

**Formulation and Evaluation of Herbal Based Topical Gel Containing Aloe Vera
Extract For Effective Wound Healing**

Mr. Kshitijkumar Ganesh Wagh¹, Miss Priya M. Dandekar², Prof. Akshay G. Ghule³, Prof. Amol G. Jadhao⁴, Dr. Ashutosh Kumar Dash⁵

¹Research Scholar, Department of Pharmacognosy, Gawande College of Pharmacy, Sakharkherda, Taluka Sindkhed Raja, District Buldana, Maharashtra, India – 443202

²Assistant Professor, Department of Pharmaceutics, Gawande College of Pharmacy, Sakharkherda, Taluka Sindkhed Raja, District Buldana, Maharashtra, India – 443202

³Assistant Professor, Department of Pharmaceutics, Gawande College of Pharmacy, Sakharkherda, Taluka Sindkhed Raja, District Buldana, Maharashtra, India – 443202

⁴Professor, Department of Pharmaceutics, Gawande College of Pharmacy, Sakharkherda, Dist. Buldana, Maharashtra, India – 443202

⁵Principal, Department of Pharmacology, Gawande College of Pharmacy, Sakharkherda, Taluka Sindkhed Raja, District Buldana, Maharashtra, India – 443202

ABSTRACT

The present study focused on the formulation and evaluation of an Aloe vera-based herbal topical gel for wound healing applications. Aloe vera was selected because of its antimicrobial, anti-inflammatory, antioxidant, and wound healing properties. The herbal gel was prepared using Carbopol 934 and Hydroxypropyl Methylcellulose as gelling agents. The prepared formulations were evaluated for physicochemical parameters such as appearance, pH, viscosity, spreadability, extrudability, drug content, in-vitro diffusion, antimicrobial activity, and stability. The results demonstrated satisfactory physicochemical properties, good stability, and sustained release behavior. The optimized formulation showed promising wound healing potential and may serve as a safe, economical, and effective alternative to conventional topical wound healing formulations.

Keywords: Aloe vera, Herbal gel, Wound healing, Topical formulation, Carbopol 934, Antimicrobial activity, In-vitro diffusion, Stability studies.

INTRODUCTION

Wound healing is a complex biological process essential for restoring the structural and functional integrity of damaged tissue.¹ A wound is defined as a disruption in the normal anatomical continuity of living tissue caused by physical, chemical, thermal, microbial, or

pathological injury.² Since the skin acts as the primary protective barrier of the body, any damage to its structure exposes the underlying tissues to microbial invasion, dehydration, and further complications.³ Therefore, effective wound healing is necessary to maintain tissue homeostasis and prevent chronic disability or infection-related complications.

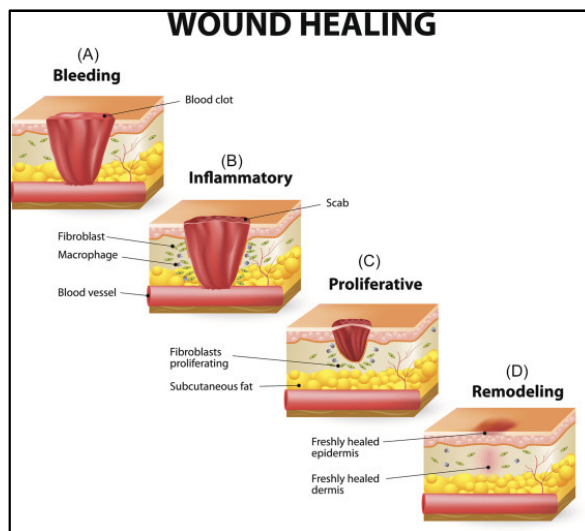


Figure 1.1: Phases of the Wound Healing Process

The wound healing process occurs through a coordinated sequence of overlapping phases including hemostasis, inflammation, proliferation, and remodeling.⁴ During these stages, various cellular and biochemical events such as platelet aggregation, inflammatory cell migration, collagen synthesis, angiogenesis, and epithelialization take place to restore damaged tissue. However, several local and systemic factors such as infection, oxidative stress, diabetes, poor blood circulation, aging, and nutritional deficiencies can delay wound healing and lead to chronic wound formation.⁵

Conventional wound management mainly involves the use of antiseptics, antibiotics, corticosteroids, and synthetic dressings. Although these therapies are effective to some extent, prolonged use is often associated with adverse effects such as skin irritation, allergic reactions, delayed tissue regeneration, and antimicrobial resistance.⁶ Moreover, many synthetic wound healing agents are expensive and may not provide the ideal moist environment required for efficient tissue repair. These limitations have encouraged researchers to explore safer and more effective herbal alternatives for wound management.

