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Research Article

A CRITICAL REVIEW ON APPLICATION OF SILK SERICIN AND ITS MECHANICAL PROPERTIES IN VARIOUS INDUSTRIES

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ABSTRACT:
Silk has turned into valuable biological material for a wide range of research applications. Sericin in silk can be utilized as a final material for natural or handmade fibers in the textile, cosmetics, and hygiene industries because of its various biological characteristics such as antibacterial, antioxidant, anti-tumor action, UV resistance, and absorbency. Sericin is disposed of annually as sewage in silk industries, according to findings on silk sericin and its application in industry. If sericin is recycled and recovered, it will have significant economic advantages in addition to reducing pollution. Since researches on the utilization of waste produced in the silk industry and the development of mechanical properties for use in many industries have not been performed simultaneously, a gap in this field has remained. The main aim of this review was to investigate sericin recycling in the silk industry while also improving mechanical properties for various applications in the industry. Sericin has a variety of biochemical and biological characteristics, according to past works. However, its mechanical characteristics are poor. There are a few ways to improve mechanical characteristics, the best of which is to increase sericin molecular weight. Better performance could be achieved by enhancing mechanical characteristics for application in various industries such as medical and cosmetics. New methods for obtaining high-value-added products have also been developed to provide environmental, social, and economic advantages. Hence, this review aims to explore some of the uses of sericin in different industries. Moreover, one of the most significant drawbacks of sericin forms is their poor mechanical properties. In addition, the present review considers the solutions of improvement for the mechanical characteristics of sericin.

Keywords: *Textile, Silk sericin, Biological characteristics, Mechanical properties*

1. INTRODUCTION

Silkworm silk is a natural protein produced by distilling and polymerizing several harmonized alpha-amino acids with long chains. Silk fibers contain 97% protein, with the rest made up of waxes, carbohydrates, pigments, and mineral compounds. Silk fibers contain 70-80% fibroin and 20-30% sericin (Table 1) [1]. In cold water, sericin is insoluble. It is, however, hydrolyzed by the breakdown of long protein molecules into smaller fractions that can be quickly dispersed or dissolved in hot water [2]. By extracting sericin from the fibroin, sericin can be derived from silk. There are several methods for separating sericin from silk. The separation procedure affected the solubility,

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molecular weight, and gelling characteristics of sericin [3, 4]. Sericin has been studied for a variety of potential uses due to its remarkable biochemical and biophysical characteristics. These products include the skincare and food industry, as well as biomedical coating materials for anticoagulants, drug delivery, anticancer drugs, and tissue engineering. When sericin is utilized as a component of cell culture in serum-free media, it promotes cell proliferation. 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 [5]. Today, there is an amount of research on silk sericin, for example, Sarovart et al. developed a sericin solution for nylon and polyester coatings that can be used as an antioxidant and antimicrobial to improve the properties of air filters [6]. Doa Khan et al. derived sericin from raw silk by boiling it in hot water and dispersing nano-TiO_2 in its solution. Dry powder was used to prepare cotton fabric with and without poly (carboxylic acid) crosslinking agents. Modified cotton fabrics were evaluated for antibacterial activity against gram-positive (Staphylococcus aureus) and gram-negative (Escherichia coli) bacteria [7]. Aramwit et al. [8] produced a sericin-containing ointment with silver sulfadiazine (SSD). They used its collagen and antimicrobial properties. They eventually noticed the healing of the wound. Fatahian et al. [9] investigated methods for extracting sericin from silk gum effluent solution as well as the properties of extracted sericin. They also tested sericin antibacterial properties in bacterial models. The outcome of this research demonstrated that sericin could be separated from gum effluent and that it exhibited antibacterial properties.

Table 1: Components of silk sericin Bombyx mori [10].

Components	Percent (%)
Fibroin	70-80
Sericin	20-30
Wax matter	0.4-0.8
Carbohydrates	1.2-1.6
Inorganic matter	0.7
Pigment	0.2

The purpose of the present review was to consider sericin recycling in the silk industry while also increasing mechanical properties for a variety of applications. In the present review, the important properties of silk sericin especially the mechanical properties, its special applications in many industries namely medicine, food, cosmetics, textiles, and other industries were considered in detail. By recognizing these applications, this precious and cost-effective material can be used in diverse industries.

