

Development and Characterization of Manjistha-Enriched Hydrogel for Skin Pigmentation Treatment: Comparative Evaluation with Commercial Anti-Pigmentation Formulations.

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Abstract:-

Skin hyperpigmentation disorders, including melasma and post-inflammatory hyperpigmentation, are common dermatological conditions that can significantly affect an individual's appearance and quality of life. Although several synthetic depigmenting agents are available, their long-term use is often associated with skin irritation, allergic reactions, and other adverse effects. These limitations have encouraged the exploration of herbal alternatives with improved safety and therapeutic potential. *Rubia cordifolia* (Manjistha), a well-known medicinal plant in traditional medicine, possesses antioxidant, anti-inflammatory, and skin-brightening properties that make it a promising candidate for topical anti-pigmentation therapy. The present study aimed to develop and characterize a Manjistha-enriched hydrogel intended for the management of skin pigmentation disorders and to compare its performance with a commercially available anti-pigmentation formulation. The hydrogel was prepared using a suitable polymeric base and evaluated for its physicochemical characteristics, including appearance, pH, viscosity, spreadability, homogeneity, drug content, washability, extrudability, and stability. Comparative evaluation was carried out to assess its overall performance against a marketed product. The developed formulation demonstrated desirable physicochemical properties, good stability, and satisfactory topical applicability, indicating its suitability as a herbal hydrogel delivery system. The incorporation of Manjistha extract into the hydrogel matrix is expected to enhance skin retention and provide sustained release of bioactive phytoconstituents, thereby improving therapeutic effectiveness. Overall, the developed hydrogel represents a promising herbal formulation for topical management of hyperpigmentation and offers potential as a safer alternative to conventional anti-pigmentation products. Further preclinical and clinical studies are warranted to establish its long-term safety and clinical efficacy.

Keywords: Manjistha; *Rubia cordifolia*; Hydrogel; Skin hyperpigmentation; Melasma; Herbal cosmetics; Topical drug delivery; Antioxidant; Comparative evaluation; Dermatological formulation.

1. Introduction

Skin pigmentation disorders are among the most common dermatological concerns, affecting both cosmetic appearance and psychological well-being. Excessive melanin production caused by genetic, hormonal, environmental, and inflammatory factors often results in conditions such as melasma and post-inflammatory hyperpigmentation. Although several synthetic depigmenting agents are available, their prolonged use is associated with adverse effects that limit patient compliance. Consequently, herbal formulations have gained increasing attention because of their safety, biocompatibility, and therapeutic potential. Hydrogels containing plant-derived bioactive compounds offer an attractive approach for topical drug delivery by providing sustained release, improved skin hydration, and enhanced patient acceptance.

1.1 Skin Pigmentation

Skin colour is primarily determined by **melanin**, a pigment synthesized by melanocytes located in the basal layer of the epidermis. Melanin protects the skin against ultraviolet (UV) radiation by absorbing harmful rays and reducing oxidative damage. However, excessive melanin production or abnormal melanin distribution leads to **hyperpigmentation**, which appears as localized or diffuse dark patches on the skin. **Melasma** is one of the most common forms of

hyperpigmentation and is frequently associated with hormonal changes, pregnancy, and chronic sun exposure. In addition, prolonged exposure to ultraviolet radiation stimulates melanogenesis through activation of the enzyme tyrosinase, leading to **UV-induced pigmentation** and persistent skin discoloration [1, 2].

1.2 Current Anti-Pigmentation Therapy

Several topical agents are currently used for the management of hyperpigmentation. **Hydroquinone** inhibits tyrosinase activity and remains one of the most effective skin-lightening agents. **Kojic acid** suppresses melanin synthesis through copper chelation, while **arbutin** gradually reduces pigmentation by inhibiting tyrosinase. **Azelaic acid** possesses both depigmenting and anti-inflammatory properties and is widely used for melasma treatment. Despite their effectiveness, these agents may cause skin irritation, erythema, allergic reactions, contact dermatitis, and, in some cases, long-term adverse effects with prolonged use. These limitations have encouraged the search for safer herbal alternatives [3, 4].

