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Comparative Tensile Strength Analysis of Silk Sericin-Based Bioplastics with and without Cocoon Powder

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Abstract— This study aims to develop bioplastics based on natural biomaterials by utilizing silk sericin extracted from silk cocoons as the primary matrix. The degumming process was conducted at 100°C for 90 minutes with a 1:20 ratio (silk cocoons: distilled water) to obtain high-quality sericin. The extracted sericin exhibited gel-like characteristics, supporting bioplastic film formation. The bioplastics were synthesized using a combination of gelatin, chitosan, sericin, sorbitol, glycerol, and acetic acid, with two variations: with and without cocoons powder as a reinforcing agent. The mixture was homogenized using a magnetic stirrer at 80–100°C for 1 hour and dried at room temperature for 5 days. Mechanical properties were evaluated following ASTM D638 Type V standards. The results showed that bioplastics without cocoons powder exhibited a tensile strength of 3.774 MPa, elongation of 0.672%, and Young's modulus of 5.506 MPa. In contrast, bioplastics with cocoons powder showed a tensile strength of 3.354 MPa, elongation of 0.624%, and Young's modulus of 5.950 MPa. The addition of cocoons powder increased stiffness but reduced tensile strength and flexibility. Overall, silk sericin demonstrates strong potential as a sustainable bioplastic material, although further optimization is required to improve mechanical performance.

Keywords— Bioplastic, Silk Sericin, Silk Cocoon, Cocoon Powder, Mechanical Properties

I. INTRODUCTION

Plastic production based on fossil-derived materials has increased dramatically over the past 72 years, rising from 1.7 million tons in 1950 to 400 million tons in 2022, representing an approximate increase of 23,429% [1][1]. This rapid growth reflects the widespread dependence on plastic materials across various industrial and consumer sectors due to their versatility, durability, and low production cost. However, of the total plastic produced, only about 10% is recycled, 14% is incinerated, and 76% is discarded without proper treatment, leading to severe environmental pollution and long-term ecological consequences.

Currently, plastic waste has become a major global concern due to its non-biodegradable nature and its persistence in the environment for hundreds of years. Accumulated plastic waste can contaminate soil and aquatic systems, disrupt ecosystems, and pose serious threats to biodiversity and human health [2]. Furthermore, the formation of microplastics has raised significant concerns, as these particles can be easily ingested or absorbed by living organisms, leading to bioaccumulation and potential toxic effects within biological systems [3][4]. This growing environmental crisis highlights the urgent need for sustainable and biodegradable alternatives to conventional plastics.

The increasing use of petroleum-based plastics has led to serious environmental problems due to their non-biodegradable nature, thereby driving the development of more environmentally friendly alternative materials such as bioplastics [5], [6], [7]. Conventional plastics persist in the environment for long periods, contributing to pollution and ecological imbalance, which further emphasizes the urgency of transitioning to sustainable materials. Bioplastics are materials derived from renewable resources, including biomass, waste, and microorganisms, and have the potential to reduce dependence on fossil fuels while minimizing environmental pollution [7], [8]. In addition, their biodegradability and lower carbon footprint make them attractive candidates for replacing conventional plastics in various applications. Within the framework of a circular economy, bioplastics play a crucial role as they can be produced by microorganisms utilizing waste streams, such as sludge from wastewater treatment plants, thereby converting waste into value-added products that are biodegradable and non-toxic [9]. Furthermore, bioplastics have broad applications ranging from eco-friendly packaging to sustainable agriculture, with raw materials such as starch, cellulose, and proteins enhancing sustainability through the utilization of renewable resources and industrial or agricultural waste [7], [8].



