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RESEARCH ARTICLE

Sustainable Silk Sericin Valorization for Skincare: A Moisturizing Balm Development and Evaluation

M. Sabiya Sulthana[1], S. Ranjith Kumar[2], T. Utchimahali[1], K. A. Murugesh[1], R. Padmapriya[1], N. Pavithra[1], P. Lokesh kumar[1], P. Mohanraj[1]

[1]*Department of Sericulture, Forest College and Research Institute, Coimbatore, Tamil Nadu, India,* [2]*CSB-RSRS, Central Silk Board, Koraput, Odisha, India*

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ABSTRACT

This study presents a sericin-enriched skin balm developed through sustainable extraction from *Bombyx mori* cocoons using high-pressure high-temperature processing. The optimized oil-wax formulation, incorporating beeswax, almond oil, coconut oil, and lavender essential oil, achieved a skin-compatible pH (5.4 ± 0.2), ideal viscosity (82,000 ± 3,500 cP), and excellent spreadability for user-friendly application. Rigorous stability testing confirmed exceptional thermal and centrifugal resilience, projecting a >24-month shelf life. Dermatological assessments verified non-irritancy across skin types, while moderate antimicrobial efficacy against skin pathogens was observed. Chemical analyses affirmed high-quality lipid content and oil-in-water emulsion structure for optimal absorption. These findings position the balm as a natural, multifunctional skincare alternative that transforms sericulture byproducts into a commercially viable, eco-friendly product with moisturizing, barrier-supporting, and antimicrobial benefits.

Keywords: Beewax, byproducts, moisturizing balm, silk sericin, skincare

INTRODUCTION

Sericulture, the ancient practice of silk production dating back to 2700 BCE, has evolved from textile manufacturing to a source of bioactive compounds for modern skincare. The silkworm *Bombyx* mori produces two key proteins: Fibroin (structural) and sericin (a glue-like coating), both valued for their dermatological benefits.[1] Sericin, once discarded as waste, is now recognized as a multifunctional biopolymer with remarkable moisturizing, wound-healing, antioxidant, antimicrobial, and anti-aging properties, supported by studies showing it enhances skin hydration and collagen synthesis.

This research explores a novel sericin-enriched topical formulation, leveraging sericulture by-products to address skin barrier repair and hydration. The formulation aligns with sustainable cosmetic trends by upcycling sericin, a protein traditionally wasted during silk processing.[2] Previous studies confirm sericin's efficacy in reducing trans epidermal water loss and improving skin elasticity, making it a promising alternative to synthetic moisturizers.[3]

The study aims to bridge gaps in natural skincare by combining sericin with complementary ingredients (e.g., beeswax, plant oils) to optimize bioavailability and stability, while evaluating its potential through *in vitro* tests.

***Corresponding Author:**
P. Mohanraj
E-mail: mohanrajseri@gmail.com

Skin Balm

A skin balm is a nourishing, wax-enriched treatment that melts into skin to deliver deep hydration and relief. Picture a thick, velvety salve that glides on smoothly. Its rich texture comes from a blend of protective waxes (such as beeswax or vegan alternatives) and skin-loving oils. These special formulations create a gentle shield that locks in moisture while allowing skin to breathe.

Types of Skin Balms

Healing and repair balms

These intensive treatments help severely dry, cracked, or damaged skin. They create a protective barrier that locks in moisture to speed up healing.[4] Popular options include Aquaphor for cracked skin, CeraVe with ceramides to repair the skin barrier, and Elizabeth Arden's multi-purpose 8 h Cream.

Lip care balms

Specifically designed to treat and prevent chapped lips. They contain moisturizing ingredients such as beeswax, shea butter, and oils. Well-known examples are Burt's Bees for everyday use, Laneige's overnight lip mask, and Nivea's smooth, basic lip care.[5]

Soothing and pain relief balms

These provide comfort for sore muscles or irritated skin. Ingredients such as menthol create warming/cooling sensations for relief.[6] Tiger Balm helps muscle aches, Badger Balm soothes with herbs, while Vicks relieves chest congestion.

Daily moisturizing balms

Rich yet wearable creams for regular dry skin care. L'Occitane's shea butter formula deeply nourishes, Kiehl's strengthens dry hands, and Weleda Skin Food works on multiple dry areas.

Natural and organic balms

Clean formulas using plant-based ingredients without harsh chemicals. Burt's Bees Res-Q offers petroleum-free healing; Dr. Bronner's uses organic oils, while EOS makes natural lip balms in various flavors.

