Formulation and Evaluation of an Herbal Wound Healing Gel Containing Mussaenda erythrophylla Leaf Extract

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***Abstract*—The present study entitled "Formulation and Evaluation of Wound Healing Gel Containing Mussaenda erythrophylla Leaves Extract" was undertaken with the aim of developing a safe, effective, and stable herbal topical formulation for wound healing applications. Leaves of Mussaenda erythrophylla were collected from SRTMU campus, Nanded, and authenticated at Science College, Nanded, by Dr. Marathe. The collected plant material was shade dried, powdered, and subjected to extraction using a suitable solvent system. The obtained extract was evaluated for phytochemical constituents, confirming the presence of flavonoids, tannins, and phenolic compounds, which are known to contribute to wound healing activity. The extract was further characterized using FTIR spectroscopy to identify functional groups and confirm the presence of bioactive compounds. Based on preliminary studies, five gel formulations (HG1–HG5) were prepared using appropriate gelling agents and varying concentrations of the plant extract. All prepared formulations were evaluated for physicochemical parameters including physical appearance, homogeneity, pH, viscosity, spreadability, drug content, and washability. The formulations exhibited satisfactory organoleptic properties with smooth texture and good consistency. The pH of all batches ranged between 6.05 and 6.24, which is suitable for topical application. Viscosity values indicated good gel strength, while spreadability ensured ease of application. Drug content analysis confirmed uniform distribution of the extract in all formulations. Among all batches, formulation HG3 was identified as the optimized formulation due to its superior characteristics, including optimal pH (6.18), highest viscosity, maximum spreadability, and highest drug content (99.4%). The formulation also showed excellent homogeneity and washability. The optimized batch (HG3) was subjected to accelerated stability studies, which indicated no significant changes in physical appearance, pH, viscosity, spreadability, and drug content over a period of six months, confirming the stability of the formulation. In conclusion, the developed herbal gel containing Mussaenda erythrophylla leaves extract demonstrated satisfactory physicochemical properties and stability, indicating its potential as an effective wound healing agent. The study supports the use of plant-based formulations as a promising alternative to conventional synthetic products.**

***Index Terms*—Mussaenda erythrophylla, wound healing, herbal gel, topical formulation, phytochemical screening, FTIR, viscosity, spreadability, stability studies**

I. INTRODUTION

Wound infections represent a pervasive health challenge, particularly in less developed nations characterized by unsanitary living conditions. In addressing this issue, it becomes imperative to formulate effective action plans aimed at restoring the compromised functional state and anatomical integrity of the skin .(19)

Wound healing is a multifaceted process that involves the collaboration of various types of epithelial and mesenchymal cells, along with the influence of cytokines, chemokines, and growth factors. These intricate interactions work together to orchestrate the regeneration of damaged skin, a phenomenon that has been extensively studied in the field of medicine. One significant player in this process is Keratinocyte Growth Factor (KGF), which acts as a paracrine growth factor.(20)

A. Hemostasis:

The process of wound healing unfolds in several distinct stages, each playing a crucial role in the

restoration of damaged tissue. The initial phase, known as Hemostasis, begins immediately after injury and is characterized by the rapid constriction of blood vessels to halt blood flow. This serves as the body's immediate response to injuries, and the objective is to create a clot to seal the wound. Platelets within the bloodstream aggregate to repair any cracks in the blood vessel wall. The coagulation process reinforces the platelet plug by weaving fibrin threads, effectively acting as a molecular adhesive. (21)

