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ORIGINAL ARTICLE

A Review on Potential Applications of Sericin, and its Biological, Mechanical, and Thermal Stability Characteristics

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ABSTRACT – Because of its adequate biological and mechanical properties, sericin has been considered for different applications. Sericin is found to have anti-tumoral properties against colon cancer, mechanical properties, as well as anticoagulant and cryoprotective properties. According to these findings, sericin is a significant component of the health industry. Silk sericin exhibits biodegradability, non-toxicity, oxidation resistance, UV resistance, and moisturizing characteristics. The present review is mainly focused on considering the mechanical and biological characteristics of silk sericin, as well as its applications in many industries, especially in the medical industry. In addition, one of the most notable limitations of sericin forms in many application fields is their lack of mechanical properties. Better crystallinity and a longer molecular chain result in improved mechanical properties. Additionally, mechanical properties are influenced by the macromolecular structure, notably porosity. The textile silk procedure has the ability to influence the features of sericin samples, such as thermal stability and structure. Therefore, the present study reviews the past works on the improvement solutions of the mechanical characteristics of sericin.

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INTRODUCTION

The fibroin and sericin components of silkworm cocoons are being studied in depth for wound healing, drug delivery, and other purposes [1]. Sericin is mainly amorphous, more water-soluble, and works as a gum binder to retain the structural integrity of the cocoon [2]. Since sericin is a hydrophilic (soluble in hot water) protein, it may be removed or separated from fibroin using a simplified thermochemical technique known as 'degumming' [3]. Removing sericin from silk can be accomplished in a variety of ways. High-temperature, whether or not combined with high pressure by autoclaving; acidic, primarily citric acid solution; alkali, using sodium carbonate solution; and urea [4],[5]. The separation technique affected sericin's solubility, molecular weight, and gelling properties [6]. Sericin has been studied for a variety of potential uses due to its remarkable biochemical and biophysical characteristics. The cosmetics and food industries, as well as biomedical coating materials for anticoagulants, drug delivery, anticancer treatments, and tissue engineering, are examples of these products. Sericin stimulates cell proliferation when used as a component of cell culture in a serum-free medium. In addition, when sericin is applied in pure form and/or mixed in matrices, sericin promotes cell adhesion and proliferation. Future solutions for these requirements include sericin film, 3D scaffold, nanoparticle, composite, conjugated drug, and recombinant sericin [7]. Many studies have been carried out on silk sericin properties. Dong et al. [8] investigated the hypoglycemic effects and methodology of sericin protein from silk-processing waste supplemented to the regular diet at 0.8% (g %) level fed orally to type 2 diabetic (T2D) mice. Silk sericin hydrolysate, prepared by boiling a 0.025 percent calcium hydroxide solution, is the oral protein. The protein reduced fasting blood glucose, and fasting plasma insulin, significantly improved oral glucose and insulin tolerance, and promoted anti-oxidative activity. Dihan et al. [9] observed the physicochemical and biological characteristics of industrially manufactured silk-based products in comparison to regenerated silk fibroin to investigate the possible applications in biological and therapeutic domains. When compared to regenerated silk fibroin, the results indicated that sericin might be the most appropriate silk material to employ as an effective solution in tissue engineering. Fatahian et al. [10] studied the extraction of sericin from silk gum effluent solution as well as the characteristics of extracted sericin. They also investigated the antibacterial effects of sericin in bacterial models. The findings of this study revealed that sericin could be separated from gum effluent and therefore has antibacterial characteristics. Li et al. [11] revealed the production and use of a carbon nanotube/sericin nerve conduit with electrical conductivity and mechanical capabilities favorable for nerve healing. They demonstrated that an electric conductive CNT/sericin conduit paired with electrical stimulation has the potential to be a novel approach for repairing transected peripheral nerves.

According to the existing literature, there are only a few studies on the biophysical and mechanical properties of silk sericin, as well as its potential in a variety of areas, particularly the medical industry. In addition, one of the major limitations of sericin forms in many application fields is their lack of mechanical characteristics. Therefore, the present

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study reviews previous studies on approaches for enhancing the mechanical properties of sericin. This valuable and cost-effective substance may be utilized in a wide range of industries by recognizing sericin possibilities and enhancing solutions.