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However, despite their promising potential, bioplastics still face several challenges, including high production costs, limited scalability, and often inferior mechanical properties compared to conventional plastics. Therefore, continuous innovation in material formulation and processing technologies is required to improve their performance and enable wider adoption, while also considering economic feasibility, social aspects, and public acceptance[10]

One of the promising sources is silk cocoon waste, particularly the protein sericin, which has been underutilized and is often discarded, thereby contributing to environmental pollution[11]. In many sericulture processes, sericin is removed during degumming and released as waste effluent, despite its valuable functional properties. Sericin possesses several advantageous characteristics, including biocompatibility, biodegradability, antioxidant activity, and the ability to retain moisture and promote cell growth, making it a highly promising candidate for sustainable biomaterials[12], [13], [14], [15]. Additionally, its hydrophilic nature and film-forming capability further support its application in polymer-based materials. The extraction process of sericin is relatively simple and environmentally friendly, typically involving aqueous methods without the use of hazardous chemicals, which enhances its suitability for green material applications. In the development of bioplastics, sericin can be utilized to produce biodegradable materials that reduce dependence on conventional plastics while adding value to industrial waste, especially when combined with other biopolymers to improve mechanical strength and stability[11]. Moreover, biomaterials derived from silk cocoons have demonstrated the potential to produce biodegradable plastics with favorable mechanical properties and controllable degradation behavior[3]. Therefore, the utilization of sericin from silk cocoons represents an innovative and sustainable approach to supporting circular economy-based bioplastic materials[16].

II. MATERIALS AND METHODS

2.1 Materials

This study utilizes silk cocoons (*Bombyx mori*) as the primary source of biomaterials through an extraction process to obtain silk sericin and silk fibroin, which are subsequently used as the main components in bioplastic

fabrication. The extraction process was carried out using distilled water as an environmentally friendly solvent, while gelatin and chitosan were incorporated to enhance the mechanical properties, stability, and biodegradability of the material[17], [18]. Sorbitol and glycerol function as plasticizers to improve flexibility and reduce brittleness, whereas acetic acid serves as a supporting agent in the formation of the polymer matrix. In addition, cocoons powder was employed as a reinforcing agent to improve the structural strength of the resulting material. The combination of these components is expected to produce environmentally friendly bioplastics with favorable mechanical properties and strong potential as an alternative to conventional plastics.

2.2 Methods

2.2.1 Silk sericin extract

The degumming process to obtain silk sericin from silk cocoons was carried out through a boiling method using distilled water at 100°C for 90 minutes, with a ratio of silk cocoons to distilled water of 1:20, representing a modification of a previously reported method[19]. This process is specifically designed to effectively separate the water-soluble sericin from the insoluble fibroin structure, yielding a sericin-rich solution with high purity and stability. The use of distilled water ensures an environmentally friendly and chemical-free extraction, minimizing potential contamination and preserving the intrinsic properties of sericin. The resulting sericin solution exhibits desirable characteristics such as homogeneity and gel-forming ability, making it highly suitable for further processing. Consequently, the extracted sericin can be effectively utilized as a renewable and biodegradable raw material in the development of bioplastics and other sustainable biomaterials.

2.2.2 Bioplastic matrices processing

At the initial stage, 10 mL of distilled water, 5 g of bovine gelatin, 10 mL of liquid chitosan, 10 mL of silk sericin, 3 mL of sorbitol, 3 mL of acetic acid, 1 mL of glycerol, and 0.2 g of cocoons powder were prepared as the primary components for bioplastic fabrication.

Each component plays a specific role, where gelatin and sericin act as the main polymer matrix, chitosan contributes to structural reinforcement and functional properties, while sorbitol and glycerol serve as plasticizers to improve flexibility and reduce brittleness. All materials were subsequently mixed and homogenized using a magnetic stirrer at a controlled temperature of 80–100°C for 1 hour until a uniform and stable solution was achieved. The elevated temperature facilitates polymer interaction, dissolution, and dispersion, ensuring better compatibility among the components. This method represents a modification of previously reported studies, aimed at enhancing intermolecular interactions within the biopolymer system to produce bioplastic materials with improved mechanical strength, structural integrity, and overall stability.[3], [11]

$$\epsilon = \frac{\Delta L}{L_0} \times 100\%$$

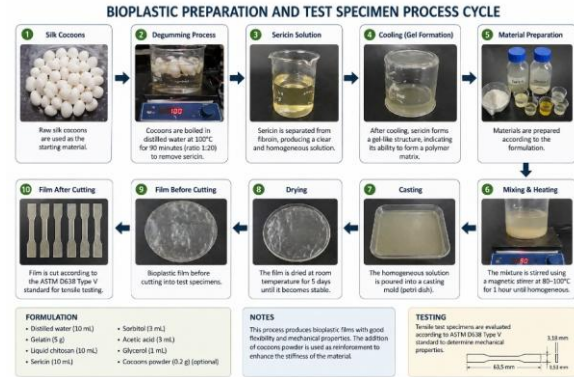


Figure 1 Preparation Process of Silk Cocoons into Bioplastics up to Testing Stage