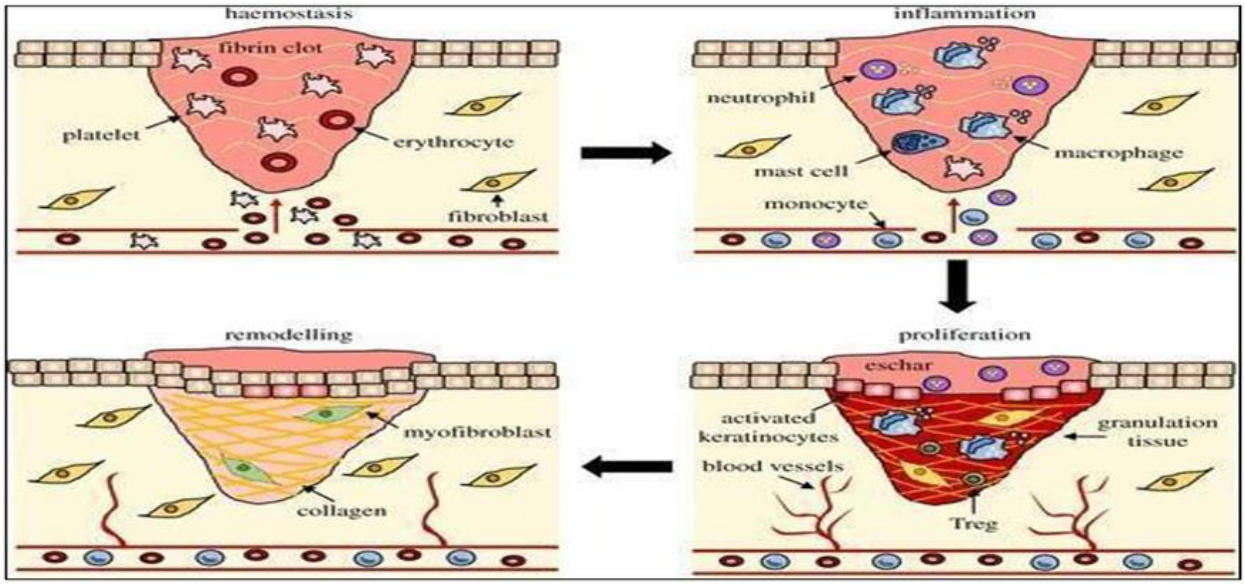

Figure. 1.1. Wound Healing Stages (23)

B. Inflammation (1-4 days): The second phase in the process of wound healing is inflammation, which typically commences within the first four days after an injury. During this phase, a substance known as transudate, comprising water, salt, and proteins, starts to seep from the damaged blood vessels, leading to localized edema. While the presence of white blood cells (WBCs), along with nutrients, enzymes, and growth factors, contributes to this phenomenon, it results in characteristic symptoms such as swelling, redness, heat, and pain. These sensations are indicative of the body's active wound-healing process. (24)

C. Proliferative Phase (5-21 days): The proliferative phase, occurring between the 5th and 21st days following an injury, is characterized by the formation of fresh tissue that contains extracellular matrix and collagen. During this stage, new tissues are generated, contributing to the reduction in the wound's size. Myofibroblasts, akin to smooth muscle cells, play a crucial role in this phase by grasping the edges of the wound and pulling them together, ultimately sealing the wound. In a healthy wound-healing process, granulation tissue exhibits an uneven texture and a pink or red hue. Notably, healthy granulation tissue is relatively resistant to bleeding. (25)

D. Remodeling Phase (21-2 years): This phase, often referred to as the maturation phase, marks the culmination of the wound healing process. During this stage, the wound fully closes, and a transformation of collagen occurs, shifting from type III to type I remodeling. Moreover, cells that are no longer required for the healing process undergo programmed cell death, a phenomenon known as apoptosis. Collagen, which was initially disorganized and deposited during the proliferative phase, becomes aligned and undergoes reabsorption of water. This realignment brings collagen fibers closer together and culminates in their cross-linking. Collagen crosslinking plays a pivotal role in determining scar thickness and fortifying the skin in the wound area. (53)

- Mechanism of wound healing

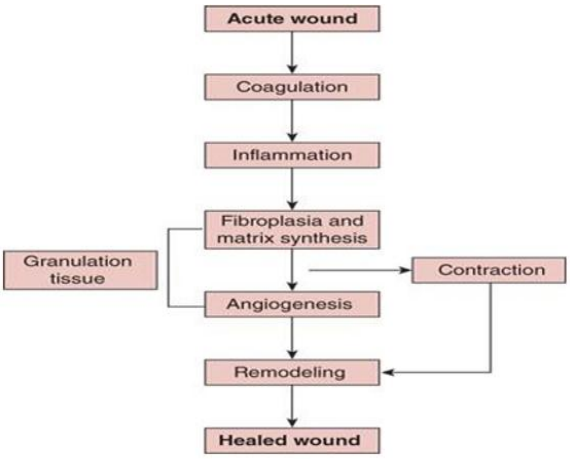

Figure. 1.2. Mechanism of wound healing

- Categorizing Wounds

Understanding the Basis of Classification Wounds are categorized based on their underlying etiology and the physiology of wound healing. Two primary classifications are open wounds and closed wounds, while wounds can also be classified as acute or chronic, depending on the nature of the healing process. (26)