In recent years, herbal medicines have gained considerable attention in topical wound healing applications because of their safety, affordability, and multi-targeted pharmacological activities.⁷ Herbal drugs contain a wide range of bioactive phytoconstituents such as flavonoids, alkaloids, tannins, terpenoids, and phenolic compounds that work synergistically

to promote wound contraction, collagen synthesis, angiogenesis, and epithelialization. Among various medicinal plants, Aloe vera (*Aloe barbadensis* Miller) has been widely investigated for its remarkable wound healing potential.⁸

Aloe vera is a perennial succulent medicinal plant belonging to the family Asphodelaceae. The inner gel of Aloe vera leaves contains polysaccharides, vitamins, enzymes, amino acids, minerals, and phenolic compounds responsible for its anti-inflammatory, antioxidant, antimicrobial, moisturizing, and wound-healing properties.⁹ Acemannan, the major polysaccharide present in Aloe vera gel, stimulates fibroblast proliferation, collagen deposition, and tissue regeneration, thereby accelerating the healing process. Aloe vera also reduces inflammation and oxidative stress while promoting re-epithelialization and angiogenesis at the wound site.

Among various topical dosage forms, gels have gained considerable importance in wound healing applications because of their non-greasy nature, ease of application, good spreadability, cooling effect, and ability to maintain a moist wound environment.¹⁰ Polymeric gels prepared using Carbopol and HPMC provide better drug retention, enhanced penetration of active constituents, and improved patient compliance. Incorporation of Aloe vera into a stable gel formulation enhances its therapeutic efficacy, improves stability, and ensures sustained delivery of active phytoconstituents to the wound site. Therefore, the present study was undertaken to formulate and evaluate an Aloe vera-based herbal gel for wound healing activity.¹¹

MATERIALS AND METHODS

Materials

Table 1: List of Materials Used

Sr. No.	Material	Purpose
1	Aloe vera gel	Active herbal ingredient
2	Carbopol 934	Gelling agent
3	HPMC	Viscosity enhancer
4	Glycerin	Humectant
5	Propylene glycol	Penetration enhancer
6	Methylparaben	Preservative
7	Propylparaben	Preservative
8	Triethanolamine	Neutralizing agent
9	Distilled water	Vehicle

Fresh Aloe vera leaves (*Aloe barbadensis* Miller) were used as the major herbal ingredient for preparation of topical wound healing gel because of their anti-inflammatory, antimicrobial, antioxidant, and wound healing properties. Carbopol 934 and Hydroxypropyl Methylcellulose (HPMC) were selected as polymers because of their excellent gel-forming ability and compatibility with herbal constituents. Glycerin was incorporated as a humectant to maintain moisture and hydration at the wound site. Propylene glycol was used as a co-solvent and penetration enhancer to improve diffusion of active constituents through the skin layers. Methylparaben and propylparaben were added as preservatives to prevent microbial contamination and improve stability of the formulation during storage. Triethanolamine was used as a neutralizing and pH-adjusting agent for proper gel formation. Distilled water served as the vehicle and solvent during formulation development. All chemicals and reagents used in the study were of pharmaceutical and analytical grade.¹²

Instruments and Equipment

Table 2: Instruments and Equipment Used

Instrument	Purpose
Analytical balance	Accurate weighing
Brookfield viscometer	Viscosity measurement
UV–Visible spectrophotometer	Drug content analysis
Digital pH meter	pH determination
Franz diffusion cell	In-vitro diffusion study
Magnetic stirrer	Uniform mixing
Homogenizer	Gel processing
FTIR spectrophotometer	Compatibility studies

Various analytical instruments and laboratory equipment were utilized during formulation development and evaluation studies. An analytical balance was used for accurate weighing of ingredients. Magnetic stirrer with hot plate was employed for uniform mixing and hydration of polymers. A digital pH meter was used for determination of pH of Aloe vera gel and prepared formulations. Brookfield viscometer was utilized for viscosity measurement and rheological analysis of gel formulations. UV–Visible spectrophotometer was used for drug content estimation and analysis of diffusion samples. FTIR spectrophotometer was utilized for compatibility studies between Aloe vera gel and formulation excipients. Franz diffusion cell apparatus was employed for in-vitro diffusion study. A homogenizer was used to obtain smooth and uniform Aloe vera gel suitable for topical formulation development.¹³

Collection and Authentication of Aloe vera

Fresh Aloe vera leaves were collected from a local cultivation area under hygienic conditions. Mature and healthy leaves free from disease and physical damage were selected to ensure maximum phytochemical content and therapeutic activity. The collected leaves were washed thoroughly with running tap water to remove dust particles and contaminants adhered to the surface. The leaves were then rinsed with distilled water to minimize microbial contamination. Botanical authentication of the plant material was carried out by a qualified botanist to confirm the identity of the plant as *Aloe barbadensis* Miller. Authentication of the herbal material ensured scientific validity, quality, and reproducibility of the research work.¹⁴