MECHANICAL PROPERTIES OF SERICIN

Mechanical properties

Sericin contains different amino acids, the most important of which are serine, aspartic acid, and glycine [12]-[15]. This protein also contains hydroxy amino acids (serine and threonine), polar amino acids, and non-polar amino acids [16],[17]. Sericin is beneficial due to its unique properties including antioxidant, anti-bacterial, Anti-elastase, UV protection and absorption and releases moisture easily, blood coagulation, mechanical properties, gel properties, anti-inflammatory, anti-tyrosinase, Anti-tumor, etc. [18]-[21]. In many applications, one of the major drawbacks of sericin forms is their lack of mechanical properties. As a result, various studies have been done to improve sericin's mechanical characteristics. On the other hand, past studies have adopted simpler and easier methods to augment mechanical properties [22]. Sericin, for example, has additives such as sorbitol [23], graphene oxide [24], glycerin, poloxamer [25], and glycerol. Although this is a simple process, it is ineffective since the addition of additives may modify the unique features of sericin, making biological applications more complex.

The combined influence of numerous variables can explain the improvement in sericin's mechanical properties: 1) sericin molecular weight, 2) sericin crystallinity, and 3) porosity web, film, sponge, etc. Silk protein's molecular weight (MW) has a significant impact on its characteristics. Different extraction methods might result in sericin samples with different MWs. The MW of a polymer influences the viscosity of a solution because a longer polymer chain length causes a higher degree of molecular entanglement, which raises the viscosity of the solution [26]-[29]. In a silk sericin, a longer molecular chain length and greater crystallinity result in superior mechanical characteristics. Furthermore, the macromolecular structure, namely its porosity, has an impact on mechanical characteristics (or bulk density). As the porosity decreases, the density increases due to the strength and strain of the porous material.

Jo et al. [30] utilized sericin solutions and films using formic acid, a novel solvent. The impacts of formic acid on the structural and mechanical characteristics of sericin solutions and films were investigated and compared to those of water. The sericin/formic acid solutions had fewer aggregated sericin molecules than the sericin/water solution, resulting in lower turbidity. Furthermore, when compared to water, the gelation of the sericin solution was delayed in formic acid. The tensile strength and elongation of sericin films cast from formic acid solution were more than double that of water-cast sericin films. Park et al. [22] studied the mechanical properties and structure of silk sericin. gel, sponge, and film are affected by MW. In their investigation, the swelling ratio decreased as the MW of sericin raised and the porosity of the sericin sponge decreased. Their results revealed that changing the MW of sericin might control various characteristics of sericin types, possibly improving biomedical and cosmetic applications. Likitamporn and Magaraphan [31] studied the thermal and mechanical characteristics of a sericin/PVA/bentonite scaffold experimentally. The thermogravimetric test was employed in their investigation to explore the effect of sericin and chemical cross-linking on thermal stability. The addition of sericin to scaffolds considerably enhanced both thermal and mechanical properties when compared to scaffolds without sericin. By increasing the sericin content, the mechanical and thermal characteristics might be improved even more.

Ultraviolet (UV) protection and thermal stability

The skin protects against microbes, pollutants, ultraviolet (UV) radiation, and thermal or mechanical factors [32]. Chronic UV radiation exposure, on the other hand, increases reactive oxygen species (ROS) formation, which causes inflammation, photoaging, erythema, and skin cancer [33],[34]. As a result, UV radiation protection for the skin is critical for mitigating UV radiation-induced oxidative damage [35],[36]. Silk sericin is a glycoprotein that aids in cocoon production and protects the pupa and fibroin from UV-induced oxidative damage [37]. Sericin was found to be beneficial in minimizing skin oxidative stress [38], preventing UVB-induced apoptosis [39], and absorbing UVC radiation [40] in a study evaluating the photoprotective capabilities of Bombyx mori.