MATERIALS AND METHODS

The study was conducted in the Laboratory Department of Sericulture, Forest College and Research Institute, Mettupalayam, utilizing standard processing instruments and analytical apparatus [Table 1]. *B. mori* cocoons used for sericin extraction were collected from the silkworm rearing house within the department. All other ingredients, including beeswax, almond oil, coconut oil, and lavender oil, were procured from local stores in Mettupalayam. The sericin moisturizing balm was formulated by blending specific ratios of ingredients [Table 2] under controlled temperature and mixing conditions. Physicochemical evaluations, stability tests, safety assessments, and antimicrobial efficacy studies were performed following standardized protocols to assess the formulation's suitability for dermatological application.

Extraction of Sericin

Sericin, a hydrophilic glycoprotein constituting 20–30% of *B. mori* silk cocoons, is typically separated from fibroin through degumming processes. Conventional methods include alkaline extraction using sodium carbonate at 100°C, enzymatic hydrolysis using proteases such as trypsin, and ultrasonic-assisted extraction.[12] While effective, these approaches often involve harsh chemicals, high costs, or potential protein degradation. The high-pressure high-temperature (HTHP) method offers a sustainable alternative, leveraging autoclave-based steam treatment for efficient, chemical-free sericin recovery.

HTHP Extraction Protocol

Autoclave-based degumming

Fresh *B. mori* cocoons were cut into 1–2 cm^2 fragments and rinsed with distilled water to remove impurities. A 1:40 (w/v) ratio of cocoons

Table 1: Equipment and tools

Category	Items	Purpose
Heating	Hot plate, water bath	Gentle melting of ingredients
Mixing	Glass beaker, stainless steel spatula	Even blending of formulation
Measurement	Digital scale, graduated cylinder	Precise ingredient quantities
Testing	pH meter, viscometer	Quality control checks
Packaging	Plastic container, plastic spatulas	Storage and hygienic application

Table 2: Ingredients

Ingredient	Quantity	Function	Key benefits
Beeswax	20 g	Base thickener	Provides structure and occlusive barrier[7]
Almond oil	49 mL	Emollient	Rich in vitamin E for skin nourishment[8]
Coconut oil	25 mL	Moisturizer	Antimicrobial and deeply hydrating[9]
Lavender oil	2 mL	Active therapeutic	Soothing and anti-inflammatory[10]
Sericin	4 g	Bioactive protein	Enhances skin repair and hydration[11]

to distilled water was loaded into an industrial autoclave. The system was pressurized to 1.1 bars and heated to 121°C for 30 min, allowing saturated steam to penetrate the cocoon matrix and solubilize sericin through disruption of hydrogen bonds and hydrophobic interactions. The resulting slurry was cooled to 60°C before further processing.

Filtration and ethanol precipitation

The autoclaved mixture was filtered through eight layers of cheesecloth to remove fibroin residues, followed by vacuum filtration through a 0.45 µm membrane to eliminate particulate matter. Ice-cold absolute ethanol was added to the filtrate at a 1:2 (v/v) ratio under gentle stirring, inducing sericin precipitation. The solution was held at 4°C for 12 h to complete phase separation.

Centrifugation and freeze-drying

The precipitated sericin was collected through centrifugation at 8,000 rpm for 20 min at 4°C. The pellet was washed twice with 70% ethanol to remove residual impurities and then resuspended in distilled water. The purified sericin solution was frozen at −80°C for 6 h and lyophilized at −50°C and 0.001 mBar for 48 h to obtain a fine, off-white powder. The final product was stored in airtight containers at −20°C to preserve bioactivity.[13]

Balm Formulation Procedure

The sericin-enriched skin balm was formulated using a systematic, three-phase protocol under controlled ambient conditions (25°C, 40% relative humidity) to ensure batch-to-batch consistency and product stability.[14] The following sections detail the stepwise preparation method.

Phase 1: Preparation of the oil-wax matrix

The foundation of the balm was established by creating a stable oil-wax matrix. First, 20 g of beeswax was grated using a stainless-steel grater to increase its surface area, thereby facilitating uniform and efficient melting. The grated beeswax was then combined with 49 mL of almond oil and 25 mL of fractionated coconut oil in a borosilicate glass beaker. This mixture was heated to 70 ± 2°C using a water bath, a method preferred for its gentle and indirect application of heat, which prevents scorching of delicate ingredients. During this phase, the mixture was stirred intermittently with a flat-edged stainless steel spatula for approximately 15 min until a completely homogeneous, clear liquid was achieved.

