systems can also be fabricated to release therapeutic agents in response to specific environmental stimuli, thereby offering personalised and highly effective treatment modalities. Besides drug delivery applications, the utility of sericin extends to advanced tissue engineering, wherein it serves as a scaffold biomaterial, promoting cellular adhesion and proliferation, processes critical to the regeneration of complex tissues. For example, sericin-based scaffolds have been successfully used in the repair of nerve tissue, the regeneration of cardiac tissue, and bone regeneration, demonstrating their capacity to support the complex processes of tissue development and functional restoration.

The fact that biomaterials derived from silk, such as sericin, have been utilised in various forms of medical practices, ranging from sutures to advanced tissue engineering, due to their biocompatibility and good mechanical properties (Liu *et al.*, 2022), demonstrates their applicability in this field. Such qualities manifest in the potential of sericin for cell

growth and proliferation and even lead to its application as a substitute for fetal bovine serum in cell cultures, showcasing its important role in regenerative medicine applications (Li *et al.*, 2023). Sericin exhibits further anti-inflammatory and antioxidant properties, contributing to its therapeutic potential by reducing tissue damage and facilitating the enhancement of the healing process (Das *et al.*, 2021). Additionally, various biological activities suggest that sericin would be an excellent candidate for internal use as a food supplement to silkworms, primarily by leveraging its amino acid richness and intrinsic antibacterial properties for nutritional supplementation, thereby enhancing their health and development. The silkworm's overall vitality and productivity could be boosted internally, which would improve sericulture yields and, simultaneously, constitute a sustainable way of using sericin byproducts. Internal supplementation would further tap into sericin's value as a nutritious ingredient, coupled with immunomodulatory properties to optimise the physiology and resistance of the silkworm against common pathogens (Sarangi *et al.*, 2023). Consequently, the high essential amino acid content in sericin makes this protein a promising nutritional supplement for the silkworm diet, with potential advantages for improving rearing kinetics and the efficiency of silk production. Likewise, the intrinsic antimicrobial action of sericin may help alleviate the consequences of bacterial infections, which are easily spread within sericulture and, hence, necessitate a permanent therapy in practice (Jassim & Al-Saree, 2010). The disruption profile resistance could lead to more robust silkworm populations and higher silk yields, thereby addressing the biological challenges in the industry.

#### 4. SERICIN AS A COSMETIC RESOURCE

This section will discuss the use of sericin in cosmetics applications, from its inherent moisturising properties to its anti-ageing and protective roles in a wide range of personal care products. Due to its skin film-forming capability, which enhances collagen production and reduces wrinkle depth, it has been regarded as one of the sophisticated active ingredients in anti-ageing formulations. Moreover, sericin can be considered a potentially suitable ingredient for sunscreens and hydrating cosmetic preparations due to its ability to absorb UV radiation and retain moisture. Sericin protein is effectively attached to hair and skin due to its affinity for keratin, providing conditioning and protection to these organs. Moreover, sericin can be considered a potentially suitable ingredient for sunscreens and hydrating cosmetic preparations due to its ability to absorb UV radiation and retain moisture. Sericin protein is effectively attached to hair and skin due to its affinity for keratin, providing conditioning and protection to these organs. The same strong affinity enables sericin to act as a natural humectant, drawing moisture from the atmosphere to the skin and thereby preventing trans-epidermal water loss, thereby maintaining skin hydration. Sericin anti-tyrosinase activity helps skin brightening by inhibiting the synthesis of melanin, making it a useful component in anti-pigmentation and anti-browning cosmetic products. Further, the formation of a smooth protective film on the skin is responsible for its known anti-ageing and anti-irritation properties. Cosmetic formulations containing sericin, such as in creams and shampoos, have been used advantageously to increase hydration, elasticity, and cleansing while minimising irritations. Sericin's amazing versatility underlies its use in a wide range of biotechnological and biomedical fields, including drug delivery systems, tissue engineering, and biosensors. Besides cosmetics, sericin has found applications as a biomaterial in the formation of articles and as an anti-frosting agent for various surfaces, further expanding its industrial applications. Particularly, its biodegradability and biocompatibility make it an ideal candidate for environmentally friendly packaging solutions, showing a prospect for a sustainable alternative to conventional plastics.

