

PREPARATION AND EVALUATION OF NOVEL MUCOADHESIVE HERBAL GEL FOR THROAT SOOTHING AND COUGH SUPPRESSION

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➤ Abstract

Cough and throat irritation are among the most prevalent symptoms encountered in clinical practice and are often manifestations of underlying respiratory infections, allergic reactions, or inflammation of the upper respiratory tract. Conventional cough syrups containing synthetic agents such as dextromethorphan, codeine, and guaifenesin are widely used but often produce side effects like sedation, gastrointestinal discomfort, and short-lived relief. Moreover, most liquid formulations suffer from limited mucosal contact and low patient compliance. In recent years, there has been a renewed global interest in plant-based therapies that offer safer and more holistic management of respiratory ailments. The present study aims to develop and evaluate a novel mucoadhesive herbal gel for throat soothing and cough suppression using hydroalcoholic extracts of *Adhatoda vasica*, *Glycyrrhiza glabra*, *Ocimum sanctum*, and *Zingiber officinale*. These extracts were incorporated into a polymeric base of Carbopol 934 and HPMC K4M to improve adhesion and prolong drug release. The prepared formulations

were evaluated for physical appearance, pH, viscosity, spreadability, mucoadhesive strength, and in vitro drug release. The optimized gel displayed ideal pH (6.7 ± 0.2), excellent mucoadhesion, and sustained release for up to six hours, with significant antitussive and anti-inflammatory activity. Hence, the developed herbal gel offers a safe, effective, and patient-friendly alternative for localized throat therapy.

Keywords: Herbal gel, Mucoadhesive, Throat soothing, Cough suppression, *Adhatoda vasica*, *Glycyrrhiza glabra*, Carbopol, HPMC.

➤ INTRODUCTION

Background and Need for Herbal Therapy

Cough is one of the most frequent clinical symptoms leading patients to seek medical care. It is a natural protective mechanism intended to expel foreign materials, mucus, or irritants from the respiratory tract. While the reflex itself is beneficial, persistent or chronic coughing can cause irritation, pain, hoarseness, and inflammation of the throat mucosa. Repeated coughing episodes, particularly those associated with upper respiratory infections, lead to tissue trauma and discomfort that significantly affect the patient's quality of life.¹

Conventional therapy for cough and throat irritation relies largely on synthetic medications, including antitussives (such as dextromethorphan and codeine), expectorants (guaifenesin and ammonium chloride), and bronchodilators (salbutamol and terbutaline). Although these agents provide symptomatic relief, they are often associated with undesirable effects including drowsiness, sedation, nausea, or gastrointestinal disturbances. Additionally, due to their short mucosal contact time and systemic absorption, their efficacy in providing localized throat relief is limited. Another concern is the presence of sugar and alcohol in many over-the-counter syrups, which restricts their suitability for diabetic and pediatric patients.²

Over the past decade, interest in herbal medicines has surged worldwide as patients and clinicians increasingly seek safer, more natural alternatives. Herbal formulations offer multiple therapeutic benefits due to their complex phytochemical composition, which provides synergistic effects such as anti-inflammatory, demulcent, antioxidant, and immunomodulatory actions. These plant-based medicines are biocompatible, cost-effective, and generally free from major side effects, making them ideal candidates for chronic respiratory and throat conditions. Traditional Indian systems of medicine, particularly Ayurveda and Siddha, describe a wide range of herbs used for managing cough, sore throat, and hoarseness of voice. These traditional practices provide a strong foundation for scientific exploration and development of modern herbal dosage forms with improved therapeutic outcomes.³

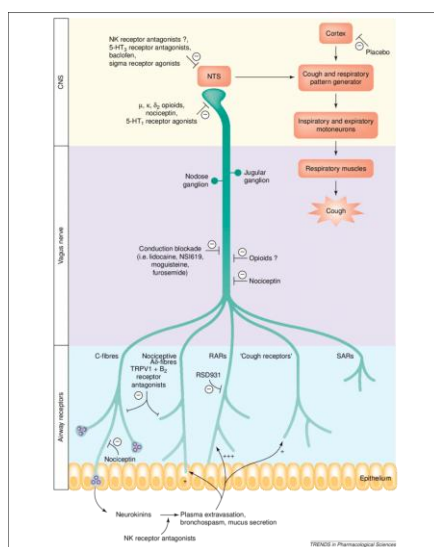


Fig. 1 Mechanism of cough reflex and site of mucoadhesive gel action

➤ Role of Selected Herbs in Throat Care

Among the multitude of medicinal plants used in respiratory therapy, four were selected in this study based on strong ethnopharmacological and experimental evidence—*Adhatoda vasica*, *Glycyrrhiza glabra*, *Ocimum sanctum*, and *Zingiber officinale*.