1.3 Herbal Approach

Herbal cosmetics have become increasingly popular because they contain naturally derived bioactive compounds with multiple pharmacological activities and generally exhibit better skin compatibility than many synthetic ingredients. Plant-based formulations often provide antioxidant, anti-inflammatory, and skin-protective effects while reducing the risk of severe adverse reactions. Their growing acceptance has encouraged the development of herbal topical formulations for the treatment of pigmentation disorders [5].

1.4 Manjistha (*Rubia cordifolia*)

Rubia cordifolia L., commonly known as **Manjistha**, is a medicinal plant widely used in traditional Ayurvedic medicine for the management of skin disorders and blood purification. The roots contain bioactive phytochemicals such as anthraquinones, flavonoids, tannins, glycosides, and phenolic compounds. These constituents possess antioxidant and anti-inflammatory activities that help reduce oxidative stress and inflammation associated with abnormal melanin production. Experimental studies have also suggested that Manjistha exhibits depigmenting potential by modulating melanogenesis and protecting the skin from oxidative damage, making it a promising herbal ingredient for topical anti-pigmentation formulations [6, 7].

1.5 Hydrogels in Dermatology

Hydrogels are three-dimensional polymeric networks capable of absorbing large amounts of water while maintaining structural integrity. Their soft texture, high moisture content, and excellent biocompatibility make them suitable for topical drug delivery. Hydrogels provide controlled drug release, improve drug residence time on the skin, produce a cooling effect, and enhance patient comfort and compliance. These properties make hydrogel systems particularly useful for the delivery of herbal extracts intended for long-term dermatological therapy [8].

1.6 Research Gap

Although several herbal extracts possess promising depigmenting properties, their clinical effectiveness is often limited by poor stability, inadequate skin retention, and inconsistent drug release. A stable herbal hydrogel formulation capable of maintaining the biological activity of Manjistha while providing controlled topical delivery may improve therapeutic efficacy and patient compliance. Therefore, developing and evaluating a Manjistha-enriched hydrogel is important for advancing safer and more effective anti-pigmentation therapy.

1.7 Aim

The present study aims to develop and characterize a **Manjistha-enriched hydrogel** for the topical management of skin pigmentation disorders and to compare its physicochemical characteristics and overall performance with a commercially available anti-pigmentation formulation. The study also seeks to evaluate the suitability of the developed hydrogel as a stable and effective herbal topical delivery system.

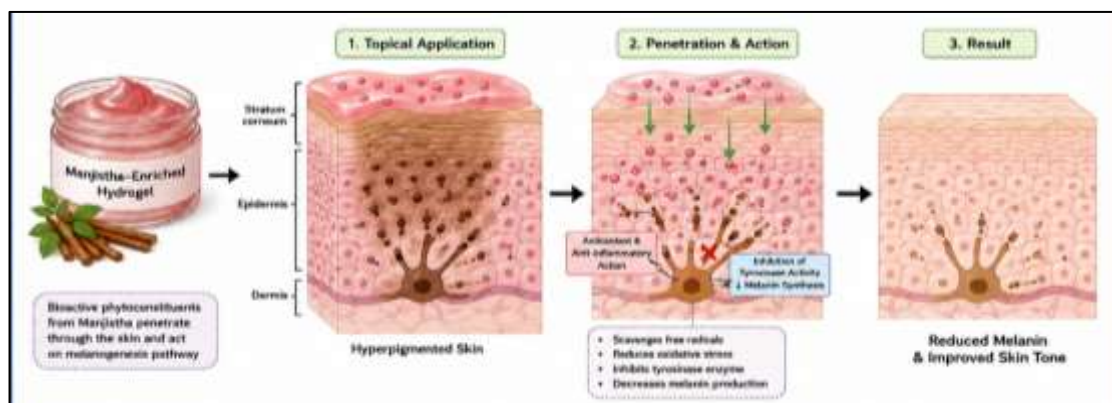


Figure 1. Mechanism of Topical Manjistha-Enriched Hydrogel in Hyperpigmented Skin

2. Materials and Methods

2.1 Materials

The materials used for the preparation of the Manjistha-enriched hydrogel were of analytical grade and procured from standard commercial suppliers.