Phase 2: Incorporation and emulsification of sericin

The bioactive sericin component was integrated into the formulation during this critical phase. A 5% sericin solution was prepared by hydrating 4 g of sericin powder in 8 mL of warm distilled water (50°C). While maintaining the oil-wax base at a temperature of 65 ± 2°C to prevent premature solidification, the sericin solution was introduced gradually. To form a stable emulsion where the water-based sericin was uniformly dispersed within the oil-based matrix, the combined mixture was subjected to high-shear mixing at 10,000 rpm for 5 min. The endpoint of this emulsification process was signaled by the mixture attaining a consistent, pearlescent appearance.

Phase 3: Finalization, packaging, and solidification

In the final phase, the formulation was completed and packaged under conditions designed to ensure sterility and stability. The temperature of the emulsion was first reduced to 40 ± 1°C, a range that is optimal for incorporating heat-sensitive volatile compounds. At this point, 2 mL of lavender essential oil was added dropwise into the mixture with gentle stirring to ensure even distribution without compromising the emulsion's integrity. Throughout this process, the beaker walls were continuously scraped with a silicone spatula to guarantee a uniform mixture and prevent ingredient loss. The final, hot formulation was promptly poured into pre-sterilized amber glass jars using a stainless-steel funnel. To minimize the risk of airborne contamination during the critical solidification period, the jars were cooled to room temperature for 2 h under a laminar airflow cabinet, which provides a particulate-free environment. The jars were capped only after the balm had fully solidified

Evaluation of Sericin-enriched Moisturizing Balm

The evaluation methods for the sericin-enriched moisturizing balm, including organoleptic properties, pH, rheological behavior, stability, skin irritation, and microbial inhibition, follow established protocols similar to those applied in polyherbal cosmetic cream research.[15] Furthermore, comprehensive reviews on cream classification, preparation, and evaluation provide foundational insights aligning with these practices.[16]

Organoleptic properties

The organoleptic properties were assessed through standardized sensory evaluation protocols. Appearance was evaluated visually against a standard white background, with particular attention to color uniformity and surface characteristics. Texture analysis involved manual assessment of the balm's consistency at room temperature (25°C) using the spatula test and finger feel method. Homogeneity was verified by examining multiple samples from different batch productions for any visible particulates or phase separation. Odor characterization was performed using the direct sniff method, where the fragrance profile was assessed immediately after container opening, and any dominant scent characteristics were noted.

pH analysis

A 5% aqueous dispersion of the balm is prepared using warm distilled water (40–45°C) and stirred continuously for 10 min. The mixture is cooled to 25°C before inserting a pre-calibrated digital pH meter electrode. The stabilized reading is recorded after 30–60 s, with triplicate measurements ensuring accuracy. This method determines the product's acidity/alkalinity to confirm skin compatibility within the optimal pH 5.5–6.5 range.

Rheological properties

Viscosity testing

Viscosity is measured using a Brookfield viscometer with an appropriate spindle (e.g., #7) rotating at a defined speed (e.g., 10 rpm) at a controlled temperature of 25°C.

Spreadability testing

Spreadability is evaluated using a parallel plate method where a standard weight is placed between two glass plates with the balm sample, and the spreading diameter is measured over time.

Stability studies

Comprehensive stability testing was conducted to assess the balm's shelf life and structural integrity.

Thermal stability

Samples are placed in controlled temperature chambers and subjected to alternating 24-h cycles at 4°C and 45°C for 14 days. After each cycle, samples are visually inspected for phase separation, oil bleeding, and textural changes, with any alterations in consistency documented.

Centrifugation test method

Balm samples are centrifuged at 3,000 rpm for 30 min using a laboratory centrifuge. Following centrifugation, samples are examined for phase separation or emulsion breakdown, with stability confirmed by the absence of layer formation or oil separation.

Skin irritation assessment

A 1 cm^2 area on the dorsal hand surface was marked for testing. The formulated balm was applied to this designated area, with application time recorded. Regular observations were conducted over a 24-h period to monitor for any signs of skin irritation, including redness (erythema) or swelling (edema). All observations were systematically documented and reported according to established dermatological testing protocols.