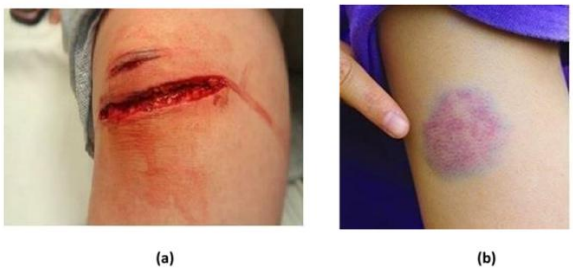

Figure.1.3. Types of wounds: (a) Open wound (b) Closed wound.

II. PLANT PROFILE

Figure.2.1. Mussaenda erythrophylla

Table: 2.1 Taxonomic Classification of Mussaenda erythrophylla

Kingdom	Plantae
Phylum	Streptophyta
Class	Equistopsida
Sub-class	Magnolidae
Order	Gentianales
Family	Rubiaceae
Genus	Mussaenda
Species	M.Erythrophylla

Phytochemical Constituents Driving Wound-Healing Mechanisms

The therapeutic efficacy of the leaf extract of Mussaenda erythrophylla in promoting wound contraction and tissue remodeling is attributed to a rich matrix of specific bioactive secondary metabolites. These main constituents function synergistically across the overlapping phases of wound healing:

Flavonoids (Quercetin and Kaempferol), Tannins, Terpenoids and Steroids (beta)-sitosterol), Saponins.

III. RATIONALE FOR SELECTION

The leaves of Mussaenda erythrophylla possess significant therapeutic potential, particularly due to their documented anti-inflammatory, antimicrobial, and tissue-regenerating properties. These medicinal benefits are attributed to bioactive phytochemicals-such as flavonoids, tannins, and saponins-which can be effectively isolated using ethanol as a solvent. The resulting ethanolic extract serves as an excellent agent to stimulate cellular proliferation and accelerate the natural wound recovery cascade.

Despite these pharmacological benefits, applying raw liquid extracts directly to an injured skin site is impractical due to poor retention, rapid evaporation, and inconsistent dosing. To resolve these delivery challenges, this study aims to incorporate the ethanolic extract of Mussaenda erythrophylla leaves into a simple, standardized topical gel base. Utilizing a straightforward hydrogel network provides a physically stable, bioadhesive system that stays in direct contact with the affected tissue. This formulation maintains an optimal, moist environment efficient skin healing. necessary for cellular migration, ensures uniform distribution of the plant's active constituents, and offers an easy, non-greasy application that supports.

IV. MATERIAL & MATERIAL

Table. 4.1 Comprehensive List of Ingredients, Botanical Materials, and Procurement Sources