Table 1. Materials used in the study

Material	Supplier	Purpose
<i>Rubia cordifolia</i> (Manjistha) Root Powder	Local Ayurvedic Supplier	Herbal active ingredient (Anti-pigmentation)
Disodium EDTA	Merck Pvt. Ltd., India	Chelating agent
Trehalose 100	Sigma-Aldrich, India	Moisturizing agent
Acrylates/C10-30 Alkyl Acrylate Crosspolymer	Lubrizol India Pvt. Ltd.	Gelling agent
Glycerin	Merck Pvt. Ltd., India	Humectant
Propanediol	Sigma-Aldrich, India	Humectant and penetration enhancer
Triethanolamine (TEA)	Merck Pvt. Ltd., India	Neutralizing agent and pH adjustment
Sodium Hyaluronate	Sigma-Aldrich, India	Moisturizing and skin-conditioning agent
Purified Water	Laboratory	Vehicle

2.2 Plant Collection

Fresh roots of *Rubia cordifolia* (Manjistha) were collected from a reliable herbal supplier and authenticated by a qualified botanist. The collected plant material was washed to remove impurities, shade dried at room temperature, and coarsely powdered using a mechanical grinder. The powdered material was stored in an airtight container until extraction.

2.3 Extraction

The powdered Manjistha roots were extracted using a suitable solvent by the maceration method. The extract was filtered to remove plant debris and concentrated under reduced pressure to obtain a semisolid extract. The dried extract was stored in airtight containers under refrigerated conditions until further use in hydrogel preparation.

2.4 Hydrogel Formulation

Manjistha-enriched hydrogel was prepared using the Acrylates/C10-30 Alkyl Acrylate Crosspolymer dispersion method. The required quantity of Disodium EDTA was dissolved in purified water, followed by the gradual addition of

Acrylates/C10-30 Alkyl Acrylate Crosspolymer under continuous stirring until a uniform gel base was formed. Trehalose 100, Glycerin, Propanediol, and Sodium Hyaluronate were then incorporated sequentially with continuous mixing. The required quantity of Manjistha (*Rubia cordifolia*) root extract was added slowly to the hydrated gel base and mixed until a homogeneous formulation was obtained. Finally, Triethanolamine (TEA) was added dropwise to neutralize the polymer and adjust the pH, resulting in a smooth, stable, and uniformly dispersed herbal hydrogel suitable for topical application.

Table 2. Composition of Manjistha-Enriched Hydrogel Formulations

Ingredient (% w/w)	Quantity	Function
Manjistha (<i>Rubia cordifolia</i>) Root Extract	5.0	Anti-pigmentation agent
Disodium EDTA	0.10	Chelating agent
Trehalose 100	0.10	Moisturizing agent
Acrylates/C10-30 Alkyl Acrylate Crosspolymer	0.80	Gelling agent
Glycerin	5.0	Humectant
Propanediol	5.0	Humectant and penetration enhancer
Triethanolamine (TEA)	0.30	Neutralizer and pH adjuster
Sodium Hyaluronate	0.20	Moisturizing and skin-conditioning agent
Purified Water	q.s. to 100	Vehicle

2.5 Evaluation of Hydrogel Formulation

The prepared Manjistha-enriched hydrogel formulations were evaluated for their physicochemical properties to determine their suitability for topical application.

2.5.1 Organoleptic Properties

The formulations were visually examined for **colour, odour, and appearance**. A smooth, homogeneous hydrogel with a pleasant appearance and characteristic herbal odour was considered acceptable.

2.5.2 pH

The pH of each formulation was measured using a calibrated digital pH meter at room temperature to ensure compatibility with normal skin.

2.5.3 Viscosity

Viscosity was determined using a Brookfield viscometer under controlled experimental conditions to evaluate the consistency and flow characteristics of the hydrogel.

2.5.4 Spreadability

Spreadability was evaluated by measuring the ease with which the hydrogel spread between two glass plates under a specified weight. Good spreadability indicates ease of application.

2.5.5 Homogeneity

The formulations were visually inspected for uniformity, absence of lumps, and phase separation to ensure a homogeneous gel structure.

2.5.6 Drug Content

Drug content was determined to evaluate the uniform distribution of Manjistha extract within the hydrogel matrix using a suitable analytical method.

2.5.7 Washability

Washability was assessed by applying the hydrogel to the skin and observing the ease of removal with water.

2.5.8 Extrudability

Extrudability was evaluated by measuring the ease with which the hydrogel was expelled from a collapsible tube under gentle pressure [10-12].