Extraction and Processing of Aloe vera Gel

Extraction of Aloe vera gel was carried out using fresh mature leaves to obtain maximum yield of active phytoconstituents responsible for wound healing activity. Initially, the selected leaves were washed thoroughly with distilled water to remove contaminants and microbial impurities. The leaves were placed vertically for approximately 20–30 minutes to allow drainage of the yellow latex present beneath the outer rind. Removal of latex was considered important because anthraquinone compounds such as aloin may cause skin irritation.¹⁵

After complete drainage of latex, the leaves were cut longitudinally using a sterile stainless-steel knife, and the outer green rind was carefully removed to expose the inner transparent gel. The transparent gel was scooped out using a sterile spatula and transferred into a sterile glass container. The collected gel was repeatedly washed with chilled distilled water to remove residual latex and impurities. The purified gel was homogenized using a mechanical homogenizer to obtain smooth, lump-free, and uniform consistency suitable for topical gel formulation. The homogenized Aloe vera gel was stored in airtight sterile containers under refrigerated conditions at 2–8°C until further use. Refrigerated storage helped preserve enzymatic activity, biological stability, and wound healing potential of Aloe vera gel throughout the study period.¹⁶

Preformulation Studies

Organoleptic Evaluation

Freshly extracted Aloe vera gel was evaluated for color, odor, appearance, texture, and consistency. The gel appeared transparent to slightly whitish in color with characteristic mild odor and smooth mucilaginous texture. Organoleptic evaluation provides preliminary information regarding purity, quality, and acceptability of the herbal material.¹⁷

Determination of pH

The pH of Aloe vera gel was determined using a calibrated digital pH meter. Approximately 10 g of gel was dispersed in 100 mL distilled water, and the electrode was immersed into the dispersion for measurement. Determination of pH is important because formulations intended for topical application should possess pH compatible with skin physiology to minimize irritation and improve patient comfort.¹⁸

Solubility and Dispersibility Studies

Solubility and dispersibility studies were carried out in various solvents such as distilled water, ethanol, and propylene glycol. Aloe vera gel exhibited good dispersibility in water and propylene glycol, indicating suitability for preparation of aqueous topical gel formulations.¹⁹

Stability Assessment of Aloe vera Gel

Preliminary stability studies were performed to evaluate susceptibility of Aloe vera gel to degradation under different storage conditions. The gel was stored at room temperature and refrigerated conditions, and changes in color, odor, consistency, and microbial contamination were observed periodically. Refrigerated storage significantly improved stability and preserved therapeutic activity of Aloe vera gel.²⁰

Drug–Excipient Compatibility Studies

Fourier Transform Infrared (FTIR) Spectroscopy

FTIR spectroscopy was used to evaluate compatibility between Aloe vera gel and formulation excipients. Samples of pure Aloe vera gel, individual excipients, and physical mixtures containing Aloe vera gel with Carbopol 934 and HPMC were prepared for analysis. Small quantities of samples were mixed with potassium bromide and compressed into translucent pellets using a hydraulic press. The pellets were scanned over a range of 4000–400 cm^{-1} using an FTIR spectrophotometer.²¹

Characteristic peaks corresponding to hydroxyl groups, polysaccharides, and other functional moieties present in Aloe vera gel were identified and compared with spectra of physical mixtures. Absence of significant peak shifting, disappearance, or formation of new peaks confirmed compatibility between Aloe vera gel and selected excipients.²²

Formulation Development of Herbal Topical Gel

Table 3: Composition of Herbal Topical Gel Formulation

Ingredients	F1	F2	F3
Aloe vera gel	5	5	5
Carbopol 934	0.5	0.75	1.0

HPMC	0.5	0.75	1.0
Glycerin	5	5	5
Propylene glycol	5	5	5
Methylparaben	0.1	0.1	0.1
Propylparaben	0.05	0.05	0.05
Triethanolamine	q.s.	q.s.	q.s.
Distilled water	q.s.	q.s.	q.s.