S.No.	Name of Ingredient / Material	Official Grade	Commercial Source / Procurement Origin	Specific Functional Role in the Formulation
1.	Mussaenda erythrophylla leaves	Botanical Crude	Locally collected from authenticated botanical gardens, dried, and processed in-house.	Active Pharmaceutical Ingredient (Source of bioactive flavonoids/tannins for wound healing).
2.	Carbopol 940 (Carbomer 940)	Pharma Grade	Lubrizol Advanced Materials India Pvt. Ltd., Mumbai.	Primary hydrophilic gelling polymer (imparts viscosity and bioadhesive behavior).
3.	Colloidal Silicon Dioxide (Silica Powder / Aerosil 200)	Pharma Grade	Merck Life Science Pvt. Ltd., Mumbai.	Structural modifying matrix, rheological stabilizer, and anti-syneresis agent.
4.	Propylene Glycol	AR Grade	Merck Life Science Pvt. Ltd., Mumbai.	Co-solvent for plant extracts, humectant, and skin penetration enhancer.
5.	Glycerol (Glycerin)	AR Grade	Merck Life Science Pvt. Ltd., Mumbai.	Co-humectant, plasticizer, and moisturizing agent to maintain a moist wound environment.
6.	Methyl Paraben	IP / BP Grade	Clariant India Ltd., Mumbai.	Hydrophilic antimicrobial preservative (prevents fungal and bacterial growth in the gel).
7.	Propyl Paraben	IP / BP Grade	Clariant India Ltd., Mumbai.	Lipophilic antimicrobial preservative (works synergistically with methyl paraben).
8.	Triethanolamine (TEA)	AR Grade	Merck Life Science Pvt. Ltd., Mumbai.	Alkaline neutralizing agent (adjusts pH to induce polymer swelling and gelation).
9.	Absolute Ethanol (99.9%)	AR Grade	Changshu Hongsheng Fine Chemical Co., Ltd. (Imported via standard Indian distributors).	Extraction solvent used to prepare the 80% v/v aqueous ethanolic extraction medium.
10.	Purified Water	IP Grade	Generated in-house, D. K. Patil Institute of Pharmacy, Loha.	Continuous vehicle phase, solvent base, and moisturizing medium.
11.	TLC Silica Gel GF254 Plates	Analytical	Merck KGaA, Darmstadt, Germany.	Stationary phase matrix for phytochemical fingerprinting and (R_f) value determination.
12.	Vanillin, Sulphuric Acid, Toluene, Ethyl Acetate, Formic Acid	AR Grade	SD Fine-Chem Limited (SDFCL), Mumbai.	Mobile phase solvents and chemical derivatization spray reagents for TLC visualization.

- Authentication: The Mussaenda erythrophylla leaves were officially identified and verified by a botany expert to ensure research purity.
- Washing: The sorted leaves were washed under running tap water, followed by multiple rinses with distilled and deionized water.
- Drying: The leaves were shade-dried on stainless-steel trays at controlled room temperature and humidity for 21 days.
- Pulverization: Dried leaves were ground into a coarse powder and passed through a 1mm mesh sieve to achieve uniformity.
- Extraction: An 80% v/v aqueous ethanolic solvent system was selected as the optimal method for extracting active plant compounds.

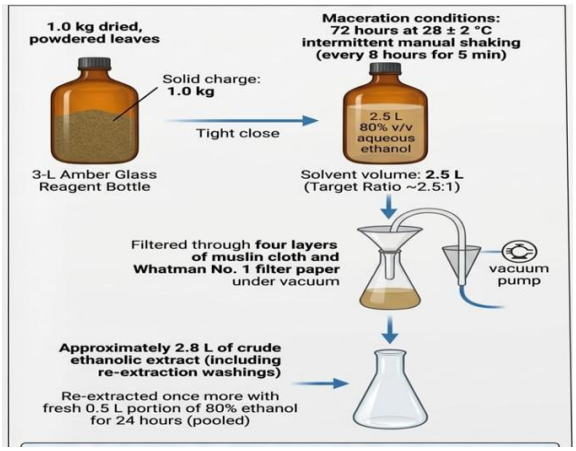

Figure. 4.1. Modified Cold Maceration Procedure

Gel Formulation Process Summary

The document outlines a four-stage experimental sequence for preparing an herbal gel formulation using Mussaenda erythrophylla extract:

Stage 1: Polymer Hydration

- Material: 1.0 g Carbopol 940 dissolved in 60 g distilled water.
- Process: Stirred at 500 rpm and soaked for 12–14 hours.
- Purpose: Achieves maximum polymer swelling and uniform dispersion.

Stage 2: Extract Integration

- Material: 5.0 g dried plant extract blended with silica powder.
- Process: Formed into a slurry and mixed into the polymer at 1000–1200 rpm.
- Purpose: Uniformly distributes active phytochemicals and prevents clustering.

Stage 3: Preservatives & Humectants

- Material: Propylene glycol, glycerol, methyl paraben, and propyl paraben.
- Process: Heated at 40 °C to dissolve, cooled, and stirred in at 600 rpm.
- Purpose: Incorporates stabilizing agents and moisture-retaining ingredients.