2.5.9 Stability Studies

Stability studies were carried out according to **ICH guidelines** by storing the formulations under recommended conditions and periodically evaluating their appearance, pH, viscosity, and homogeneity to assess physical stability [9].

2.5.10 Skin Irritation Test

The optimized formulation was evaluated for skin irritation by topical application to the test area. The treated skin was observed for erythema, edema, or any visible signs of irritation during the study period.

2.5.11 Comparative Evaluation

The optimized hydrogel formulation was compared with a commercially available anti-pigmentation cream/gel based on **appearance, pH, viscosity, spreadability, and stability** to assess its overall quality and topical performance [10, 12].

Table 3. Comparative Evaluation of Optimized Hydrogel with Marketed Formulation

Parameter	Optimized Hydrogel	Marketed Formulation
Appearance	Smooth, homogeneous	Smooth cream/gel
pH	Skin compatible	Skin compatible
Viscosity	Appropriate	Comparable
Spreadability	Good	Good
Stability	Stable	Stable

Flowchart of Preparation of Manjistha-Enriched Hydrogel

Collection of Manjistha Roots

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Authentication

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Shade Drying

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Powdering

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Extraction of Manjistha

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Preparation of Carbopol Gel Base

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Addition of Manjistha Extract

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Addition of Propylene Glycol

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Addition of Preservatives

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pH Adjustment with Triethanolamine

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Homogeneous Hydrogel Formation

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Evaluation and Stability Studies

Figure 2. Flowchart illustrating the preparation and evaluation of the Manjistha-enriched hydrogel formulation.

3. Results and Discussion

3.1 Organoleptic Evaluation

Table 3. Organoleptic Evaluation of Optimized Manjistha Hydrogel

Sr. No.	Parameter	Observation
1	Color	Clear Transparent
2	Odor	Pleasant
3	Consistency	Good

Discussion

The optimized Manjistha hydrogel exhibited desirable organoleptic properties suitable for topical application. The formulation was clear, transparent, possessed a pleasant odour, and showed good consistency, indicating acceptable aesthetic quality.

3.2 pH

Table 4. pH of Optimized Manjistha Hydrogel

Formulation	pH
Developed Hydrogel	5.5 ± 0.5

Discussion

The developed hydrogel exhibited a pH of 5.5 ± 0.5 , which is within the normal physiological skin pH range (4.5–6.5). This indicates good skin compatibility and minimizes the possibility of irritation following topical application. The obtained pH is comparable to commercially available topical hydrogel formulations.

3.3 Viscosity

Result

Viscosity = 1050 ± 0.2 cP

Discussion

The hydrogel showed a viscosity of 1050 ± 0.2 cP, providing suitable consistency for topical application. The formulation was neither too fluid nor excessively thick, allowing easy dispensing while maintaining adequate retention on the skin surface.

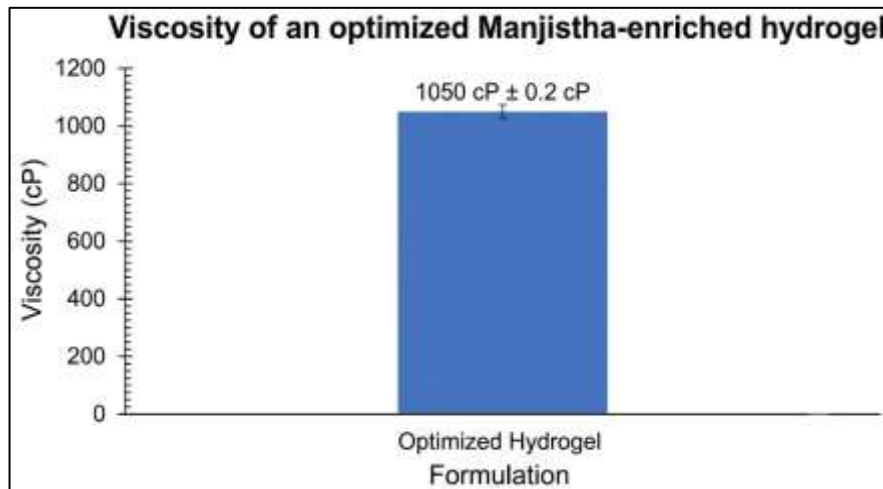


Figure 3. Viscosity of Optimized Manjistha Hydrogel.