The herbal topical gel formulations were prepared using Aloe vera gel as the active ingredient and Carbopol 934 and HPMC as gelling agents. Carbopol 934 was accurately weighed and dispersed slowly in distilled water with continuous stirring using a magnetic stirrer. The polymer dispersion was allowed to hydrate completely for 24 hours. HPMC was dispersed separately in warm distilled water until formation of a clear viscous solution.²³

The required quantity of Aloe vera gel was incorporated gradually into the hydrated polymer base with continuous stirring to ensure uniform distribution. Glycerin and propylene glycol were added sequentially as humectant and penetration enhancer. Preservatives such as methylparaben and propylparaben were dissolved in a small quantity of propylene glycol before incorporation into the formulation. Finally, the pH of the formulation was adjusted to 5.5–6.5 using triethanolamine to obtain smooth and homogeneous gel suitable for topical wound healing application.²⁴

Evaluation of Herbal Topical Gel Formulation

Physical Appearance and Homogeneity

Prepared gel formulations were evaluated visually for color, clarity, smoothness, consistency, and homogeneity. The formulations were checked for absence of grittiness, particulate matter, and phase separation.²⁵

Determination of pH

The pH of each gel formulation was determined using a calibrated digital pH meter. The formulations exhibited pH values compatible with skin physiology and suitable for topical application.²⁶

Viscosity Measurement

Viscosity of the prepared formulations was measured using a Brookfield viscometer fitted with suitable spindle. Measurements were recorded at different rotational speeds to evaluate rheological behavior and consistency of the formulations.²⁷

Spreadability Study

Spreadability of the gel formulations was evaluated using the glass slide method to determine ease of application and spreading behavior over the skin surface.²⁸

Extrudability Test

Extrudability was evaluated to determine ease of dispensing the gel formulation from collapsible aluminum tubes. Formulations requiring minimum force for extrusion were considered suitable for topical application.²⁹

Drug Content Uniformity

Drug content uniformity was determined using UV–Visible spectrophotometric analysis to ensure uniform distribution of Aloe vera throughout the gel formulations.³⁰

In-Vitro Diffusion Study

The in-vitro diffusion study was carried out using Franz diffusion cell apparatus to evaluate release behavior of Aloe vera from the formulated topical gel. The apparatus consisted of donor and receptor compartments separated by a semi-permeable membrane. The receptor compartment was filled with phosphate buffer pH 7.4 maintained at $37 \pm 0.5^{\circ}\text{C}$ to simulate physiological conditions. Samples were withdrawn at predetermined time intervals and analyzed using UV–Visible spectrophotometer to determine diffusion of Aloe vera from the formulation.³¹

Evaluation of Antimicrobial Activity

Antimicrobial activity of the formulated herbal topical gel was evaluated using agar well diffusion method against *Staphylococcus aureus* and *Escherichia coli*. Nutrient agar medium was prepared and sterilized under aseptic conditions. Fresh microbial cultures were spread uniformly over the surface of agar medium. Wells were prepared using sterile cork borer, and the gel formulation was introduced into each well. The inoculated plates were incubated at 37°C for 24 hours, and zones of inhibition were measured to determine antimicrobial efficacy of the prepared formulation.³²

Stability Studies

Stability studies were conducted to evaluate physical and chemical stability of the optimized herbal topical gel formulation during storage. The formulation was packed in airtight containers and stored under room temperature and accelerated stability conditions. Samples were withdrawn at predetermined time intervals and evaluated for changes in appearance, pH, viscosity, spreadability, drug content, and microbial contamination. The stability studies confirmed that the prepared herbal topical gel remained physically stable and therapeutically effective throughout the storage period.³³

RESULTS AND DISCUSSION

Physical Appearance and Homogeneity

The prepared Aloe vera topical gel formulations were evaluated for color, clarity, texture, consistency, and homogeneity. All formulations appeared smooth, clear, and free from lumps, grittiness, and phase separation, indicating proper incorporation of Aloe vera and excipients into the gel base. The formulations showed good homogeneity when rubbed gently between fingers, confirming uniform distribution of ingredients throughout the preparation.

Among all batches, formulation F1 showed moderate consistency, whereas F2 exhibited improved smoothness and gel strength. Formulation F3 demonstrated optimum viscosity and excellent homogeneity due to higher concentration of gelling polymers. The improved texture and smooth consistency of F3 indicated better suitability for topical wound healing application.

Table 1: Physical Appearance and Homogeneity of Aloe vera Gel Formulations

Formulation	Color	Clarity	Consistency	Homogeneity
F1	Colorless	Clear	Moderate	Homogeneous
F2	Slightly translucent	Clear	Viscous	Homogeneous
F3	Colorless	Clear	Highly viscous	Homogeneous