2. SERICIN AND ITS PROPERTIES

Silk sericin is a natural macromolecular protein extracted from the Bombyxmori silkworm, which makes up about 20-30% of the silk protein [11]. Sericin maintains the adhesion of the cocoon by gluing the silk strands together. Most sericin is released during the production of raw silk in the spool workshop and other stages of the silk process. It is currently mostly disposed of in silk effluents [12]. Sericin contains 18 amino acids, the most important of which are serine (32%), aspartic acid (18%), and glycine (16%). This protein also contains 45.8% hydroxy amino acids (serine and threonine), 42.3% polar amino acids, and 12.2% non-polar amino acids [13, 14]. Sericin is beneficial due to its unique properties. Including antioxidant, anti-bacterial, UV protection and absorption and releases moisture easily, blood coagulation, Mechanical properties, Gel properties, anti-inflammatory, etc (Fig. 1) [15]. Acid, alkali, and enzymes are used in the degumming procedure [16]. Different extraction procedures produce sericin with varying molecular weights, zeta power, particle size, and amino acid content [17, 18]. The quantity of isolated sericin is affected by parameters such as temperature, time, and pH [9].

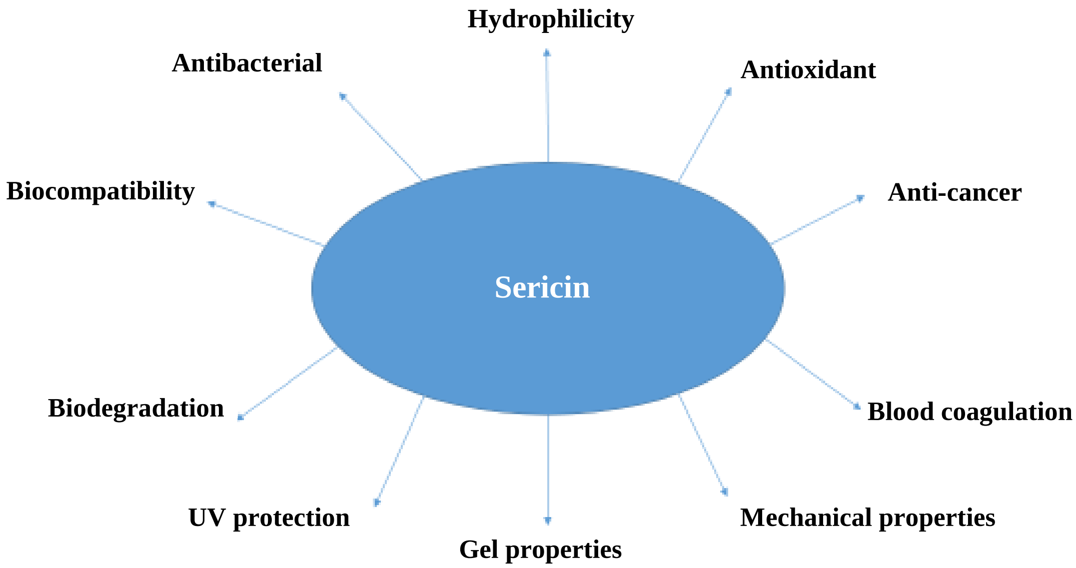

Fig. 1. Biochemical and biological properties of sericin.

2.1 Mechanical properties

One of the most significant disadvantages of sericin forms in many applications is their lack of mechanical characteristics. Hence, several works have been conducted to enhance sericin mechanical properties. On the other hand, researchers have selected easier and simpler approaches to increase mechanical characteristics [19]. For instance, the inclusion of additives such as sorbitol [20], graphene oxide [21], glycerin, poloxamer [22], and glycerol in sericin. Although this is a simple approach, it is ineffective since the inclusion of additives may adversely alter the specific characteristics of sericin and make biomedical uses of sericin more challenging. Before incorporating a foreign material, it is vital to identify an approach to improve the sericin performance. In other words, because the mechanical characteristics of sericin are affected by the preparation procedures, it is required to know the connection between them, and the optimal fabrication condition giving the best-performing sericin should be achieved before using an additive. The molecular weight (MW) of silk protein is a substantial factor influencing their properties. Hence, the influence of MW on the characteristics of Silk Fibroin (SF) solution, wet-spun fiber, electro-spun web, and gelation has been studied extensively. Furthermore, different extraction procedures can yield sericin samples with varying MWs. The MW of a polymer determines the viscosity of a solution since a longer chain length of the polymer caused a larger degree of molecular entanglement, leading to raising the solution viscosity [19, 23-26].