According to Kumar et al. [41], silk sericin derived from A. assamensis cocoons protected human keratinocytes and female SKH-1 hairless mice against UV radiation-induced oxidative damage. In another investigation, Kumar et al. [42] investigated the inhibitory potential of Silk sericin against UVR-induced melanogenesis. In UVA and UVB irradiated melanocytes, silk sericin extracted from the cocoons of Philosamia ricini sericin (PRS) and Antheraea assamensis sericin (AAS) reduced mushroom tyrosinase activity and downregulated melanin production. In both UVA and UVB irradiated cells, AAS pretreatment dramatically reduced tyrosinase expression. As a result, in vitro investigations revealed that AAS effectively prevented UVR-induced melanogenesis by scavenging ROS and decreasing intracellular tyrosinase activity.

The textile silk process has the potential to influence the characteristics of sericin samples, such as their thermal stability and structure [43]. Furthermore, the thermal stability of different kinds of sericin varies. In a Thermogravimetric analysis, Sahu et al. [44] assessed the mass stability of sericin concerning time and temperature fluctuations. Moreover, the temperature stability of sericins derived from mulberry and non-mulberry silkworms was examined. Non-mulberry sericins were indicated to be more stable than mulberry sericin. The highest stability was referred to as sericin. Kim et al. [45] used several instrumental analyses to investigate the structural and thermal characteristics of sericin extracted by sodium carbonate. They concluded that sericin had a wide endothermic peak at approximately 220° C (Figure 1).

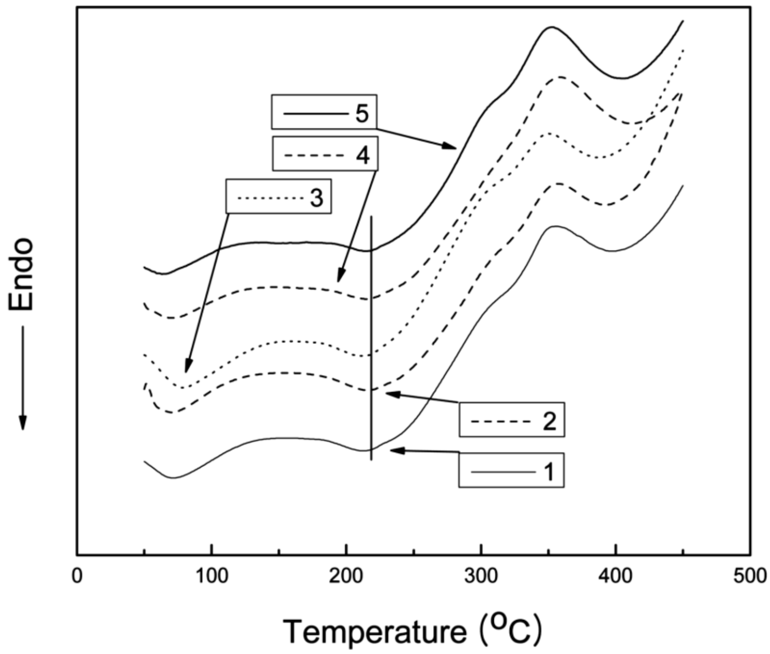

Figure 1. Circular dichroism (CD) spectra of sericin [45].

BIOLOGICAL PROPERTIES OF SERICIN

Antioxidant and antibacterial properties

Many studies investigated the antioxidant characteristics of silicon sericin. Nowadays, antioxidants have gained increased attention, owing to the findings on the influence of free radicals in the body, which have significant consequences if their contents are not neutralized by an appropriate antioxidant system [46],[47]. These pigments contain biological effects such as antioxidants and antityrosinase. Sericin antioxidant capabilities may be related to its high serine and threonine content, which contain hydroxyl groups that function as chelators for trace elements like copper and iron [48]. Dash et al. [39] investigated the antioxidant and photoprotective properties of Antheraea mylitta sericin in irradiated human keratinocytes. According to flow cytometry studies, previous treatment with sericin inhibited UVB-induced apoptosis. They concluded that sericin is a highly effective antioxidant and antiapoptotic agent. Silk sericin has antibacterial properties. Sericin stimulates bacterial cell membrane blebbing, which inhibits bacterial growth and reproduction [49]-[51]. When employed as a cover over test tubes containing nutritional broth, a nanofibrous mat containing sericin revealed zero microbial penetration [52].