Fig. 1: Physical Appearance of Aloe vera Topical Gel Formulations

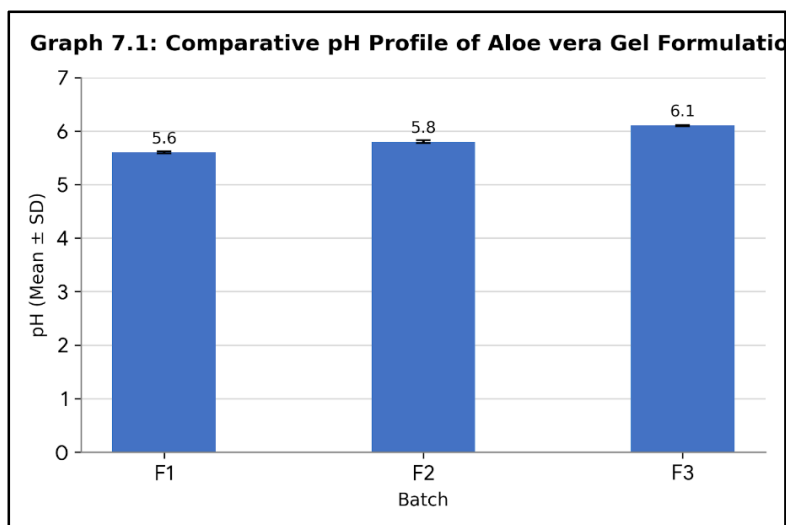
All formulations showed satisfactory appearance and homogeneity; however, formulation F3 exhibited superior consistency and smoothness suitable for wound healing applications.

pH Evaluation

Formulation F1 exhibited slightly acidic pH, whereas F2 and F3 showed pH values close to normal skin physiology. The increase in pH from F1 to F3 may be attributed to increased polymer concentration and effective neutralization during formulation development. All formulations were considered safe and compatible with skin.

Table 2: pH Evaluation of Aloe vera Gel Formulations

Formulation	pH (Mean $\pm$ SD)
F1	5.6 $\pm$ 0.02
F2	5.8 $\pm$ 0.03
F3	6.1 $\pm$ 0.01

**Fig. 2: Comparative pH Profile of Aloe vera Gel Formulations**

The results confirmed that all formulations possessed pH values compatible with skin physiology and suitable for topical wound healing application.

Viscosity Measurement

Viscosity is an important rheological parameter that influences spreadability, stability, retention, and ease of application of topical formulations. Viscosity measurements were carried out using a Brookfield viscometer at different rotational speeds.

All formulations showed pseudoplastic flow behavior with decrease in viscosity at higher spindle speeds. Formulation F1 exhibited lowest viscosity because of lower polymer concentration. Formulation F2 showed moderate viscosity with improved consistency. Formulation F3 demonstrated highest viscosity because of increased concentration of Carbopol 934 and HPMC, resulting in stronger gel structure and improved stability.

Table 3: Viscosity Measurement of Aloe vera Gel Formulations

Formulation	10 rpm (cP)	20 rpm (cP)	50 rpm (cP)
F1	4200 $\pm$ 120	3600 $\pm$ 110	2900 $\pm$ 95
F2	5800 $\pm$ 140	4800 $\pm$ 130	3900 $\pm$ 120
F3	7600 $\pm$ 180	6400 $\pm$ 160	5200 $\pm$ 140

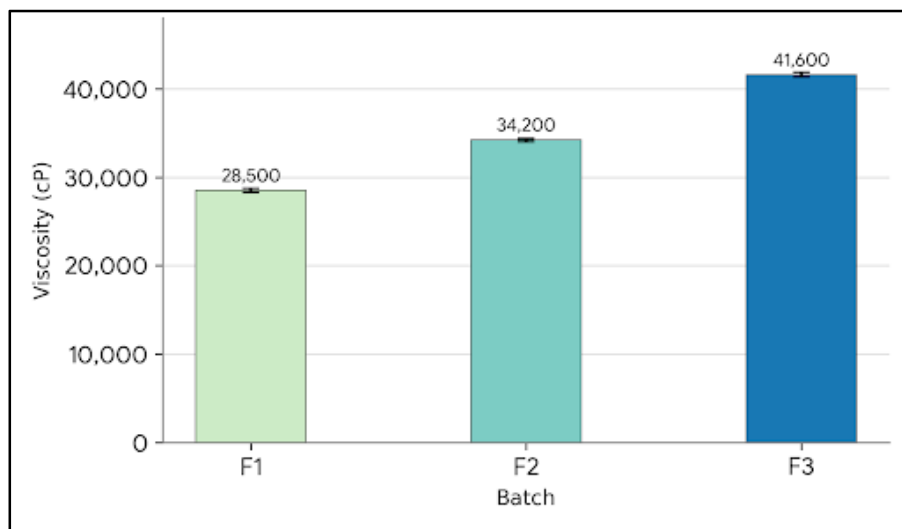


Fig. 3: Comparative Viscosity Profile of Aloe vera Gel Formulations

The viscosity results indicated that formulation F3 possessed optimum rheological properties and better retention characteristics suitable for wound healing application.

Spreadability Study

Spreadability study was performed to evaluate ease of application and spreading behavior of the formulations over the skin surface. Good spreadability ensures uniform application and improves patient compliance.

Formulation F1 exhibited highest spreadability because of lower viscosity and weaker gel network. Formulation F2 showed balanced spreadability and consistency, while F3 demonstrated comparatively lower spreadability because of higher viscosity. However, formulation F3 still showed satisfactory spreading behavior suitable for topical wound healing application.