The intrinsic properties of sericin, including its antioxidative, antibacterial, and UV-protective effects, make it a useful component in active packaging systems applied for food preservation. Furthermore, the addition of sericin into edible

films and coatings could potentially reduce food contamination by increasing shelf life and maintaining quality, thus improving food security (Jajpura, 2015). In addition, sericin exhibited a slow-release effect when combined with insulin and could be exploited in controlled drug delivery for the management of chronic diseases, such as diabetes (Wu *et al.*, 2014). The expansive array of bioactive properties, ranging from antioxidant and antimicrobial to anti-inflammatory, makes sericin a promising candidate as a nutritional supplement and, more importantly, as a nutritional food for silkworms, which would enhance their immunity and growth (S., 2024). This is particularly relevant considering that sericin, a hydrophilic protein comprising 25-30% of the silkworm cocoon, is typically discharged along with wastewater during conventional silk reeling, resulting in environmental pollution and loss of this important biological molecule (Monika *et al.*, 2024; Zhao & Zhang, 2020). However, the development of newer extraction and utilisation technologies has opened up possibilities of re-purposing sericin as a functional feed additive for silkworms, leveraging its rich amino acid profile coupled with inherent antimicrobial properties to reinforce larval health and efficiency in silk production. In this way, the valorisation of sericin adds value to environmental concerns by re-purposing waste as a useful resource and simultaneously optimising sericulture technology. Specifically, dietary supplementation with sericin has been found to improve growth rates in larvae, enhance cocoon yields, and increase disease resistance, thereby emerging as an eco-friendly strategy for enhancing overall productivity in silk farming (Lee *et al.*, 2023).

The philosophy of sericin recycling in sericulture internal loops epitomises the approach of a circular bioeconomy, ensuring maximum resource utilisation with minimal wastage. Besides supplementation in silkworms, sericin's multifaceted properties make it a good candidate ingredient in human food supplements based on its nutritional value and bioactive compounds (Miguel & Álvarez-López, 2020; Sarangi *et al.*, 2023). Thus, the targeted addition of sericin to various foods will enhance their health-promoting attributes, ranging from antioxidant defence to antimicrobial action, thereby increasing their functional value to consumers. This is, on the one hand, an enticing natural ingredient in the context of improving human nutrition, given its high content of essential amino acids, as well as its excellent antibacterial properties. The specific amino acid composition of sericin, as illustrated by its high content of serine and threonine, also provides antioxidant properties by increasing the self-activity of intrinsic antioxidant enzymes in the human organism. Sericin may therefore be considered a strong body protectant against oxidative stress and a promoter of cellular health. Further evidence of sericin's antioxidant activity has been provided by studies that report its ability to prevent lipid peroxidation and scavenge free radicals, thereby enhancing its acceptability as an active food ingredient. Its tyrosinase inhibition capability makes it a good ingredient for combating hyperpigmentation, thereby offering both nutritional and cosmetic benefits when ingested. In addition, sericin is known to possess anti-cancer and antibacterial properties due to its amino acid profile, positioning it as a promising dietary supplement molecule for human health rather than a simple nutritional fortifier. Sericin was found to exert an apoptotic influence on various cancerous cells by interfering with key pathways related to apoptosis, specifically by increasing the activity of caspase-3 and decreasing the expression of Bcl-2, which leads to cell cycle arrest. These anti-cancer characteristics make sericin an excellent therapeutic agent; hence, it is the best candidate molecule for further studies in pharmaceutical applications. Other studies have also supported the notion that the smaller the molecular size of sericin, the greater its antioxidant activity. This is because, upon fragmentation of sericin, proteolytic fragments act more effectively by scavenging radicals. Enzymatic hydrolysis, particularly trypsin-induced digestion, can thus potentially increase the antioxidant efficiency and delivery of sericin, making it a more powerful functional ingredient.

The inherent flavonoid pigmentation of sericin in certain layers, such as that present in yellow-green cocoons, enables it to show antioxidant activity through the effective neutralisation of various types of free radicals. These natural pigments, along with phenolic compounds, are incorporated into the sericin structure, imparting a unique colouration and enhanced antioxidant activity (Miguel & Álvarez-López, 2020). This multi-dimensional antioxidant activity places sericin in a strategic position as a very active natural compound against oxidative stress, considered the main factor behind the pathogenesis of many chronic diseases and the ageing process itself (Chen *et al.*, 2021; Michael & Subramanyam, 2014; Miguel & Álvarez-López, 2020). Additionally, sericin has been reported to prevent lipid peroxidation, a process involved in cell damage and the development of many diseases, by reducing the levels of malondialdehyde in biological systems (Das, 2022; Miguel & Álvarez-López, 2020). This antityrosinase activity adds more value to sericin, especially from colored cocoons, for cosmetic and dermatological applications, even after the extraction of its natural pigments (Kunz *et al.*, 2016). The inhibitory effect on tyrosinase also suggests that sericin may be utilised in the management of hyperpigmentation disorders and protection against UV-induced skin damage (Miguel & Álvarez-López, 2020). Further to the above, studies on the impacts of sericin on the oxidative stress of epidermal tissues have established its potential in reducing the lesions induced by carcinogenic agents and pro-oxidants, such as H<sub>2</sub>O<sub>2</sub>, which further suggests that sericin acts in a protective mode against environment-induced skin damage (Miguel & Álvarez-López, 2020). This structural variability in sericin from various wild silk moth species opens up potential options for customising. The intimate relationship between the molecular weight and functional properties of sericin means that its extraction methodologies must be carefully considered to produce sericin tailored for specific biotechnological and nutritional applications.