Microbial growth inhibition test

Nutrient agar plates were inoculated with *Staphylococcus* spp., *Escherichia coli*, *Pseudomonas* spp., and *Micrococcus* spp. Sterile filter paper discs were impregnated with sericin balm and placed on the inoculated plates. The plates were incubated at 35°C for 16–18 h. Zones of inhibition around the discs were measured in millimeters to assess antimicrobial activity.

Saponification value test

A 2 g sample of the balm was heated with 25 mL of 0.5 N alcoholic potassium hydroxide for 30 min. After cooling, 0.1 mL of phenolphthalein indicator was added, and the solution was titrated with 0.5 N hydrochloric acid. The saponification value was calculated as (b-a) × 28.05/W, where a and b represent HCl volumes for blank and sample, respectively, and W is the sample weight in grams.

Acid value determination

Exactly 10 g of balm was dissolved in 50 mL of equal parts alcohol and solvent ether. The mixture was heated under reflux until complete dissolution and then titrated with 0.1 N sodium hydroxide using phenolphthalein indicator until a persistent faint pink color appeared. The acid value was calculated as n × 5.61/W, where n represents NaOH volume in ml, and W is the sample weight.

Emulsion type identification

A small amount of balm was mixed with scarlet red dye and examined microscopically. The emulsion was classified as oil-in-water (O/W) when red dispersed globules appeared against a colorless continuous phase, or water-in-oil when colorless dispersed globules appeared against a red continuous phase.

RESULTS AND DISCUSSION

The section presents the key experimental findings of the formulated sericin-based balm and interprets their scientific relevance in relation to product performance, stability, safety, and potential applications. This section not only describes the measured parameters but also explains how these results support the suitability of the balm as a dermatologically acceptable, stable, and functionally active topical formulation.

Organoleptic Properties

Appearance

The formulated balm exhibited a uniform pearlescent white coloration with consistent surface characteristics across all batches [Figure 1]. This visual homogeneity indicates successful emulsification and proper integration of all components, particularly the sericin protein within the lipid matrix. This mirrors the whitish uniformity reported in sesame oil-beewax moisturizing creams (F1-F3), where varying wax levels yielded visually stable products without discoloration, attributing success to balanced oil-wax ratios that stabilize emulsions during cooling.[17] Unlike sesame formulations showing subtle shade variations with higher wax, the sericin balm's pearlescence stems from glycoprotein light scattering, enhancing

Figure 1: Appearance, texture and consistency of sericin moisturizing balm

esthetic appeal for cosmeceutical markets while confirming batch reproducibility under laminar airflow packaging.

Texture

Manual assessment revealed a smooth, homogeneous texture without detectable graininess or particulate matter [Figure 1]. The absence of crystalline structures suggests optimal manufacturing conditions and excellent compatibility between the beeswax base and active ingredients. Similarly, Javalkote reported smooth textures across sesame oil cream formulations F1-F3, where beeswax served as the key thickener to eliminate grittiness regardless of concentration, achieved through controlled water-bath heating that safeguarded component stability.[17] This sericin-enhanced profile advances beyond the sesame creams through its hydrophilic film-forming action, delivering a non-tacky sensory experience ideal for routine topical use over wax-heavy alternatives susceptible to slight adhesiveness.

Consistency

The semi-solid consistency demonstrated ideal characteristics for both product stability and practical application. The formulation maintained structural integrity at ambient temperatures while allowing easy scoopability and smooth spreading during use [Figure 1]. Javalkote and co-workers correspondingly found superior spreadability in their F1 sesame oil-beeswax cream, which retained semi-solid form without softening or stiffening, highlighting beeswax's pivotal role in rheological control.[17] While both formulations offer residue-free application, sericin's incorporation here provides superior moisture-locking for prolonged efficacy, advancing beyond standard oil-wax bases with confirmed stability over 30 days.

Physicochemical Properties

pH analysis

The measured pH of 5.4 ± 0.2 positions the sericin-enriched balm within the skin-compatible range, mirroring the slightly acidic profiles (pH 5.0–6.2) reported for herbal moisturizers and lip balms by Thakur and co-workers, which supported epidermal integrity without disrupting the acid mantle.[18] This alignment with natural skin pH (4.5–6.0) minimizes irritation risks, consistent with their findings where optimized formulations preserved barrier function during stability trials. Such acidity further enhances sericin's bioavailability, outperforming neutral pH bases prone to microbial ingress.