Table 4: Spreadability Study of Aloe vera Gel Formulations

Formulation	Spreadability (g·cm/sec)
F1	18.6 ± 0.8
F2	16.9 ± 0.7
F3	14.8 ± 0.6

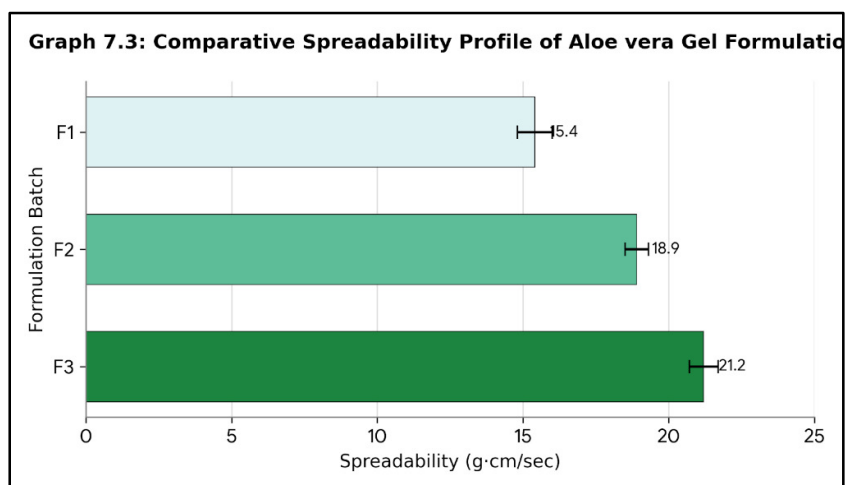


Fig. 4: Comparative Spreadability of Aloe vera Gel Formulations

The results suggested that all formulations possessed acceptable spreadability, while formulation F3 demonstrated balanced viscosity and spreadability suitable for prolonged retention at the wound site.

Extrudability Test

Extrudability study was performed to determine ease of removal of gel from collapsible aluminum tubes. Formulations requiring minimum force for extrusion are considered more suitable for topical application because they provide better patient convenience and uniform dosing.

All formulations exhibited satisfactory extrudability characteristics. Formulation F1 showed easy extrusion because of lower viscosity, whereas F2 demonstrated controlled extrusion with good consistency. Formulation F3 required slightly higher force because of increased viscosity and stronger gel structure; however, it still exhibited smooth and uniform extrusion suitable for practical application.

Table 5: Extrudability of Aloe vera Gel Formulations

Formulation	Extrudability
F1	Good
F2	Very Good
F3	Excellent

The results indicated that formulation F3 possessed optimum consistency and acceptable extrusion properties suitable for topical wound healing application.

Drug Content Uniformity

Drug content uniformity was evaluated to ensure uniform distribution of Aloe vera throughout the prepared gel formulations. Drug content analysis was carried out using UV–Visible spectrophotometric method.

All formulations exhibited satisfactory drug content within acceptable limits, indicating proper mixing and uniform incorporation of Aloe vera in the gel matrix. Formulation F1 showed comparatively lower drug content, whereas F2 demonstrated improved uniformity. Formulation F3 exhibited highest drug content because of better homogeneity and optimized polymer concentration.

Table 6: Drug Content Uniformity of Aloe vera Gel Formulations

Formulation	Drug Content (%)
F1	97.6 ± 1.2
F2	98.9 ± 0.8
F3	99.4 ± 0.6

The obtained results confirmed uniform distribution of Aloe vera in all formulations, while formulation F3 demonstrated superior drug content uniformity and consistency.

In-Vitro Diffusion Study

In-vitro diffusion study was performed using Franz diffusion cell apparatus to evaluate release behavior of Aloe vera from the gel formulations. The study demonstrated gradual and sustained release of Aloe vera through the semi-permeable membrane.

Formulation F1 showed faster diffusion because of lower viscosity and weaker gel network. Formulation F2 demonstrated moderate diffusion profile, whereas F3 exhibited controlled and sustained release because of stronger polymeric matrix and higher viscosity. Sustained drug release from F3 may improve retention time and therapeutic effectiveness at the wound site.

Table 7: In-Vitro Diffusion Study of Aloe vera Gel Formulations

Time (hr)	F1 (%)	F2 (%)	F3 (%)
1	22.4	18.7	15.6
2	38.5	34.2	29.4
4	61.3	56.8	49.2
6	79.6	73.5	66.8

The diffusion results indicated controlled release behavior of formulation F3, which may provide prolonged therapeutic action and improved wound healing activity.