Stage 4: Neutralization & Packaging

- Material: Triethanolamine (TEA) added to neutralize the mixture.
- Process: Adjusted to pH \(6.0 \pm 0.2\), brought to 100 g, and tubed.
- Outcome: Forms a stable gel matrix, with batch HG03 selected for evaluation

V. RESULT & DISCUSSION

5.1 Collection and Authentication of Plant Material

The collected leaves were healthy, free from disease, and free from any visible signs of contamination. The plant material was collected during the appropriate growing season and transported to the laboratory for further processing. The collected plant material was authenticated. The authenticated leaves were washed thoroughly with distilled water to remove adhering dust and other foreign matter. The cleaned leaves were then shade-dried, powdered, and stored in airtight containers for further extraction and formulation studies.

Figure. 5.1. Prepared powder sample of Mussenda erythrophylla leves

5.2 Extraction Yield

The modified cold maceration of 1000 g of powdered plant material yielded a dark green, amorphous, and highly hygroscopic powder. The total mass of the recovered lyophilized dry extract was 118.4 g.

The percentage yield was calculated as follows:

$$\% \text{ Yield} = \left(\frac{\text{Weight of dried extract obtained}}{\text{Weight of powdered plant material taken}} \right) \times 100$$

$$\% \text{ Yield} = \left(\frac{118.4 \text{ g}}{1000 \text{ g}} \right) \times 100 = 11.84\% \text{ w/w}$$

5.3 Extraction of Mussenda erythrophylla leves

Figure: 5.2: Mussenda erythrophylla leves extract

Extraction of Mussenda erythrophylla powder was done by cold macesseration process in D K Patil Institute of pharmacy Loha, Nanded.

5.4 Qualitative Phytochemical Tests

Table: 5.1: Phytochemical Tests

Phytoconstituent	Result	Observation
Alkaloids	+	Creamish ppt
Flavonoids	+++	Pink
Tannins	+++	Bluish-black
Saponins	+++	Froth formed
Terpenoids	+++	Reddish-brown
Steroids	+	Bluish-green
Phenols	+++	Greenish-blue
Glycosides	+	Brown ring
Anthraquinones	+	Pink/red

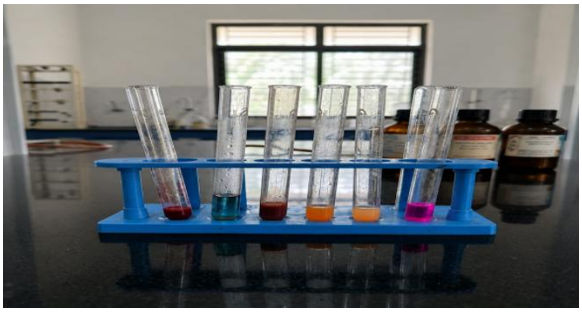

Figure: 5.3: Phytochemical tests

5.5 FTIR analysis

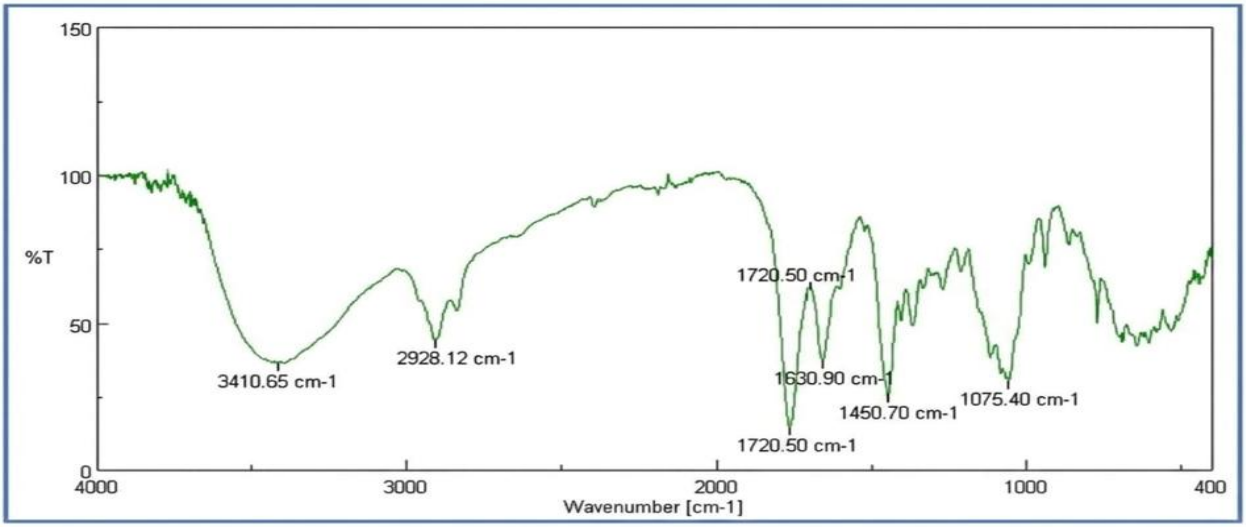

Figure: 5.4: FT-IR spectra of Leaf Extract (Mussaenda erythrophylla)