Park et al. [19] investigated how MW affects the mechanical properties and structure of silk sericin gel, sponge, and film. In their study, the swelling ratio decreased as the MW of sericin raised when the sericin sponge became denser and the porosity decreased. Their findings suggested that regulating the MW of sericin could modulate different characteristics of sericin types, potentially enhancing biomedical and cosmetic applications. Likitamporn and Magaraphan [27] investigated experimentally the thermal and mechanical properties of sericin/PVA/bentonite scaffold. In their study, the thermogravimetric test was used to investigate the impact of sericin and chemical cross-linking on thermal stability (Fig. 2). When compared to the scaffolds without sericin, the addition of sericin to scaffolds significantly improved both thermal and mechanical characteristics. The mechanical and thermal properties could be increased further by increasing sericin content.

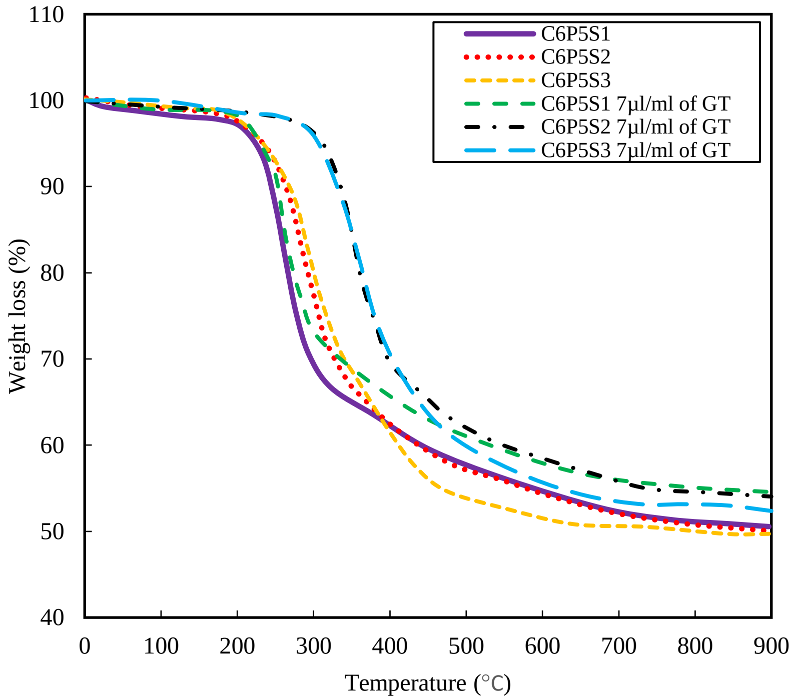

Fig. 2. Thermogravimetric curves.

2.2 Antioxidant

Today, antioxidants received more attention, especially because of the results on the impact of free radicals in the body, which have serious consequences if their substances are not neutralized by an efficient antioxidant system [28]. B. Mori cocoons can contain natural pigments such as flavonoids and carotenoids, which accumulate in sericin layers [29]. These pigments have biological properties such as antioxidants and antityrosinase. Sericin antioxidant properties may be connected to its high serine and threonine content, whose hydroxyl groups act chelating trace elements such as copper and iron [30]. Many researchers studied the antioxidant properties of silicon sericin. In the study of Takechi et al. [31], The methodologies of 1,1-diphenyl-2-picrylhydrazyl (DPPH), chemiluminescence, and oxygen radical absorbance capacity (ORAC) demonstrated that sericin derived from the yellow-green cocoon had significant antioxidant potential. According to the findings, this property is caused by a flavonoid pigment found in the sericin layers. In addition, the authors found that all sericin had excellent antioxidant properties against various free radicals, and the addition of sericin powder improved the antioxidant property of the bread. Dong et al. [32] examined the hypoglycemic effects and mechanism of sericin protein from silk-processing waste added to the usual diet at 0.8% (g%) level delivered orally to type 2 diabetic (T2D) mice. The oral protein is silk sericin hydrolysate, which was obtained by boiling a 0.025 percent calcium hydroxide solution. The protein substantially reduced fasting blood glucose, fasting plasma insulin, and glycosylated serum protein levels; enhanced oral glucose and insulin tolerance; and increased antioxidative activity. Dash et al. [33] studied the antioxidant and photoprotective ability of Antheraea mylitta sericin against UVB in irradiated human keratinocytes. Flow cytometry research showed that prior treatment with sericin prevented UVB-induced apoptosis. They concluded that sericin is a powerful antioxidant and antiapoptotic agent [34].