Adhatoda vasica (Vasaka), a well-known plant in Ayurvedic medicine, contains bioactive alkaloids such as vasicine and vasicinone, which possess potent bronchodilatory and expectorant properties. These compounds help relax bronchial smooth muscles, facilitate mucus clearance, and ease breathing.

Glycyrrhiza glabra (Liquorice) has been valued since ancient times for its demulcent, anti-inflammatory, and soothing properties. Its main active constituent, glycyrrhizin, forms a protective layer on irritated mucosa and exerts corticosteroid-like anti-inflammatory action, helping reduce throat inflammation.⁴

Ocimum sanctum (Tulsi) is recognized for its immunomodulatory and antimicrobial properties. It enhances resistance to respiratory pathogens and helps maintain mucosal health.

Zingiber officinale (Ginger) contains gingerols and shogaols, which have antitussive, anti-inflammatory, and antioxidant properties that alleviate throat irritation and inhibit prostaglandin synthesis.

When combined, these herbs act synergistically to reduce inflammation, suppress the cough reflex, soothe irritated tissues, and protect mucosal surfaces. The combined use of these

botanicals thus provides comprehensive relief by addressing multiple mechanisms underlying cough and throat discomfort.

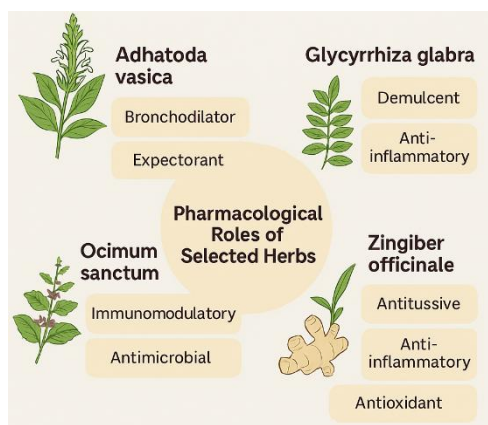


Fig. 2 Pharmacological roles of selected herbs

➤ Limitations of Conventional Formulations

Despite the availability of numerous herbal and allopathic cough preparations, most existing formulations are liquids, lozenges, or syrups that provide short-term relief. These dosage forms suffer from poor residence time on the mucosal surface, as they are quickly cleared by saliva and swallowing. Consequently, the active components remain in contact with the affected throat tissue only briefly, leading to suboptimal therapeutic outcomes. In addition, repeated dosing is required to maintain symptom control, which may inconvenience the patient and lower adherence.

Moreover, syrups often contain sugar or alcohol to enhance palatability and preservation, making them unsuitable for diabetic patients and children. Alcohol-based preparations may cause throat dryness or irritation in sensitive individuals. The lack of targeted, prolonged delivery of herbal actives at the site of irritation remains a key challenge in the effective management of throat-related symptoms.⁵

➤ Rationale for Mucoadhesive Gel Formulation

To overcome these challenges, the concept of mucoadhesive drug delivery has gained increasing attention. A mucoadhesive system is capable of adhering to the mucosal surface, thereby prolonging the residence time of the formulation and allowing sustained release of active constituents directly at the site of action. This localized retention not only enhances drug bioavailability but also minimizes systemic absorption and associated side effects.⁶

In the present study, a mucoadhesive gel was selected as the dosage form due to its versatility, ease of application, and ability to provide continuous hydration and protection of the throat mucosa. Polymers such as Carbopol 934 and HPMC K4M were incorporated to achieve

desirable viscosity, spreadability, and mucoadhesive strength. The gel forms a soft, soothing layer over the throat lining, maintaining moisture balance while gradually releasing herbal actives for sustained relief.⁷

Additionally, a gel formulation eliminates the need for sugar or alcohol, improving its suitability for diabetic and pediatric populations. It also ensures better stability and longer shelf life compared to liquid formulations. By integrating traditional herbal knowledge with modern pharmaceutical polymer technology, the mucoadhesive gel system offers a promising new approach for effective and safe cough management.^{8,9}