FTIR analysis of Mussaenda erythrophylla leaves extract was carried out to identify the various functional groups and specific bioactive compounds present in the extract. The FTIR spectrum exhibited a broad absorption peak at 3410.65 cm^{-1}, indicating O-H stretching vibrations characteristic of phenolic and flavonoid aglycones, specifically validating the presence of Quercetin and Kaempferol derivatives. Peaks observed at 2928.12 cm^{-1} correspond to aliphatic C-H stretching vibrations, pointing to the structural hydrocarbon skeletons of triterpenoids like Oleanolic acid and Ursolic acid, as well as phytosterols like β-sitosterol.

A strong, sharp peak at 1720.50 cm^{-1} confirmed the presence of carbonyl C=O ester and lactone functional groups, which directly align with the distinctive iridoid core structure found in Iridoid glycosides (such as Aucubin and Mussaendoside groups). The absorption peak at 1630.90 cm^{-1} indicated aromatic C=C stretching vibrations, validating the highly conjugated benzene ring systems inherent to Quercetin and condensed tannins.

Furthermore, the absorption bands at 1450.70 cm^{-1} and 1075.40 cm^{-1} reflect aliphatic text C-H deformations and C-O stretching linkages from sugar moieties, heavily suggesting the presence of flavonoid glucosides**,** saponins, and structural carbohydrates. The intricate fingerprint region below 1000 cm^{-1}further confirms the presence of complex secondary metabolites unique to this plant family.

Overall, the FTIR analysis demonstrated a rich density of core wound-healing biomarkers - specifically Quercetin, Kaempferol, Mussaendosides, Aucubin, Oleanolic acid, and Tannins - which collectively orchestrate its therapeutic pharmacological activity.

5.6 Formulation of Gel

Table No: 5.2: Quantitative Master Formula for Silica-Stabilized Herbal Gel

S.No.	Ingredient Name	HG01 (g)	HG02 (g)	HG03 (Optimized) (g)	HG04 (g)	HG05 (g)	Specific Functional Role
1.	MELE (M. erythrophylla Extract)	5.00	5.00	5.00	5.00	5.00	Active Pharmaceutical Ingredient
2.	Carbopol 940	1.00	1.00	1.00	1.00	1.00	Hydrophilic Gelling Agent
3.	Colloidal Silicon Dioxide (Silica)	1.00	2.00	3.00	4.00	5.00	Structural Modifier / Stabilizer
4.	Propylene glycol	10.00	10.00	10.00	10.00	10.00	Co-solvent / Skin Humectant
5.	Glycerol	5.00	5.00	5.00	5.00	5.00	Moisture Retaining Plasticizer
6.	Methyl paraben	0.18	0.18	0.18	0.18	0.18	Hydrophilic Preservative
7.	Propyl paraben	0.02	0.02	0.02	0.02	0.02	Lipophilic Preservative
8.	Triethanolamine (TEA)	q.s. to pH 5.92	q.s. to pH 6.05	q.s. to pH 6.00	q.s. to pH 6.08	q.s. to pH 5.97	pH Adjuster & Gel Activator
9.	Purified water	q.s. to 100 g	q.s. to 100 g	q.s. to 100 g	q.s. to 100 g	q.s. to 100 g	Aqueous Dispersion Vehicle

5.6.1: Prepared Gel

Figure: 5.5: Prepared Gel (Mussaenda erythrophylla)