3. Application of Silk Sericin

Recent works have indicated the possible application of sericin in the medical, pharmaceutical, food, cosmetic, and textile industries, and others. Because sericin absorbs ultraviolet light, it may be utilized in sunscreen and can be used in textiles for producing UV protection. Sericin has antibacterial properties and is used in the manufacture of medical textiles such as surgical sutures, gloves, pads and bandages, aprons, and sheets [3]. To avoid the spread of HIV, it can be applied in toothpaste and shaving creams [11]. Table 2 summarizes some of the uses of silk sericin.

Table 2: Application of silk sericin in different industries

Industries	Applications	References
Food	Combat constipation and obesity, To enhance the taste and touch of porridge, Beverage rich in amino acids, In greasy foods, an edible antioxidant is used, Prevents browning reactions in a variety of ingredients, Antioxidant used in dairy products, Mineral absorption is accelerated, Additive as a nutrient, Antioxidant and suppressant of colon tumors.	[35, 36]
Cosmetic	Skincare: Skin elasticity, Anti-wrinkle, and Anti-aging influence, UV protection impact.	[37-39]
	Nailcare: Prevents cracks, brittleness, and raises the inherent brightness.	[40]
	Haircare: Conditioner and prevent hair damage.	[41]
	Gel: Moisturizing property.	[42]
	Powder: Moisture absorption capacity and anti-dermatitis.	[43]
Biomedical, pharmaceutic	Supplement in Culture Media and Cryopreservation, On Lipid Metabolism and Obesity), Tissue Engineering, Drug delivery and Wound healing	[44-47]
Textile	In fabrics to absorb moisture, Cleaning fabrics, Improved antibacterial activity, Fabricated nanofiber	[48, 49]
Other	Air filter products, Coated film on roads and roofs, Artificial leather product	[50, 51]

4. Sericin in the Cosmetics Industry

Sericin properties such as biocompatibility, biodegradability, and wettability have been employed in skin, hair, and nail cosmetics alone or in conjunction with silk fibroin. Sericin, when utilized in lotions, creams, and ointments, demonstrates a raised skin elasticity, anti-wrinkle, and anti-aging impacts [4, 52]. Moisturizers have been developed especially; they are mostly applied for preventing and postponing the dehydration of the skin's top layer [53]. Moisturizers come in a wide range of types. Among the ingredients are wetting agents such as vegetable glycerin, water, jojoba oil, vitamin E oil, and sorbitol [54]. Sericin gels containing hydroxyproline increase the epidermal layer and reduce skin impedance, which shows the moisturizing properties of sericin. A lotion containing 1% w/w sericin and 4% w/w D-glucose has a moisturizing and conditioning impact [55, 56]. Creams containing 0.001-30% w/w sericin have better cleaning properties while causing less skin irritation [57-59]. In sunscreen compositions, sericin improves the light screening influence of UV filters such as triazines and cinnamic acids ester [60]. It also has other uses, such as substances that absorb sweat and fat secreted by the skin's sebaceous glands [61].