3.4 Spreadability

Result

Spreadability = 6.5 ± 0.6 cm

Discussion

The hydrogel exhibited good spreadability (6.5 ± 0.6 cm), enabling uniform distribution over the skin with minimal effort. Appropriate spreadability improves patient convenience and ensures better topical coverage.

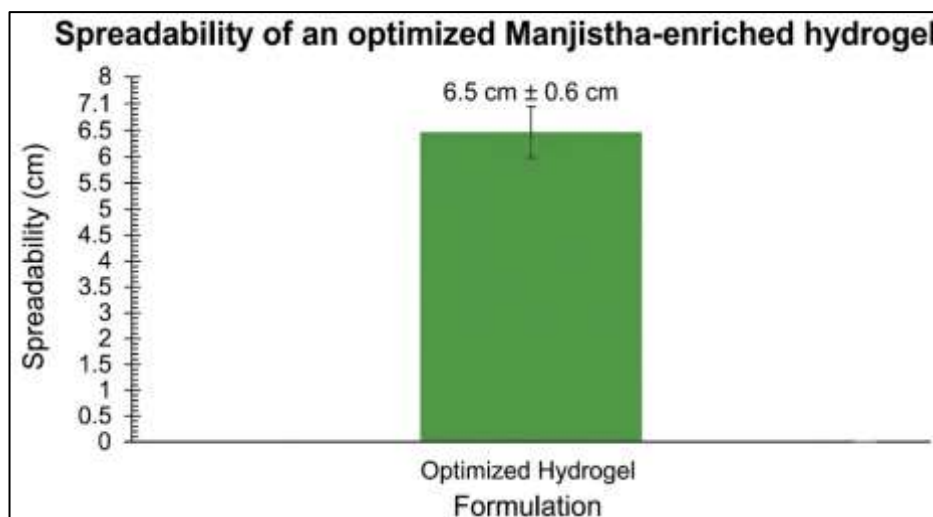


Figure 4. Spreadability of Optimized Manjistha Hydrogel.

3.5 Homogeneity

Discussion

The prepared hydrogel was smooth, homogeneous, and free from visible lumps or phase separation, indicating uniform distribution of the Manjistha extract throughout the formulation.

3.6 Drug Content

Table 5. Drug Content of Optimized Manjistha Hydrogel

Formulation	Drug Content (%)
Optimized Hydrogel	97.8 ± 0.6

Discussion

The optimized Manjistha hydrogel exhibited a drug content of 97.8 ± 0.6%, indicating uniform distribution of the herbal extract throughout the gel matrix. The high drug content reflects efficient incorporation of the active constituents with minimal loss during formulation. Uniform drug distribution is essential for maintaining consistent therapeutic efficacy and ensuring formulation quality.

3.7 Stability

Table 6. Stability of Optimized Manjistha Hydrogel

Parameter	Initial	After Storage
Appearance	No change	No change
pH	5.5	5.4
Viscosity	1050 cP	1045 cP

Discussion

The optimized hydrogel remained physically stable during the storage period, with no significant changes in appearance, pH, or viscosity, indicating good formulation stability.

3.8 Comparative Evaluation

Table 7. Comparative Evaluation of Developed Hydrogel with Commercial Anti-Pigmentation Gel

Parameter	Developed Hydrogel	Commercial Product
Appearance	Clear, Transparent	White Cream
Odour	Pleasant	Mild Fragrance
pH	5.5 ± 0.5	5.8 ± 0.3
Viscosity (cP)	1050 ± 0.2	980 ± 0.3
Spreadability (cm)	6.5 ± 0.6	6.0 ± 0.5
Washability	Easily Washable	Easily Washable
Irritability	Non-irritant	Slight Irritation on Prolonged Use
Extrudability (g/cm ²)	15.3 ± 1.2	14.6 ± 1.1

Discussion

The comparative evaluation demonstrated that the developed Manjistha hydrogel possessed physicochemical characteristics comparable to the commercial anti-pigmentation formulation. Both formulations exhibited a skin-compatible pH and were easily washable, making them suitable for topical application. However, the developed hydrogel showed slightly better viscosity, spreadability, and extrudability, which may facilitate uniform application and improved patient convenience. In addition, the absence of skin irritation indicates good dermatological compatibility. Unlike the commercial product, the developed formulation contains Manjistha, a natural herbal ingredient with antioxidant and

anti-inflammatory properties, which may offer a safer alternative for long-term management of hyperpigmentation. These findings suggest that the developed herbal hydrogel has the potential to provide effective topical performance while reducing the risk of adverse effects commonly associated with some synthetic depigmenting products.