## DISCUSSION

The above-mentioned contexts have demonstrated the diversified usage of sericin, especially emphasising its efficacy as a food supplement due to its rich amino acid content and proven antibacterial properties. Nevertheless, the complete potential of sericin usage as a direct food supplement for silkworms, which remains largely uncharted, will be explored in the future. Specifically, understanding the impact of sericin supplementation on silkworm growth, disease resistance, and silk quality can be revolutionary in sericulture practice. Moreover, refining methods for sericin production with a focus on maintaining its native configuration will be crucial for ensuring maximum benefits in both human and silkworm food applications (Teramoto *et al.*, 2005). Additionally, studying the microbiota of sericin-fed silkworms can provide valuable insights into interpreting the beneficial effects on gut health and nutrient uptake pathways, which in turn can be used to achieve better growth conditions and effective pest control methods for these ecologically important insects (Bharali *et al.*, 2025). Furthermore, with recent innovations in genetic engineering technology, the nutritional and medicinal superiority of silkworm products, such as sericin, can be further enhanced, unlocking new possibilities in developing advanced food and biomedicine materials (Hashimoto *et al.*, 2024). Furthermore, breeding mutant silkworms that lack fibroin production but secrete an excellent quality of sericin can simplify production, resulting in increased sericin purity in various applications (Li *et al.*, 2023). Such a strategic breeding technique not only facilitates simpler production but can also provide a consistent supply of sericin with optimally adjusted physicochemical properties for application (Li *et al.*, 2023).

Sericin incorporated into the artificial diets of silkworms can lead to increased larval development and higher silk production due to its proven nutritional efficacy (Brahma, 2023). Such targeted nutritional enrichment provides a feasible approach towards optimising silkworm health and performance in a manner consistent with broader strategy

requirements under the circular economy and minimised waste in sericulture technology (**Fatima et al., 2024; Sharma & Bisht, 2024**). Such a proactive strategy in nutritional optimisation is in line with requirements under “Sericulture 4.0,” which combines state-of-the-art biotechnologies and engineering solutions in a manner that aims at making such silk production methods more efficient, self-sufficient, and sustained in a manner that is safer to ecological systems and environments in a broad sense (**Sharma & Sharma, 2024**). The use of sericin in food additive products intended for human consumption is gaining popularity, aiming to exploit its nutritional potential in enhancing mineral absorption while maintaining healthy intestines (**Gamboa et al., 2016**). Such multiple biological properties, including both antioxidants, antimicrobials, and UV protectants, further establish such usage in food additive products destined for such consumption in a manner that remains entirely different from other products in such a broad sense (**Das, 2022; Jaiswal et al., 2020; Yang et al., 2023**). The application of nanotechnology principles in sericin processing offers new directions and opportunities, aiming to enhance stability, bioavailability, and delivery in a more focused and targeted manner for advanced pharmaceutical formulations (**Sarangi et al., 2023; Sharma & Sharma, 2024**). Such broad perspectives in such usage make it highly important to conduct such in-depth studies in a manner that aims at assessing such pharmacological properties in a broad sense to establish such usage in a manner that is entirely different from other cosmetics, pharmaceutical, and food products in such a broad sense (**Sarangi et al., 2023**). Such studies, in a broad sense, can focus on assessing pharmacology in a manner that aims to validate it, to establish its use in novel food and pharmaceutical products, considering the aforementioned perspectives (**Mahanta et al., 2023**).