2.3 Tensile strength and elongation at break

Tensile strength is defined as the maximum stress that a material can withstand under tensile loading until failure occurs, whereas elongation at break represents the flexibility of the material, expressed as the percentage change in length relative to its initial length. In this study, mechanical testing was conducted on three independent specimens (n = 3) to ensure the reproducibility of the results. The tensile strength and elongation at break were calculated mathematically based on commonly used methods reported in the scientific literature, using the following equations [20], [21]

$$\sigma = \frac{F_{max}}{A}$$

Where σ represents the tensile strength (MPa), F_{max} is the maximum tensile force applied to the material (N), and A is the initial cross-sectional area of the specimen (mm²). Meanwhile, the elongation at break (ϵ) can be calculated mathematically using the corresponding equation.

$$\epsilon = \frac{\Delta L}{L_0} \times 100\%$$

Where ΔL represents the change in the specimen length and L_0 is the initial length. Young's modulus (E) is used to describe the stiffness of the material, defined as the ratio of tensile stress (σ) to tensile strain (ϵ), which is calculated using the corresponding equation.

III. RESULTS

3.1 Silk sericin ekstrac

The results of the extraction (degumming) process indicate that sericin was successfully separated from the silk cocoons and obtained as a clear and homogeneous solution. Upon cooling, the sericin solution transformed into a gel-like structure, reflecting its high purity and strong intermolecular interactions, which are essential for matrix formation. This behavior highlights the excellent film-forming ability of sericin, as well as its capacity to act as a natural polymer matrix. Such characteristics underscore its significant potential as a sustainable raw material for bioplastics, enabling the development of flexible, biodegradable, and environmentally friendly materials with promising applications in green packaging and biomaterial engineering.

3.2 Bioplastic matrices processing

The composition of materials used in the bioplastic fabrication consisted of distilled water (10 mL), bovine gelatin (5 g), liquid chitosan (10 mL), silk sericin (10 mL), sorbitol (3 mL), acetic acid (3 mL), glycerol (1 mL), and cocoons powder (0.2 g). Based on this formulation, gelatin and sericin functioned as the primary biopolymer matrix, chitosan acted as a reinforcing agent and contributed to antibacterial properties, while sorbitol and glycerol served

as plasticizers to enhance flexibility. Acetic acid facilitated the dissolution process and promoted interactions among components, whereas cocoons powder was incorporated as an additional reinforcing agent in one variation of the samples.

The results of this method demonstrated that the bioplastics were successfully formed, as indicated by the production of homogeneous films that were not easily cracked and exhibited adequate flexibility. For analytical purposes, the samples were divided into two variations: bioplastics with cocoons powder and without cocoons powder, to evaluate its effect on the mechanical properties of the material. After casting, the bioplastics were dried at room temperature for 5 days until a stable condition was achieved and the samples were ready for further testing.

Tensile test specimens were then prepared according to the ASTM D638 Type V standard, ensuring appropriate dimensions for mechanical property evaluation. Through this method, the resulting bioplastics are expected to exhibit good quality and can be comprehensively analyzed to determine the influence of material composition on tensile strength and flexibility.