5.7 FT-IR spectra of Optimized Leaf Extract Loaded Wound Healing Gel

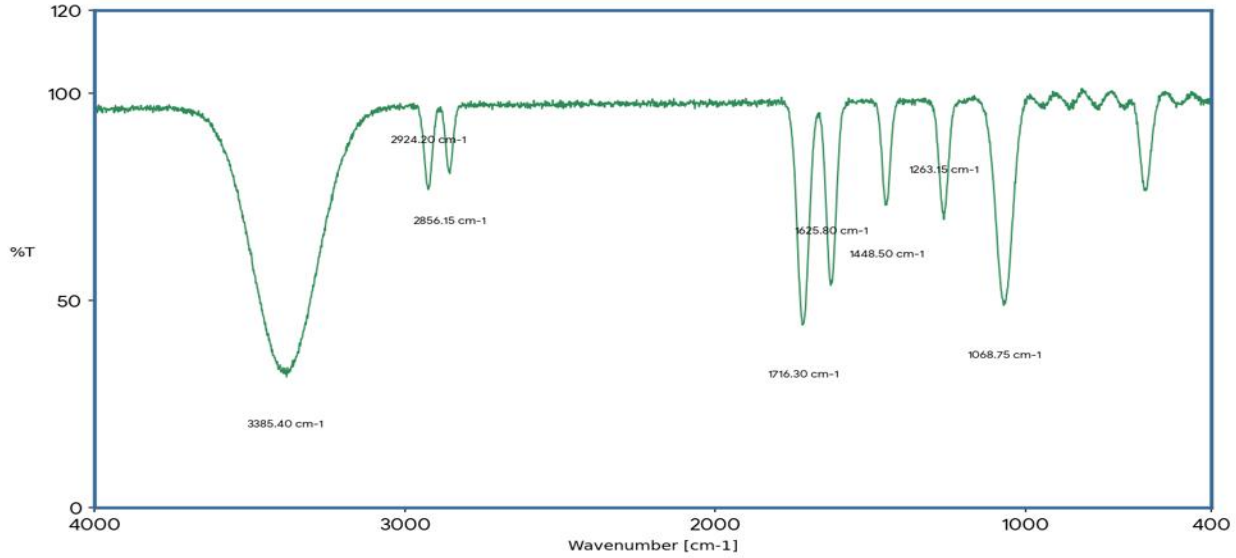

Figure 5.6: FT-IR spectra of Optimized Leaf Extract Loaded Wound Healing Gel

FTIR spectrum of Mussaenda erythrophylla leaves extract wound healing gel formulation showed several characteristic absorption peaks corresponding to important phytochemical functional groups.

The broad peak observed at 3385.40 cm^{-1}indicates O-H stretching vibrations, confirming the presence of phenolic compounds and flavonoids, which are responsible for antioxidant activity in the formulation. The peak at 2924.20 cm^{-1} corresponds to C-H stretching of aliphatic compounds, matching the triterpenoid core of Oleanolic acid.

The absorption peak at 1716.30 cm^{-1} confirmed the presence of carbonyl C=O functional groups from iridoid glycosides and the hydrogel matrix, while the peak at 1625.80 cm^{-1}suggests the presence of aromatic C=C bonds and amide groups, indicating flavonoids like Quercetin and proteinaceous components. Peaks around 1263.15 cm^{-1} and 1068.75 cm^{-1} represent C-O and C-O-C stretching vibrations, confirming alcohols, ethers, and carbohydrate/glycosidic derivatives from saponins inside the gel matrix. The fingerprint region below 1000 cm^{-1} indicates complex phytochemical constituents present in the extract. Overall, the FTIR analysis confirms the presence of various bioactive compounds such as phenols, flavonoids, terpenoids, glycosides, and carbohydrates in Mussaenda erythrophylla leaves extract wound healing gel formulation.

5.8 Evaluation

Five batches (HG1–HG5) of Mussaenda erythrophylla wound healing gel were successfully formulated and evaluated for various physicochemical parameters including physical appearance, homogeneity, pH, viscosity, spreadability, washability, and drug content.

5.8.1 Physical Appearance

All gel formulations were visually inspected for color, clarity, and consistency.

Table 5.3: Physical Appearance of HG Batches with Discussion

Batch	Color	Clarity	Consistency	Remarks	Interpretation
HG1	Light green	Clear	Smooth	Acceptable	Acceptable appearance
HG2	Green	Clear	Smooth	Acceptable	Good uniformity
HG3	Dark green	Clear	Smooth	Best	Best appearance, uniform color, proper extract incorporation
HG4	Green	Slight haze	Smooth	Good	Slight turbidity observed
HG5	Dark green	Clear	Slightly thick	Good	Slightly higher thickness

Discussion: All batches showed acceptable organoleptic properties. HG3 exhibited superior appearance with uniform color and smooth texture, indicating efficient incorporation of the plant extract.