Sericin's antibacterial properties were affected by its purity and extraction process. Rocha et al. [53] revealed that pure sericin, which is commercially available, is active against S. aureus in a similar way to antibiotics, but has extremely poor action against P. aeruginosa and S. aureus. Sericin can be combined with other antibacterial bioactive molecules to augment its activity and improve biomaterial characteristics. To further improve the antibacterial and other biological features, the biomaterials established from sericin cocoon have been combined with other biopolymers for example; chitosan nanofiber or film [54], or chemical agents such as silver nanoparticles [55], zinc oxide nanoparticles, and antibiofilm titanium [56].

APPLICATION OF MECHANICAL AND BIOLOGICAL PROPERTIES

Because of its different biological and mechanical properties including antibacterial, antioxidant, anti-tumor activity, Ultraviolet resistance, absorbency, thermal stability, and so on, silk sericin may be used in the textile, cosmetics, hygiene, and other fields which are reported in previous studies. Table 1 presents some of the applications for silk sericin.

Table 1. Sericin application

Industry	Application	Reference
Biomedical, pharmaceutic	• Antitumour Effect in different cancer • Metabolic Effects (In Gastrointestinal Tract, In the Circulatory and Immune Systems On Lipid Metabolism and Obesity) • Tissue Engineering • Skin repairment • Contact lenses • Matrix for implants • Vehicle for cell amplification • Stabilizer in vaccines • Drug delivery • Wound healing	[57]-[62]
Cosmetic	Skincare: Skin elasticity, Anti-wrinkle, and Anti-aging influence, UV protection impact Nailcare: Prevents cracks, brittleness, and raises the inherent brightness Haircare: Conditioner and prevent hair damage Gel: Moisturizing property Powder: Moisture absorption capacity and anti-dermatitis	[63]-[69]
Food	Combat constipation and obesity To enhance the taste and touch of porridge Beverage rich in amino acids In greasy foods Prevents browning reactions in a variety of ingredients Antioxidants used in dairy products Mineral absorption is accelerated Additive as a nutrient Antioxidant and suppressant of colon tumors	[70],[71]
Textile	In fabrics to absorb moisture Cleaning fabrics Improved antibacterial activity Fabricated nanofiber UV protection textiles Medical textiles	[70]-[73]
Other	Treating industrial wastewater with adsorptive pollutants Air filter products Anti-frosting agent for roads and roofs Artificial leather product Art pigments	[73]-[75]

SERICIN APPLICATION IN MEDICAL INDUSTRY

Sericin is employed in the pharmaceutical industry for various drug applications, such as solubility improvement, diffusion modification, and formulation stabilization [58], [76]-[79]. Sericin is an antioxidant as well as an anticoagulant. These qualities inspired the development of a variety of research to incorporate them into the medical field [7]. Sericin's antioxidant activity has the potential to provide significant health advantages. Consumption of sericin-containing foods helps alleviate constipation, reduces the growth of bowel cancer, and improves mineral absorption, including zinc, iron, magnesium, and calcium [80],[81]. In particular, sericin is a biological material with applications in wound dressing [82]-[84], contact lenses, blood vessels, artificial skin, and other prostheses [13]. Sericin has an antithrombotic effect when sulphonated. It is also antibacterial [83], collagen-producing, hydrophilic, and biocompatible. As a result, sericin possesses wound healing characteristics and may be utilized as a wound covering material in the form of a sericin powder-containing film or cream [85],[86]. Verma et al. [88] developed a hydrogel that included sericin/chitosan-capped silver nanoparticles. They observed that the treated hydrogel was nonirritant, a potential wound healer, and had an attractive appeal for increased patient compliance. Aramwit and Sangcakul [89] investigated the effect of sericin on wound healing and wound size reduction by producing two skin wounds on the dorsum of rats. Figure 2 illustrates the time necessary to complete wound healing at 50% and 90% in rats. The time required for 90% healing from sericin wounds was significantly less than that required for cream base-treated wounds (11 vs 15 days). They reported that sericin wounds had far fewer inflammatory responses and a significantly greater reduction in wound size than the control.