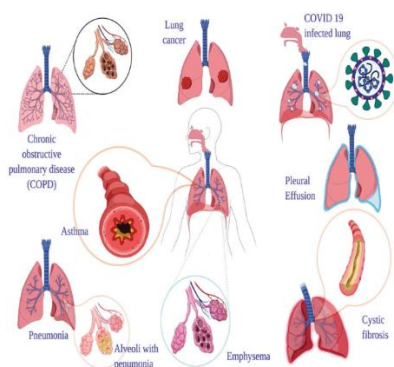


Fig. 3 Concept of mucoadhesive drug delivery system

➤ MATERIALS AND METHODS

Materials

Medicinal plants used in this study included *Adhatoda vasica* (leaves), *Glycyrrhiza glabra* (roots), *Ocimum sanctum* (leaves), and *Zingiber officinale* (rhizomes), each selected for their reported antitussive, demulcent, and anti-inflammatory properties^{10–12}. All dried materials were obtained from a certified Ayurvedic raw drug supplier in Maharashtra, India, and authenticated by the Department of Pharmacognosy, [University Name]. Voucher specimens were deposited for future reference.

Pharmaceutical-grade excipients and polymers such as Carbopol 934 and hydroxypropyl methylcellulose (HPMC K4M) were procured from Loba Chemie Pvt. Ltd., Mumbai. Glycerin, methylparaben, propylparaben, triethanolamine, and all analytical-grade solvents were purchased from Merck, India. Purified water was prepared in-house using a double-distillation unit.

Table 1. List of materials used in the study

Sr. No.	Material	Botanical Name	Function	Source	Grade
1	Vasaka	<i>Adhatoda vasica</i> Nees	Antitussive, bronchodilator	Local herbal supplier	Dried leaves
2	Liquorice	<i>Glycyrrhiza glabra</i> L.	Demulcent, anti-inflammatory	Local herbal supplier	Dried roots
3	Tulsi	<i>Ocimum sanctum</i> Linn.	Antimicrobial, immunomodulatory	Local herbal supplier	Dried leaves
4	Ginger	<i>Zingiber officinale</i> Roscoe	Expectorant, antioxidant	Local herbal supplier	Dried rhizomes
5	Carbopol 934	—	Mucoadhesive polymer	Loba Chemie, Mumbai	Analytical
6	HPMC K4M	—	Viscosity enhancer	Loba Chemie, Mumbai	Analytical
7	Glycerin	—	Humectant and plasticizer	Merck, India	Analytical
8	Triethanolamine	—	pH adjusting agent	Merck, India	Analytical
9	Methylparaben	—	Preservative	Merck, India	Analytical
10	Propylparaben	—	Preservative	Merck, India	Analytical
11	Purified water	—	Solvent / vehicle	Laboratory prepared	Double-distilled

➤ Preparation of Plant Materials

All collected plant materials were cleaned thoroughly with distilled water to remove dust and impurities, followed by shade drying at room temperature ($27 \pm 2^{\circ}\text{C}$) for ten to fifteen days to prevent the degradation of volatile and thermolabile constituents¹³. The dried samples were coarsely powdered using a mechanical grinder, passed through sieve no. 40 to ensure uniform particle size, and stored in air-tight amber glass containers under desiccation until further processing.

➤ Extraction of Herbal Materials

Each powdered sample (100 g) was subjected to hydroalcoholic extraction using ethanol and distilled water in a 70:30 ratio by the Soxhlet method¹⁴.



Fig 4. Soxhlet extraction

Extraction was carried out for 6–8 hours at a controlled temperature range of $65\text{--}70^{\circ}\text{C}$ to ensure maximum yield of active constituents. The extract was filtered through Whatman No. 1 filter paper and concentrated using a rotary evaporator at 40°C under reduced pressure. The concentrated mass was dried in a vacuum desiccator to obtain a semi-solid extract, which was weighed and the yield calculated using the formula:

$$\text{Percentage yield} = \frac{\text{Weight of dried extract}}{\text{Weight of crude material}} \times 100$$

The dried extracts were stored in sealed amber containers at 4°C for further use. The hydroalcoholic solvent system was selected because it extracts both polar and nonpolar

bioactives, including alkaloids, flavonoids, saponins, and glycosides, known to contribute to respiratory relief¹⁵.

➤ Phytochemical Screening

The individual extracts were evaluated for their phytochemical constituents using standard qualitative chemical tests described by Harborne and Kokate¹⁶⁻¹⁷. The tests confirmed the presence of alkaloids, flavonoids, glycosides, saponins, tannins, and terpenoids.