5. Sericin in Medical and Pharmaceutical Industries

Recently, polymers, nanoparticles, lipidic carriers, micelles [62], natural proteins [4], and other pharmaceutical carriers also received more attention. Silk sericin-based drug delivery systems are attracting attention among different naturally occurring molecules as admirable vehicles capable of releasing their active content at a particular location and rate in the body [4, 63-65]. Sericin is used in a variety of drug applications, including solubility improvement, diffusion modification, and formulation stabilization in the pharmaceutical industry [66]. Sericin is both an antioxidant and an anticoagulant. These characteristics also prompted the creation of several studies to incorporate them in the medical field [67]. The antioxidant activity of sericin has the potential to have major health benefits. Consumption of sericin-containing foods relieves constipation, inhibits the growth of bowel cancer, and increases mineral absorption such as zinc, iron, magnesium, and calcium [4, 68, 69]. Sericin is a material that can be applied in drug delivery, bonds and matrices, scaffolds, and films. The products have equal pores, good compressive strength, and high flexibility. Moreover, they indicate high porosity, improved cell cohesion, and viability. In general, sericin is a biological substance that has the potential to be used in wound dressing [70-72], contact lenses, blood vessels, artificial skin, and other prostheses [11]. When sulphonated, sericin has an antithrombotic influence. It also has antimicrobial [71], collagen-making, hydrophilic, and biocompatibility properties. Therefore, it can be said that sericin has wound healing characteristics and can be employed as a wound covering material in the type of a sericin powder-containing film or cream [4]. For wound healing, Verma et al. [73] produced a carbopol-based hydrogel including sericin/chitosan-capped silver nanoparticles. They demonstrated that the processed hydrogel was revealed to be nonirritant, a possible wound healer, and to have an elegant appeal for improved patient compliance. By creating two skin wounds on the dorsum of rats, Aramwit and Sangcakul [74] examined the influence of sericin on wound healing and the reduction of wound size. Figure 3 depicts the time required to complete 50 percent and 90 percent wound healing in rats [74]. The meantime in days for 90 percent healing from sericin wounds was significantly less than for cream base-treated wounds (11 vs 15 days). Throughout the inspection period, they found that sericin wounds had much fewer inflammatory reactions and reduction of wound size was much higher than in the control. Sericin properties such as biocompatibility, biodegradability, and wettability have been used in skin, hair, and nail cosmetics alone or in conjunction with silk fibroin.

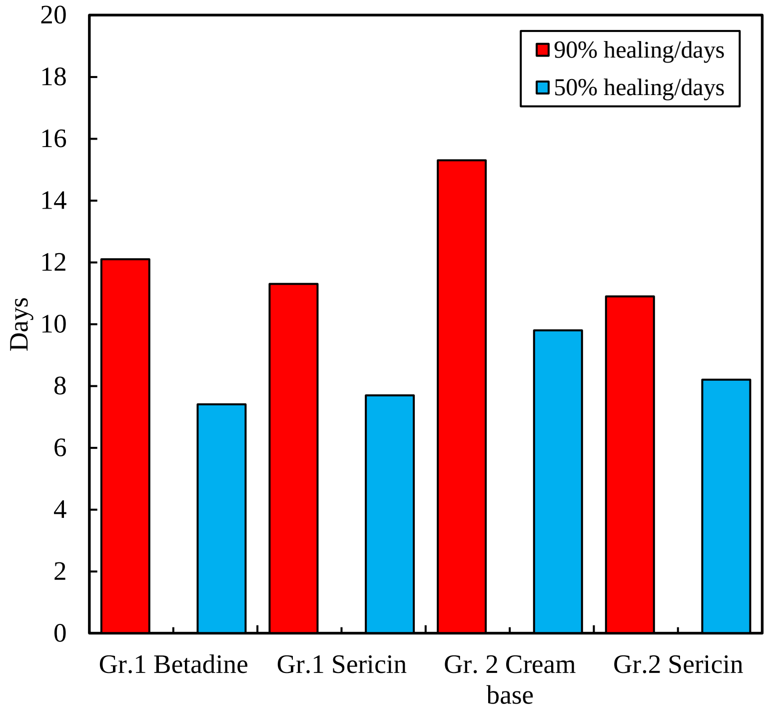

Fig. 3. Impact of sericin wounds on time.