5.8.2 Homogeneity Study

Table 5.4: Homogeneity Study

Batch	Homogeneity	Grittiness	Phase Separation	Interpretation
HG1	Good	Absent	No	Uniform dispersion
HG2	Good	Absent	No	Stable formulation
HG3	Excellent	Absent	No	Excellent uniformity and stability
HG4	Excellent	Absent	No	Proper dispersion of extract
HG5	Good	Absent	No	Acceptable homogeneity

Discussion Notes

- HG1: Shows a uniform dispersion.
- HG2: Results in a stable formulation.
- HG3: Demonstrates excellent uniformity and stability.
- HG4: Achieves a proper dispersion of the extract.
- HG5: Exhibits acceptable homogeneity.

5.8.3 Physicochemical Evaluation

Table 5.5: Physicochemical Evaluation with Interpretation (Mean ± SD, n = 3)

Batch	pH	Viscosity (cP)	Spreadability (cm)	Drug Content (% w/w)	Interpretation
HG1	6.12 ± 0.06	28,400 ± 320	5.9 ± 0.2	96.8 ± 1.9	Within acceptable limits
HG2	6.08 ± 0.04	29,100 ± 280	6.1 ± 0.1	98.2 ± 1.4	Good performance
HG3	6.18 ± 0.03	29,600 ± 210	6.3 ± 0.1	99.4 ± 0.9	Optimized formulation with best overall properties
HG4	6.05 ± 0.05	28,800 ± 310	6.0 ± 0.2	97.5 ± 1.6	Acceptable formulation
HG5	6.24 ± 0.07	28,200 ± 340	5.8 ± 0.3	97.1 ± 1.8	Slightly lower spreadability

The formulations were evaluated for pH, viscosity, spreadability, and drug content.

Results are summarized below.

pH: The pH of all formulations ranged from 6.05 to 6.24, which is within the acceptable skin pH range.

Discussion: HG3 exhibited optimal pH (6.18), making it suitable for topical application without causing irritation.

Viscosity: Viscosity ranged between 28,200 and 29,600 cp.

Discussion: HG3 showed the highest viscosity, indicating better gel consistency and retention at the site of application.

Spreadability:

Spreadability values ranged from 5.8 to 6.3 cm.

Discussion: HG3 demonstrated maximum spreadability, indicating better ease of application and improved patient compliance.

Drug Content

Drug content ranged from 96.8% to 99.4%.

Discussion: All formulations showed uniform drug distribution. HG3 exhibited the highest drug content, confirming efficient incorporation of active constituents.

5.8.4 Washability

Washability of formulations was evaluated manually.

Table 5.6: Washability Study with Interpretation

Batch	Washability	Residue	Interpretation
HG1	Easy	No	Easily removable
HG2	Easy	No	Good washability
HG3	Easy	No	Ideal formulation
HG4	Moderate	Slight	Slight residue due to higher viscosity
HG5	Moderate	Slight	Moderate washability

Discussion:

HG1-HG3 were easily washable, whereas HG4 and HG5 showed slight residue due to higher viscosity.

7.8.5 Optimization of Formulation

Based on all evaluation parameters:

- HG3 showed optimum pH
- Highest viscosity
- Maximum spreadability
- Highest drug content

Conclusion:

HG3 was selected as the optimized formulation due to its superior physicochemical properties and overall performance.

7.8.6 Stability Study of Optimized Batch (HG3)

Table 5.7: Stability Study of Optimized Batch (HG3)

Time (months)	Appearance	pH	Viscosity (cP)	Spreadability (cm)	Drug Content (%)	Interpretation
0	Green, smooth	6.18	29,600	6.3	99.4	Initial stable condition
1	No change	6.15	29,300	6.2	99.1	No significant change
3	No change	6.12	28,800	6.2	98.6	Stable formulation
6	No change	6.09	28,600	6.1	97.9	Stable

Discussion:

No significant changes were observed in physical appearance, pH, viscosity spreadibility, drug content.

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