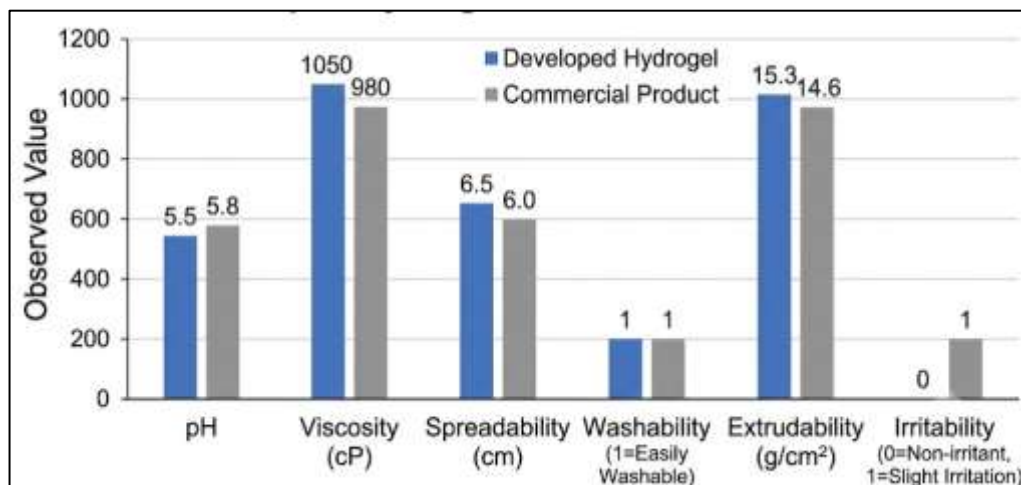


Figure 5. Comparison of Developed Manjistha Hydrogel and Commercial Anti-Pigmentation Product

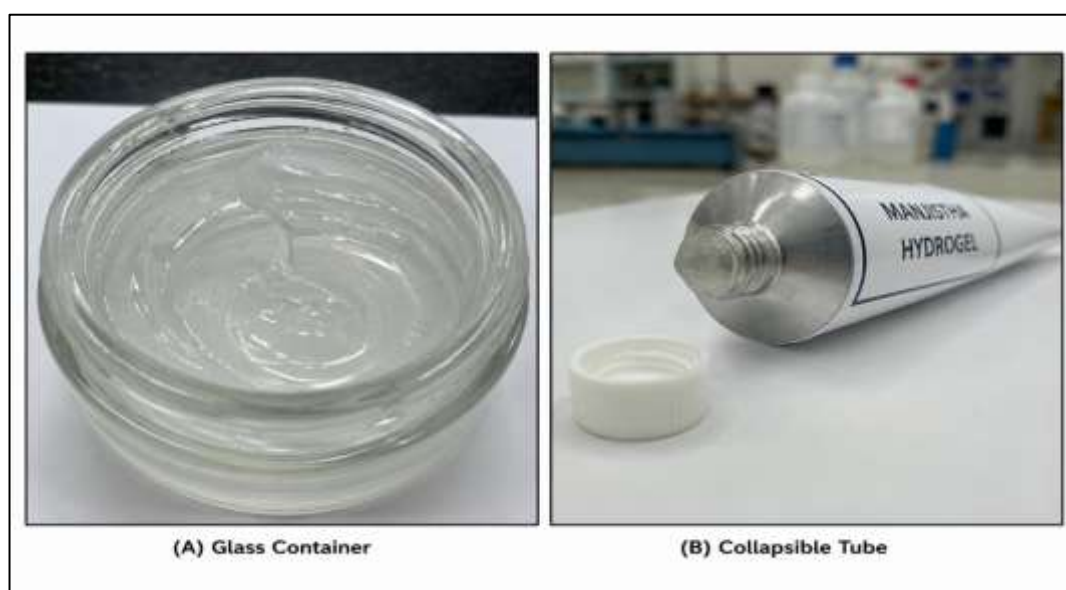


Figure 6. Photographs of Developed Hydrogel

4. Discussion

The developed Manjistha-enriched hydrogel demonstrated satisfactory physicochemical properties, including skin-compatible pH, appropriate viscosity, good spreadability, and non-irritant characteristics, indicating its suitability for topical application. The successful performance of the formulation can be attributed to the synergistic combination of the hydrogel base and the bioactive phytoconstituents present in Manjistha.