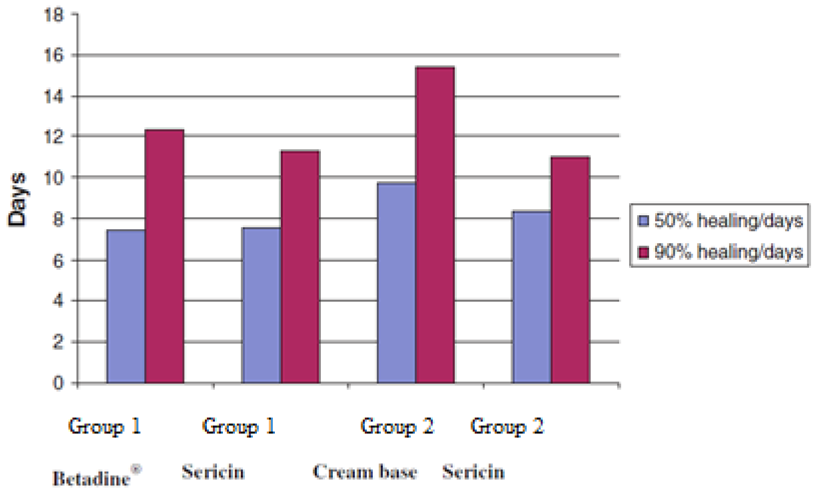

Figure 2. Impact of different cream types on wound healing in rats for two groups [89].

SERICIN APPLICATION IN VARIOUS INDUSTRIES

Recently, the Food and Drug Administration has approved sericin and its variants as GRAS (Generally Recognized as Safe) additives. This protein's key feature is its antioxidant effect; as a result, it has been recommended as a functional food [90]. Sericin can be employed in the manufacture of fortified meals and nutritional supplements since it aids in the fermentation and prevention of modular processes, as well as increasing mineral absorption and antioxidant activity, all of which contribute to improved health. Furthermore, sericin's antioxidant and emulsifying properties make it a viable element in salad dressing [91]. Sericin characteristics such as biocompatibility, biodegradability, and wettability have been used alone or in combination with silk fibroin in the skin, hair, and nail cosmetics. When used in lotions, creams, and ointments, sericin improves skin elasticity, anti-wrinkle, and anti-aging effects. Moisturizers have been designed specifically for preventing and delaying the drying of the skin's top layer. Because sericin absorbs UV radiation, it might be used as sunscreen [92],[93]. Other applications include compounds that absorb sweat and fat secreted by the skin's sebaceous glands. Sericin has the potential to change the surface of fibers and textiles. It was employed as a coating material for cellulose fibers and wool. The treated fabrics demonstrated reduced free formaldehyde content, electrical resistance, skin irritation, allergic responses, improved water retention, water absorption, and enhanced antibacterial capacity, with only a small drop in textile tensile strength. Recently, considerable research has been conducted on the successful use of sericin for the finishing of textile substrates. This is regarded as a potential solution for silk mills to address the issues of sericin recovery and wastewater treatment [91].

CONCLUSION

The main purpose of the present research is to review some of the applications of sericin in different industries and its mechanical and biological properties. One of the major drawbacks of sericin forms in many fields is the weak mechanical properties. Hence, this paper reviews the current solutions for enhancing the mechanical properties of sericin. Previous studies demonstrated that since sericin is a substance with various mechanical and biological properties including hydrophilicity, antioxidant, anti-cancer, blood coagulation, UV protection, biodegradation, and biocompatibility, this would make it possible. In order to achieve better their antibacterial and other biological characteristics, the biomaterials produced from sericin have been combined with other biopolymers such as chitosan nanofiber or film, or chemical agents such as silver nanoparticles, zinc oxide nanoparticles, and antibiofilm titanium. The textile silk method can affect sericin sample properties such as thermal stability and structure. Additionally, different types of sericin have varied thermal stability. One of the primary disadvantages of sericin forms in many applications is their lack of mechanical characteristics. As a result, several studies have been conducted to enhance sericin's mechanical properties. Based on previous studies, better crystallinity and a longer molecular chain cause a crucial improvement in mechanical properties. Moreover, mechanical properties are influenced by the macromolecular structure, notably porosity.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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