6. SERICIN IN THE FOOD INDUSTRY

Today, the food and drug administration has listed sericin and its derivatives as authorized additives (GRAS) [75]. Sericin can be used in the production of fortified foods and dietary supplements because it helps to ferment and prevent modular processes and increases mineral absorption and antioxidant activity, which leads to health. Intestines and lower levels of cholesterol, triglycerides, fat accumulation in the liver [76]. Sericin can be used on fruits and vegetables to protect them from aging due to antioxidant activity and freezing. Sericin can be included in bread baking; baked bread with the right amount of sericin reduces the specific volume of the bread, the uniformity of the inner surface of the bread, and easy swallowing. This bread can be used by diabetics and patients with oral cancer due to its good digestion and absorption, rich in fiber, and high in protein. Furthermore, the antioxidant activity of sericin, along with emulsifying activity, enables it a promising ingredient in salad dressing [76].

7. SERICIN IN THE TEXTILE INDUSTRY

Sericin may be used to modify the surface of fibers and fabrics. It was applied as a coating material for cellulose fibers and wool. The treated textiles showed a reduction in free formaldehyde content, resistance to electricity, skin irritation, allergic reactions, increased water retention, water absorption, and enhanced antibacterial ability, with only a negligible decrease in textile tensile strength. Moreover, Sericin is used to overcome the hydrophobicity of polyester and to enhance its UV absorption properties. Sericin-treated polyester was also shown to have enhanced antistat and radical scavenging behavior [77, 78]. In addition, sericin can be combined with other materials to provide antimicrobial properties in nanofibers for use in wound dressing [79]. In general, fabrics woven from sericin-coated fibers have been examined in products such as diapers, diaper liners, and medical textiles in wound dressings and healing abrasive skin injuries in patients with atopic dermatitis, pressure ulcers, and rashes [78]. Recently some studies are being carried out on the effective utilization of sericin for the finishing of textile substrates. This is considered to be a promising plan for silk mills to solve the problems of sericin recovery and wastewater treatment [77].

8. Application of sericin in other industries

Because sericin has antioxidant and antibacterial activity. It can stop the free radical oxidation reaction and prevent the growth of microorganisms that lead to numerous diseases. As a result, sericin can be used as a coating to reduce the number of free radicals and also to prevent the growth of microorganisms on air filter products [6]. Because of its antifrosting properties, the sericin-coated film is used on the surfaces of refrigeration devices. The use of coated sericin film is an important antifrosting technique that can be added to refrigerators, deep freezers, refrigerated vehicles, and ships. Furthermore, using the coated film on roads and roofs can help to avoid frost damage and make snow removal easier. Sericin can be used to make art pigments and to cover the surfaces of papers. Sericin-coated materials have outstanding weatherability, good permeability, and do not warp when dried [11]. Rubber can also be produced more biocompatible by combining it with sericin. The use of hydrolyzed sericin in rubber results in a substance that is less irritant to the skin than natural rubber. Rubber gloves, bicycle handle grips, and handles for various sports equipment can also be made from this adapted rubber. Powdered sericin with particles smaller than 20 mm in diameter can be combined with a combination of rubber and thermoplastics to create an artificial leather product.

9. Conclusion

The main aim of the present review is to consider some of the applications of sericin in different industries. Furthermore, one of the main drawbacks of sericin forms in many applications is the weak mechanical properties. Hence, the current review investigated solutions to enhance the mechanical properties of sericin. This review demonstrated that sericin is a substance with various biochemical and biological properties including hydrophilicity, antioxidant, anti-cancer, blood coagulation, UV protection, biodegradation, and biocompatibility. The main results can be obtained from the current review:

- The mechanical properties of Sericin are poor, and several approaches have been employed to enhance its properties.
- The best approach without adding a negative effect on the unique properties of sericin is to increase the molecular weight of sericin.
- By increasing the mechanical properties of sericin, it can be said that it will be possible to conduct a comprehensive study on the various functions of this material to use its potential properties in various industries.
- Sericin is considered a waste of the silk industry and millions of tons of this substance enter the sewage every year and have harmful effects.
- It is possible to use silicon sericin in various industries such as medicine, pharmaceutical, food, cosmetic-health, textile and clothing, construction, etc. It has created a potential environmental, social, and economic advantage to obtain valuable products.
- Few studies have been conducted on the reuse of wastes produced in the silk industry as well as the improvement of the mechanical properties of sericin in various industries, and a significant gap remains in this area. For this reason, research into new ways to obtain high value-added products is crucial to create a potential environmental, social and economic benefit.

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