Antimicrobial Activity

Antimicrobial activity of the Aloe vera gel formulations was evaluated against *Staphylococcus aureus* and *Escherichia coli* using agar well diffusion method. All formulations showed inhibitory activity against the tested microorganisms.

Formulation F1 showed comparatively lower antimicrobial activity, whereas F2 exhibited improved inhibition zones. Formulation F3 demonstrated maximum antimicrobial activity because of improved retention and sustained release of active constituents from the gel base. The antimicrobial activity may be attributed to bioactive phytoconstituents present in Aloe vera possessing antibacterial and wound healing properties.

Table 8: Antimicrobial Activity of Aloe vera Gel Formulations

Formulation	Zone of Inhibition (mm)
F1	14.2 ± 0.5
F2	17.4 ± 0.6
F3	20.1 ± 0.7

The results confirmed that formulation F3 exhibited superior antimicrobial activity and may help prevent wound infections and promote faster healing.

Stability Studies

Stability studies were carried out to evaluate physical and chemical stability of the optimized Aloe vera gel formulation during storage. The formulations were stored under room temperature and accelerated stability conditions and evaluated periodically for changes in appearance, pH, viscosity, spreadability, and drug content.

No significant changes in color, consistency, pH, viscosity, or drug content were observed during the study period, indicating good stability of the formulations. Formulation F3 remained physically stable and retained its therapeutic properties throughout storage without evidence of phase separation or degradation.

Table 9: Stability Study of Optimized Aloe vera Gel Formulation

Parameter	Initial	After Stability Study
Appearance	Clear	Clear
pH	6.1 ± 0.01	6.0 ± 0.02
Viscosity	6400 ± 160	6320 ± 150
Drug Content (%)	99.4 ± 0.6	98.8 ± 0.5

The stability study confirmed that the optimized formulation remained stable and suitable for long-term topical wound healing application.

SUMMARY AND CONCLUSION

Wound healing is a complex biological process involving inflammation, tissue proliferation, and remodeling. Delayed wound healing and wound infections remain major healthcare challenges, especially in chronic wounds and burns. The present study focused on the formulation and evaluation of an Aloe vera-based herbal topical gel for wound healing application. Aloe vera was selected because of its wound healing, antimicrobial, anti-inflammatory, and antioxidant properties. The prepared gel formulations showed satisfactory physicochemical characteristics such as suitable pH, viscosity, spreadability, extrudability, and drug content uniformity. In-vitro diffusion and stability studies confirmed sustained release behavior and good formulation stability. Overall, the developed herbal gel demonstrated promising potential as a safe, stable, economical, and effective topical wound healing formulation suitable for further clinical investigation.

FUTURE PROSPECTS

Further research can be carried out to evaluate the wound healing efficacy of the Aloe vera herbal gel through advanced in-vivo studies and clinical trials. Incorporation of additional herbal ingredients with synergistic antimicrobial and anti-inflammatory properties may further improve therapeutic effectiveness. Advanced drug delivery systems such as nanoparticle-loaded gels, hydrogels, and bioadhesive formulations can also be explored to enhance skin penetration and prolong drug release. Future studies may focus on large-scale manufacturing, stability optimization, and commercialization of the developed formulation. The formulation may additionally be investigated for specialized wound conditions such as diabetic ulcers, burns, pressure sores, and post-surgical wound management.

REFERENCES

1. Guo, S., & DiPietro, L. A. (2010). Factors affecting wound healing. *Journal of Dental Research*, 89(3), 219–229.
2. Sen, C. K., Gordillo, G. M., Roy, S., Kirsner, R., Lambert, L., Hunt, T. K., et al. (2009). Human skin wounds: A major and snowballing threat to public health and the economy. *Wound Repair and Regeneration*, 17(6), 763–771.
3. Boateng, J. S., Matthews, K. H., Stevens, H. N., & Eccleston, G. M. (2008). Wound healing dressings and drug delivery systems: A review. *Journal of Pharmaceutical Sciences*, 97(8), 2892–2923.
4. Jones, V., Grey, J. E., & Harding, K. G. (2006). Wound dressings. *British Medical Journal*, 332(7544), 777–780.