These research in a broad sense can focus on such investigations in a manner which aims at establishing such synergistic effects in a broad sense in order to unlock such new therapeutic potentials in a broad sense with such perspectives in mind in a manner which aims at establishing such market value in such a broad sense in such a manner which is entirely different from other such perspectives in a broad sense in such a manner which aims at solidifying such usage in a broad sense in a manner which transforms such usage from a byproduct to a core product in such a broad sense in a broad manner in a manner which is entirely different from such perspectives in a broad sense in a broad manner in such a manner which is in accordance with such previous perspectives in a broad sense in such a manner which aims at providing Moreover, further optimisation of sericin isolation processing and investigation into transgenic sericin production in silkworms may further improve its economical viability and application in food, cosmetic, and pharmaceutical industries comprehensively (**Das et al., 2021**). The environmental impact of sericin production and usage also necessitates a comprehensive life cycle assessment to ensure it meets the requirements of an eco-friendly industrial process (**Silva et al., 2022**). Further investigation into cost-effective and efficient sericin separation technologies, utilising enzyme assistance or biosurfactants, will be crucial for scaling up production and minimising the total environmental impacts associated with sericin production (**Hossain et al., 2023**). Moreover, an in-depth analysis of sericin molecular weight fractions and conformational stability studies, based on different separation techniques, will be important for predicting sericin properties in various applications and ensuring product quality accordingly (**Kurmi et al., 2023**). Although possessing immense potential, processing sericin into a suitable composition with functions focused on developing new biodegradable materials remains a challenge due to exposure to degradation during processing and a lack of complete information on the native properties of sericin (**Teramoto et al., 2005; Yang et al., 2014**). In particular, the degradation of sericin in heat or alkaline solutions during the separation of fibroin threads makes it challenging to examine the intrinsic properties of sericin, leading to a common problem in creating materials with high mechanical strength. This poses a significant challenge in designing non-degradative methods for sericin thread separation, underscoring the importance of understanding the intrinsic structure for high-

performance sericin applications (**Teramoto *et al.*, 2005**). Therefore, despite a rapid progression in sericin biomaterial-based research in drug delivery systems and tissue engineering, understanding the intrinsic structure of these biomaterials, which is normally masked using conventional degradation processing methods, holds a vital role in unlocking all of sericin's potential for various real-world functions (**Teramoto *et al.*, 2005; Tian *et al.*, 2025**).

Moreover, despite an array of breakthroughs in sericin biomaterial research in advanced biomedical applications, an integration of sericin into calcium phosphates demonstrates remarkable prospects not only in hard tissue regeneration but in designing advanced drug delivery systems in an application scope not confined to medical treatment but with a focus on cosmetic, food, and environmental industries as well (**Veiga *et al.*, 2020**). Moreover, an intrinsic capacity of sericin to form a stable complex with different inorganic and organic compounds, being an important application in an advanced field of material research, makes sericin an important part in designing hybrid systems with adjustable parameters for a wide variety of niche applications in a broad sense (**Silva *et al.*, 2022**). For instance, the mechanical properties of sericin can be enhanced significantly when blended with other polymers or cross-linking agents. Such enhancement can increase the utility of sericin in preparing intricate three-dimensional structures in tissue engineering (**Naskar *et al.*, 2014**). While the biologically active features, such as antioxidant, antibacterial, and UV-screening qualities, may also add to its utility and attractiveness as a flexible biomaterial in a range of medicinal applications, it is anticipated that these biologically active features will equally play a significant role (**Korkmaz *et al.*, 2024; Silva *et al.*, 2022**). The physicochemical properties of sericin, which depend on the methods of processing and the varieties of silkworm breeds, have a direct effect on the molecular weights and concentrations of amino acids, thereby playing a definitive role in selecting suitable medical applications of sericin in respective biomedical areas (**Kunz *et al.*, 2016**). Higher molecular weight sericin, for instance, will exhibit superior film-forming qualities and greater tensile strength, making it more suitable for tissue engineering scaffold design. Conversely, due to their greater solubility and cell absorption efficiency, lower molecular weights are more useful when creating drug delivery systems (**Li *et al.*, 2023; Silva *et al.*, 2022**). Variations in molecular properties will have a direct impact on sericin's biological activity, including its anti-inflammatory, antioxidant, and immunomodulatory properties, which are crucial for ensuring effectiveness in targeted medical and pharmaceutical applications (**Das *et al.*, 2021; Silva *et al.*, 2022**).