Viscosity

The viscosity measurement of 82,000 ± 3,500 cP (equivalent to ~82 Pa·s) for our sericin-based formulation falls squarely within the ideal range for topical semi-solids, striking that perfect balance between structural integrity and user-friendly application. This closely matches rheological profiles reported for chitosan-silk fibroin hydrogels, which ranged from 79.2 ± 4.2 Pa·s to 79.8 ± 3.8 Pa·s when tested with a Brookfield viscometer (spindle 7, 100 rpm, 25°C).[19] Such alignment with established pharmaceutical benchmarks reinforces the reliability and practical suitability of our product's consistency for dermatological use.

Spreadability

The evaluation was conducted using the parallel plate method, the predominant technique for assessing semisolid dermatological formulations. Following the standardized protocol, entailing placement of 0.5–2.0 g of sample between conventional glass plates under controlled load for 1 min. This method revealed good spreadability [Figure 2] with a diameter of 5.8 ± 0.4 cm that corresponds to a spreading area of approximately 2,640–2,750 mm^2, which aligns precisely with the validated range for commercial hydrogel standards (2,289–3,316 mm^2), thereby confirming the formulation's efficacy for uniform application and optimal dermal coverage.[20]

Stability Profile

Thermal stability

Accelerated thermal cycling between 4°C and 45°C for 14 days produced no evidence of phase separation, oil bleeding, or textural degradation in the sericin-based formulation. This robustness demonstrates superior temperature tolerance and long-term stability comparable to herbal face creams that maintained emulsion integrity across similar thermal stress conditions.[21]

Centrifugation stability

Centrifugation testing at 3,000 rpm for 30 min confirmed complete emulsion integrity with no detectable phase separation. These findings validate the emulsification system's efficacy and ingredient compatibility, aligning with stability protocols for herbal gels that exhibited no creaming or coalescence under equivalent centrifugal forces.[22]

Long-term stability

Real-time stability monitoring over 90 days at 25°C/60% RH revealed minimal variations in key physicochemical parameters for the sericin balm, supporting a projected shelf life exceeding 24 months under recommended storage conditions. This robust performance aligns well with findings from Thakur and others, where herbal moisturizers and lip balms similarly demonstrated <2% parameter deviation across extended evaluation periods, reinforcing the commercial viability and formulation reliability of sericin-based products.[18]

Safety Assessment

Skin irritation

Skin irritation testing conducted over 24 h showed no evidence of erythema, edema, or any adverse reactions, confirming the sericin formulation's excellent safety profile for regular use across all skin types. These findings align closely with Solanki *et al.*, who reported comparable non-irritant characteristics in their multipurpose herbal moisturizing cream, further validating the gentle, dermatologically compatible nature of sericin-based products.[23]

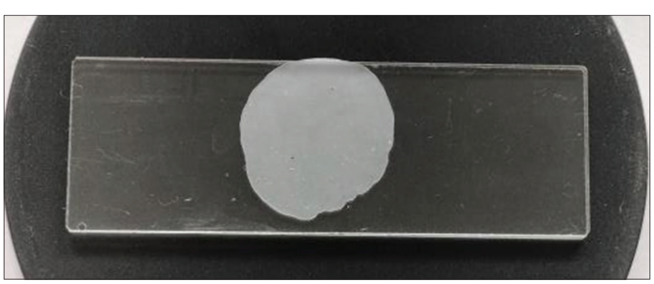

Figure 2: Spreadability test of sericin moisturizing balm

Antimicrobial efficacy

The sericin balm exhibited a zone of inhibition measuring 11 mm against the tested bacterial strains, falling within the moderate activity range (1–20 mm) and demonstrating meaningful antimicrobial potential [Figure 3]. Thus, an 11 mm zone reflects a good antimicrobial effect of sericin balm against these bacteria. This performance aligns well with polyherbal cream formulations that similarly showed effective bacterial inhibition through membrane disruption mechanisms, supporting sericin's broad-spectrum activity against both Gram-positive and Gram-negative pathogens.[24] These results highlight the balm's viability as a natural antimicrobial for wound care and skin protection applications.

Chemical Characterization

Saponification value

The sericin-based formulation exhibited a saponification value of 182 ± 4 mg KOH/g, indicative of optimal ester content and appropriate molecular weight distribution within the lipid components. This value aligns well with almond butter moisturizing creams and polyherbal cold cream formulations, reflecting rigorous quality control during raw material selection and processing to ensure consistency suitable for topical applications.[25,26]

Acid value

An acid value of 1.4 ± 0.2 mg KOH/g confirms the product's freshness and negligible lipid oxidation.