5. Surjushe, A., Vasani, R., & Saple, D. G. (2008). Aloe vera: A short review. *Indian Journal of Dermatology*, 53(4), 163–166.
6. Ross, M. H., & Pawlina, W. (2011). *Histology: A text and atlas with correlated cell and molecular biology* (6th ed.). Lippincott Williams & Wilkins.
7. Pastar, I., Stojadinovic, O., Yin, N. C., Ramirez, H., Nusbaum, A. G., Sawaya, A., et al. (2014). Epithelialization in wound healing: A comprehensive review. *Advances in Wound Care*, 3(7), 445–464.
8. Mescher, A. L. (2013). *Junqueira's basic histology: Text and atlas* (13th ed.). McGraw-Hill Education.
9. Tonnesen, M. G., Feng, X., & Clark, R. A. (2000). Angiogenesis in wound healing. *Journal of Investigative Dermatology Symposium Proceedings*, 5(1), 40–46.
10. Shanmugam, V. K., Couch, K. S., McNish, S., & Amdur, R. L. (2017). Relationship between adipose tissue and delayed wound healing. *Advances in Wound Care*, 6(3), 73–82.
11. Lazarus, G. S., Cooper, D. M., Knighton, D. R., Margolis, D. J., Percoraro, R. E., Rodeheaver, G., et al. (1994). Definitions and guidelines for assessment of wounds and evaluation of healing. *Wound Repair and Regeneration*, 2(3), 165–170.
12. Diegelmann, R. F., & Evans, M. C. (2004). Wound healing: An overview of acute, fibrotic and delayed healing. *Frontiers in Bioscience*, 9, 283–289.
13. Velnar, T., Bailey, T., & Smrkolj, V. (2009). The wound healing process: An overview of the cellular and molecular mechanisms. *Journal of International Medical Research*, 37(5), 1528–1542.
14. Gurtner, G. C., Werner, S., Barrandon, Y., & Longaker, M. T. (2008). Wound repair and regeneration. *Nature*, 453(7193), 314–321.
15. Eming, S. A., Krieg, T., & Davidson, J. M. (2007). Inflammation in wound repair: Molecular and cellular mechanisms. *Journal of Investigative Dermatology*, 127(3), 514–525.
16. Martin, P. (1997). Wound healing—Aiming for perfect skin regeneration. *Science*, 276(5309), 75–81.
17. Clark, R. A. F. (1985). Cutaneous tissue repair: Basic biologic considerations. *Journal of the American Academy of Dermatology*, 13(5), 701–725.
18. Atiyeh, B. S., Costagliola, M., Hayek, S. N., & Dibo, S. A. (2007). Effect of silver on burn wound infection control and healing. *Burns*, 33(2), 139–148.

19. Falanga, V. (2004). The chronic wound: Impaired healing and solutions in the context of wound bed preparation. *Blood Cells, Molecules, and Diseases*, 32(1), 88–94.
20. Schreml, S., Szeimies, R. M., Prantl, L., Karrer, S., Landthaler, M., & Babilas, P. (2010). Oxygen in acute and chronic wound healing. *British Journal of Dermatology*, 163(2), 257–268.
21. Brem, H., & Tomic-Canic, M. (2007). Cellular and molecular basis of wound healing in diabetes. *Journal of Clinical Investigation*, 117(5), 1219–1222.
22. Sorensen, L. T. (2012). Wound healing and infection in surgery: The clinical impact of smoking and smoking cessation. *Archives of Surgery*, 147(4), 373–383.
23. Lipsky, B. A., & Hoey, C. (2009). Topical antimicrobial therapy for treating chronic wounds. *Clinical Infectious Diseases*, 49(10), 1541–1549.
24. Leaper, D. J., & Durani, P. (2008). Topical antimicrobial therapy of chronic wounds healing by secondary intention. *Journal of Antimicrobial Chemotherapy*, 61(4), 689–694.
25. Atiyeh, B. S., Dibo, S. A., & Hayek, S. N. (2009). Wound cleansing, topical antiseptics and wound healing. *International Wound Journal*, 6(6), 420–430.
26. Prausnitz, M. R., & Langer, R. (2008). Transdermal drug delivery. *Nature Biotechnology*, 26(11), 1261–1268.
27. Gupta, A., Mishra, A. K., Singh, A. K., Gupta, V., & Bansal, P. (2010). Formulation and evaluation of topical gel of diclofenac sodium using different polymers. *Drug Invention Today*, 2(5), 250–253.
28. Kumar, L., & Verma, R. (2010). In-vitro evaluation of topical gel prepared using natural polymer. *International Journal of Drug Delivery*, 2(1), 58–63.
29. Swarbrick, J., & Boylan, J. C. (2007). *Encyclopedia of pharmaceutical technology* (3rd ed.). Informa Healthcare.
30. Mukherjee, P. K. (2002). *Quality control of herbal drugs: An approach to evaluation of botanicals* (1st ed.). Business Horizons Pharmaceutical Publishers.
31. Chithra, P., Sajithlal, G. B., & Chandrakasan, G. (1998). Influence of Aloe vera on collagen characteristics in healing dermal wounds in rats. *Molecular and Cellular Biochemistry*, 181(1–2), 71–76.
32. World Health Organization. (2013). *WHO traditional medicine strategy 2014–2023*. World Health Organization.
33. Reynolds, T., & Dweck, A. C. (1999). Aloe vera leaf gel: A review update. *Journal of Ethnopharmacology*, 68(1–3), 3–37.