Carbopol 940 played a significant role as the gelling agent by producing a smooth, stable, and homogeneous hydrogel with suitable viscosity. It improved the consistency, spreadability, and residence time of the formulation on the skin, thereby enhancing patient convenience and facilitating prolonged contact of the active constituents with the affected area. Similar findings have been reported in recent studies on Carbopol-based topical herbal formulations [8, 11, 12]. The therapeutic potential of the formulation is mainly associated with the phytoconstituents of Manjistha (*Rubia cordifolia*), including anthraquinones, flavonoids, tannins, and phenolic compounds. These bioactive constituents

possess antioxidant and anti-inflammatory properties, which help reduce oxidative stress and inflammation associated with abnormal melanin production. In addition, Manjistha has been reported to exhibit depigmenting activity by modulating melanogenesis, making it a promising herbal ingredient for managing hyperpigmentation [5-7]. The hydrogel matrix also contributed to the overall effectiveness of the formulation by providing adequate hydration, easy application, and improved retention of the herbal extract on the skin surface. The hydrated polymeric network allows gradual release of the active constituents, which may enhance local drug availability and improve therapeutic performance. Similar advantages of hydrogel-based herbal drug delivery systems have been reported in recent pharmaceutical research [3, 12, 15, 18].

Overall, the findings of the present study are consistent with published reports demonstrating that herbal hydrogels prepared with Carbopol provide good physicochemical stability, enhanced patient compliance, and effective topical delivery of plant-derived bioactive compounds. The developed Manjistha hydrogel therefore represents a promising natural alternative for the topical management of skin hyperpigmentation.

5. Conclusion

The present study successfully developed a **Manjistha-enriched hydrogel** for topical application using an appropriate hydrogel base. The formulated hydrogel exhibited desirable physicochemical properties, including suitable pH, good consistency, adequate viscosity, satisfactory spreadability, easy washability, good extrudability, and a non-irritant nature, indicating its suitability for dermal application. The formulation also demonstrated good physical stability during the study period, suggesting its potential for long-term storage and use. Comparative evaluation showed that the developed hydrogel possessed physicochemical characteristics comparable to, and in some aspects better than, the commercial anti-pigmentation formulation, particularly in terms of spreadability and skin compatibility. The incorporation of **Manjistha (*Rubia cordifolia*)**, a medicinal plant rich in antioxidant and anti-inflammatory phytoconstituents, further enhances the therapeutic potential of the formulation. Overall, the developed herbal hydrogel represents a promising natural alternative for the topical management of skin hyperpigmentation. Further **preclinical and clinical studies** are recommended to confirm its long-term safety and therapeutic efficacy before commercialization.

6. Future Scope

The present study demonstrates the potential of a **Manjistha-enriched hydrogel** as a herbal topical formulation for the management of skin hyperpigmentation. However, further investigations are required to establish its therapeutic efficacy and support its clinical application. Future research may focus on the following aspects:

- **Tyrosinase inhibition assay** to evaluate the depigmenting activity of the formulation and its ability to suppress melanin synthesis.
- **Melanin estimation studies** using suitable in vitro models to quantify the effect of the hydrogel on melanin production.
- **In vitro cell line studies** on melanocyte and keratinocyte cell lines to investigate cellular uptake, cytotoxicity, and anti-melanogenic activity.
- **Clinical trials** to assess the safety, tolerability, and therapeutic efficacy of the hydrogel in patients with hyperpigmentation disorders such as melasma.
- **Nano-hydrogel development** by incorporating nanocarrier systems to improve skin penetration, controlled drug release, and bioavailability of Manjistha phytoconstituents.
- **Scale-up and commercialization** through process optimization, long-term stability studies, regulatory evaluation, and industrial manufacturing to facilitate the development of a marketable herbal anti-pigmentation product.

Overall, these future studies will help validate the clinical effectiveness of the developed formulation and support its translation into a safe, effective, and commercially viable herbal dermatological product.

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