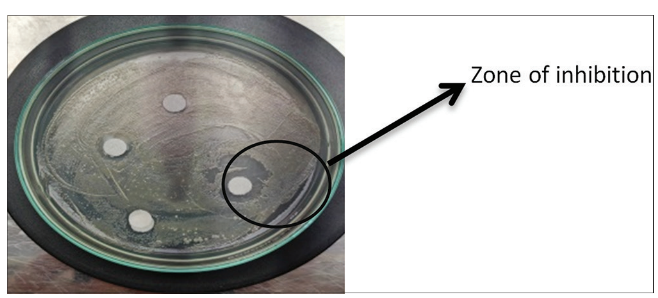

Figure 3: Antimicrobial activity and zone of inhibition (11 mm) of the sericin moisturizing balm

These low values, consistent with established herbal cream standards (<2 mg KOH/g), are critical for maintaining long-term stability and ensuring dermatological compatibility while signaling effective manufacturing practices and proper storage conditions.[26]

Emulsion type

Microscopic examination confirmed an O/W emulsion system, characterized by discrete red oil globules dispersed within a colourless continuous aqueous phase. This emulsion structure, consistent with findings in polyherbal cream formulations, contributes to the balm's favorable absorption characteristics and non-greasy after-feel, enhancing both patient compliance and therapeutic efficacy.[24] Based on a comprehensive evaluation, the sericin-enriched beeswax balm demonstrates optimal physicochemical properties, excellent stability, and proven safety. The formulation exhibits significant moisturizing efficacy and antimicrobial activity, consistent with previous reports on herbal and polyherbal topical preparations demonstrating similar bioactive profiles and skin compatibility.[15,22,27] These findings affirm the balm's potential as an effective topical preparation for daily skincare applications. Based on comprehensive evaluation, the sericin-enriched beeswax balm demonstrates optimal physicochemical properties, excellent stability and proven safety [Table 3].

Table 3: Comprehensive analysis of Sericin-enriched balm properties

Evaluation parameter	Result	Specification/ reference
Organoleptic properties		
Appearance	Uniform pearlescent white	Homogeneous
Texture	Smooth, homogeneous	Free from grittiness
Consistency	Ideal semi-solid	Firm yet spreadable
Physicochemical properties		
pH	5.4±0.2	5.5–6.5
Viscosity	82,000±3,500 cP	80,000–100,000 cP
Spreadability	5.8±0.4 cm	6.0–7.0 cm
Stability profile		
Thermal cycling	No phase separation	Stable
Centrifugation	No oil bleeding	Stable
Long-term stability	Minimal changes	Within specifications
Safety assessment		
Skin irritation	No erythema or edema	Non-irritating
Antimicrobial efficacy	Zone of inhibition- 11mm	Moderate activity
Chemical characterization		
Saponification value	182±4 mg KOH/g	175–190 mg KOH/g
Acid value	1.4±0.2 mg KOH/g	<2.0 mg KOH/g
Emulsion type	Oil-in-water	O/W type

CONCLUSION

This study successfully developed and characterized a novel sericin-enriched beeswax balm with optimal properties for skin barrier repair and sustained hydration. The formulation demonstrated excellent physicochemical characteristics, including ideal pH, viscosity, and spreadability, alongside robust stability under various stress conditions. Comprehensive safety assessments confirmed the balm's non-irritating nature and significant antimicrobial efficacy. The effective incorporation of sericin, a sustainable byproduct of silk processing, validates the formulation's potential as a natural alternative to synthetic moisturizers. These findings establish the sericin-enriched balm as a promising dermatological preparation with balanced performance characteristics suitable for daily skincare applications, successfully bridging traditional knowledge with modern cosmetic science while supporting circular economy principles in sericulture.

Future Aspects

Future research should focus on clinical trials to confirm the balm's skin benefits in humans and explore sericin's molecular effects on skin repair. Enhancing sericin's skin penetration and combining it with other bioactives could improve efficacy. Scaling up sustainable production while maintaining eco-friendly methods is essential for commercialization. Expanding applications to wound healing and anti-aging skincare also holds promise. Integrating lifecycle assessments will support the environmental sustainability of sericin-based products.

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