3.3 Tensile strength and elongation at break

Based on the tensile test results presented in the table, it can be observed that the addition of cocoons powder has a notable influence on the mechanical properties of the resulting bioplastics. In the samples without cocoons powder, the average tensile strength was 3.774 MPa, with an elongation of 0.672% and a Young's modulus of 5.506 MPa, indicating relatively better flexibility and higher resistance to tensile load. In contrast, the samples containing cocoons powder exhibited a lower average tensile strength of 3.354 MPa and a reduced elongation of 0.624%, while the Young's modulus increased to 5.950 MPa, suggesting an enhancement in material stiffness. This trend indicates that the incorporation of cocoons powder tends to restrict polymer chain mobility, resulting in a stiffer but less flexible material. The decrease in tensile strength may be attributed to the possible agglomeration or non-uniform dispersion of cocoons particles within the polymer matrix, which can create stress concentration points and weaken the overall structure. Nevertheless, the increase in stiffness demonstrates the reinforcing effect of cocoons powder, highlighting its role as a filler material

that modifies the mechanical behavior of the bioplastic system

Table 1
Average Values of Stress (MPa), Strain (%), and Young's Modulus (MPa).

Variation	Specimen	Stress (MPa)	
		Max	Average
Without Cocoon Powder	1	2,673	3,774
	2	3,616	
	3	5,031	
With Cocoon Powder	1	4,167	3,354
	2	3,616	
	3	2,28	
Variation	Specimen	Strain(%)	
		Max	Average
Without Cocoon Powder	1	0,457	0,672
	2	0,677	
	3	0,882	
With Cocoon Powder	1	0,721	0,624
	2	0,557	
	3	0,592	
Variation	Specimen	Modulus Young (MPa)	
		Max	Average
Without Cocoon Powder	1	5,342	5,506
	2	5,782	
	3	5,394	
With Cocoon Powder	1	7,11	5,95
	2	6,904	
	3	3,835	

These results indicate that the addition of cocoons powder tends to decrease tensile strength (stress) and strain, while increasing the Young's modulus. The reduction in tensile strength suggests that the material becomes slightly more brittle or less capable of withstanding maximum load before failure, which is an important consideration for applications requiring high mechanical resistance. This behavior is likely attributed to the non-uniform distribution

or possible agglomeration of cocoons powder particles within the biopolymer matrix, which can create localized stress concentration points and weaken the structural integrity of the material. In addition, the presence of rigid filler particles may disrupt the continuity of the polymer network, further contributing to the reduction in tensile performance.

On the other hand, the increase in Young's modulus in samples containing cocoons powder indicates that the material becomes stiffer (more rigid), reflecting an enhancement in resistance to elastic deformation. This occurs because cocoons powder acts as a reinforcing agent that restricts the mobility of polymer chains and promotes a more compact internal structure. As a result, the material requires greater stress to achieve the same level of deformation. Consequently, the flexibility of the material decreases, as reflected by the lower strain values compared to the samples without cocoons powder. This trade-off between stiffness and flexibility highlights the critical role of filler distribution and concentration in determining the overall mechanical performance of bioplastics

Based on the stress–strain (σ – ϵ) curves, both bioplastic variations, with and without the addition of cocoons powder, exhibit an increase in stress with increasing strain, indicating predominantly elastic behavior up to the point of failure. In Figure (a), which represents bioplastics with cocoons powder, the curves show a steeper slope in several specimens, reflecting a higher Young's modulus and, consequently, greater material stiffness. This behavior confirms the reinforcing effect of cocoons powder, which restricts polymer chain mobility and enhances resistance to deformation. However, noticeable fluctuations and irregularities are also observed in certain curves, suggesting a non-uniform distribution or possible agglomeration of cocoons powder particles within the matrix. Such inhomogeneity can lead to localized stress concentrations and inconsistent mechanical responses during loading.

In contrast, Figure (b), representing bioplastics without cocoons powder, displays smoother and more consistent stress–strain curves across specimens. This indicates better material homogeneity and a more uniform distribution of stress during tensile loading, resulting in a more stable mechanical response. Furthermore, the relatively gentler slope compared to the cocoons powder variation suggests higher flexibility and ductility, which is consistent with the higher strain values observed in the tensile test results.

These differences in curve characteristics reinforce the tensile test findings, where the addition of cocoons powder increases material stiffness, as indicated by the steeper slope, but reduces flexibility and structural uniformity. Therefore, the results confirm that cocoons powder acts as an effective reinforcing agent; however, its dispersion and concentration must be carefully optimized to minimize inhomogeneity and achieve a balanced improvement in overall mechanical performance.