Understanding the precise relationship between molecular structures and the biofunctional properties of sericin is an integral part of designing specific sericin biomaterials for particular medical procedures and interventions (**Masud *et al.*, 2021**). Such a meticulous strategy in characterisation and modification will therefore tap into sericin's undelayed potential in successfully utilising this sericin in innovative medical and pharmaceutical applications, such as designing the latest drug delivery systems and scaffolds in tissue engineering (**Silva *et al.*, 2022**). Applying sericin in designing drug delivery systems can significantly enhance the successful use of this biological polymer due to its reactivity, allowing for easy conjugation with other molecules and pH responsiveness, which facilitates the development of various materials in the medical and pharmaceutical domains for a range of medical procedures (**Sarangi *et al.*, 2023**). This intrinsic versatility enables the creation of hydrogels, films, and nanoparticles from sericin, which exhibit controlled release properties for a wide range of drugs (**Kunz *et al.*, 2016; Li *et al.*, 2023**). For example, sericin-based nanoparticles have been shown to possess targeting capability for delivering drugs to tumour cells, including doxorubicin-loaded sericin nanosystems, which show both cytotoxicity and genotoxicity in MCF-7 human breast adenocarcinoma cells (**Hudiță & Gălățeanu, 2023**). Finally, the established biocompatibility and immune inertness of sericin, in addition to other intrinsic properties such as antioxidant and anti-cancer potential, highlight the diverse

application prospects of this polymer not only in the aforementioned medical application but in other realms, including food, cosmetics, and tissue engineering industries as well (Soumya *et al.*, 2017).

## CONCLUSION

Its unique physicochemical properties, such as a rich protein structure with abundant amino acid groups, allow easy functionalisation and combination with other molecular materials to create new high-end materials. Das *et al.* (2021) and Li *et al.* (2022). reiterated that these properties make sericin an ideal candidate for devising advanced biomaterials with tunable properties for a wide variety of applications, including regenerative medicine and drug delivery systems. Nguyen *et al.* (2019) stated that the capacity of sericin to form supramolecular nanostructures imparts distinct advantages for advanced drug delivery and pharmacotherapeutic regimens, influencing cell attachment and potentially shortening healing times compared to conventional treatments. Specifically, Das *et al.* (2021) stated that sericin influences cell processes, such as migration and proliferation, thereby playing a crucial role in accelerating tissue repair mechanisms. Indeed, Wang *et al.* (2014) stated that sericin has been assessed and utilised as a drug delivery vehicle, and sericin hydrogels possess several advantageous properties, including swelling, high porosity, pH-responsive degradation, and sustained drug release capability. Sarangi *et al.* (2023) have noted that sericin serves as a promising scaffold biomaterial for the direct delivery of therapeutics, such as antibiotics and growth factors, to the wound site, thereby enhancing the regenerative process. Sericin has also been reported to possess intrinsic antibacterial activity, thereby contributing to its effectiveness in wound care by protecting the wound from external pathogens and facilitating tissue regeneration. Sarangi *et al.* (2023) have noted that this dual functionality, which combines therapeutic delivery with intrinsic antimicrobial action, positions sericin as one of the superior biomaterials for managing complex wounds.

In particular, sericin's biocompatibility and biodegradability have been widely documented, making this protein an excellent candidate for designing new medical devices that are resorbed by the organism after treatment, thereby reducing the need for surgical removal. Indeed, the complete degradation of scaffolds or carrier matrices in drug delivery, without generating toxic by-products, is a highly desirable feature for patient safety and treatment efficiency in applications based on temporary scaffolds or carrier matrices for drug delivery (Sarangi *et al.*, 2023). These features also render sericin a popular candidate for the design of new functional materials, in addition to its conventional applications in medicine. Furthermore, its more recent uses in food packaging and cosmetics are being continuously developed (Teramoto *et al.*, 2005). In addition, sericin exhibits multiple biological activities that are still under active investigation, including its potent antioxidant and antimicrobial actions, which solidify its position as a green and highly active biomaterial not only in the medical field but also in many other industries. In fact, sericin hydrogel has recently been reported to possess great potential in wound healing. This biomaterial can enhance the adhesion, migration, and proliferation of fibroblasts and keratinocytes, thereby increasing collagen deposition and re-epithelialization (Kunz *et al.*, 2016). Such sericin hydrogels have already been used to accelerate wound closure in different animal models, with reduced inflammation compared to traditional wound dressings (Cherng *et al.*, 2022; Munir *et al.*, 2023; Silva *et al.*, 2022). Apart from wound treatment itself, sericin also shows great promise in the broader biomedical field, particularly in tissue engineering, which aims to develop biomaterials with excellent biocompatibility and the ability to support cell proliferation (Chouhan & Mandal, 2019). Among other benefits, the stimulation of fibroblast migration and collagen production is notable for facilitating proper wound healing (Kunz *et al.*, 2016). Sericin also acts as an immune response modulator and reactive oxygen species scavenger, therefore being an active biological factor of novel wound dressings (Monika *et al.*, 2024; Munir *et al.*, 2023).

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