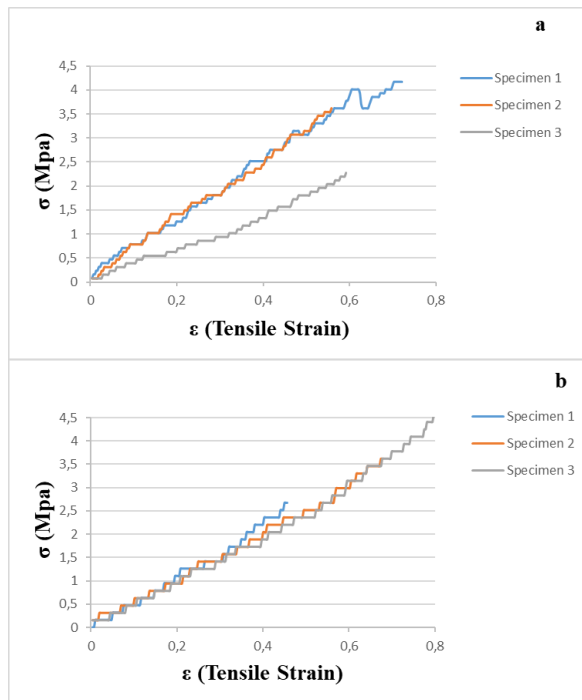


Figure 2 (a) Graph of stress and strain bioplastics with cocoon powder, and (b) Graph of stress and strain bioplastics without cocoon powder.

IV. DISCUSSION

In the degumming process, silk cocoons were boiled at 100°C for 90 minutes with a ratio of 1:20 (silk cocoons to distilled water). This process successfully separated sericin from fibroin, resulting in a clear and homogeneous sericin solution with minimal impurities. Upon cooling, the sericin exhibited a gel-like structure, indicating good quality, strong intermolecular interactions, and its ability to form a stable polymer network. This property is essential as it

supports the formation of flexible, uniform, and biodegradable bioplastic films, making sericin a promising candidate for sustainable material development.

Subsequently, bioplastics were synthesized using a composition of distilled water (10 mL), gelatin (5 g), liquid chitosan (10 mL), sericin (10 mL), sorbitol (3 mL), acetic acid (3 mL), glycerol (1 mL), and a variation with the addition of cocoons powder (0.2 g). Gelatin and sericin acted as the primary matrix components, providing film-forming capability, while chitosan served as a reinforcing and functional agent with potential antimicrobial properties. Sorbitol and glycerol functioned as plasticizers to enhance flexibility and reduce brittleness. The mixture was processed using a magnetic stirrer at 80–100°C for 1 hour until a homogeneous solution was achieved, promoting better interaction among biopolymer chains, and then dried at room temperature for 5 days to obtain stable bioplastic films ready for testing.

The tensile test results showed that the sample without cocoons powder exhibited an average tensile strength of 3.774 MPa, a strain of 0.672%, and a Young's modulus of 5.506 MPa, indicating relatively higher flexibility and tensile performance. In contrast, the sample with cocoons powder showed a decrease in tensile strength to 3.354 MPa and strain to 0.624%, while the Young's modulus increased to 5.950 MPa, reflecting enhanced stiffness but reduced ductility. These results indicate that the addition of cocoons powder tends to increase material rigidity while compromising tensile strength and flexibility, likely due to limited dispersion and interaction within the matrix.

These findings are further supported by the stress–strain curves, where bioplastics with cocoons powder exhibit steeper curves (indicating higher stiffness) but also show fluctuations that suggest non-uniform particle distribution and possible agglomeration. In contrast, bioplastics without cocoons powder display smoother and more stable curves, indicating better homogeneity and more uniform stress distribution during deformation. Overall, the results demonstrate that cocoons powder acts as a reinforcing agent; however, its application must be carefully optimized in terms of concentration and dispersion to improve mechanical properties without compromising the strength,

flexibility, and structural integrity of the bioplastics

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