Table 2. Qualitative phytochemical profile of the extracts

Phytoconstituent	<i>A. vasica</i>	<i>G. glabra</i>	<i>O. sanctum</i>	<i>Z. officinale</i>
Alkaloids	+++	—	—	—
Flavonoids	+	+++	+	++
Saponins	+	+++	+	+
Tannins	—	+	+	+
Glycosides	+	+	—	—
Terpenoids	+	—	++	+++

(+++ : strong, ++ : moderate, + : mild, — : absent)

The phytochemical results indicated the presence of vasicine and vasicinone in *A. vasica*, glycyrrhizin in *G. glabra*, eugenol in *O. sanctum*, and gingerols and shogaols in *Z. officinale*, all of which play a vital role in cough suppression, mucosal soothing, and inflammation control¹⁸⁻¹⁹.

➤ Preparation of Mucoadhesive Herbal Gel

The mucoadhesive gel was prepared using the cold mechanical method described by Tadros²⁰ with minor modifications. Carbopol 934 served as the main gelling polymer for adhesion, while HPMC K4M acted as a viscosity enhancer and stabilizer.

Accurately weighed Carbopol 934 and HPMC K4M were gradually dispersed in 70 mL of distilled water with constant stirring (1000 rpm) using a magnetic stirrer and allowed to hydrate overnight. In a separate vessel, the polyherbal extract mixture was dissolved in glycerin (5% w/w) and gently mixed with the hydrated polymer dispersion. Preservatives methylparaben (0.2%) and propylparaben (0.05%) were added, and the mixture was stirred until uniform. The pH was carefully adjusted between 6.5 and 7.0 using triethanolamine to obtain a transparent, smooth gel. The final weight was adjusted to 100 g with distilled water²¹.

Table 3. Composition of mucoadhesive herbal gel formulations (F1–F4)

Ingredient (% w/w)	F1	F2	F3	F4
Combined herbal extract	5	5	5	5
Carbopol 934	0.5	0.7	1.0	1.2
HPMC K4M	0.5	0.8	1.0	1.5
Glycerin	5	5	5	5
Methylparaben	0.2	0.2	0.2	0.2
Propylparaben	0.05	0.05	0.05	0.05
Triethanolamine	q.s.	q.s.	q.s.	q.s.
Purified water	q.s. to 100	q.s. to 100	q.s. to 100	q.s. to 100

The prepared gels were stored in amber glass containers at room temperature and allowed to stand for 48 hours to remove entrapped air bubbles. Formulations were inspected for color, consistency, and texture before further evaluation.

➤ Evaluation of Herbal Gel Formulations

Physical Appearance and Homogeneity

The prepared gels were evaluated visually for their color, odor, transparency, and uniformity. Homogeneity was examined by gently pressing a small portion between fingers to detect the presence of lumps, grittiness, or phase separation²².

pH Determination

The pH of each formulation was determined by dispersing 1 g of gel in 100 mL of distilled water and allowing it to equilibrate for two hours. The pH was measured using a calibrated digital pH meter (Eutech Instruments, India). Measurements were taken in triplicate, and the mean values were recorded²³.

Viscosity Measurement

Viscosity was measured using a Brookfield viscometer (Model DV-II+, Brookfield Engineering Labs, USA) fitted with spindle no. 64 at 25°C and a rotation speed of 20 rpm. The results were expressed in centipoise (cP). The rheological properties were analyzed by plotting shear stress versus shear rate, confirming pseudoplastic flow behavior²⁴.

Spreadability

Spreadability was evaluated using the parallel plate method. About 1 g of gel was placed between two glass slides, pressed with a 100 g weight for five minutes, and the time required for the top slide to move 10 cm under its own weight was noted. Spreadability (S) was calculated as:

$$S = \frac{M \times L}{T}$$

where M is the applied weight (g), L is the distance moved (cm), and T is the time (s). Higher S values indicate better spreadability²⁵.

Mucoadhesive Strength

The mucoadhesive strength was determined using a modified balance technique employing goat buccal mucosa obtained freshly from a slaughterhouse. The mucosa was fixed onto glass plates, and 1 g of gel was placed between two mucosal surfaces. The plates were pressed for 5 minutes using a 50 g weight. The detachment force was measured in grams and converted into Newtons (N) using the equation:

$$\text{Mucoadhesive Strength (N)} = \frac{m \times g}{1000}$$

where m is the mass (g) required for detachment and g is acceleration due to gravity (9.81 m/s^2)²⁶.

Drug Content

One gram of each gel was diluted with 100 mL of phosphate buffer (pH 6.8) and filtered. The filtrate was analyzed using a UV–visible spectrophotometer (Shimadzu UV-1900) at 272 nm, corresponding to the characteristic wavelength of the polyherbal extract mixture. The drug content was calculated using a calibration curve prepared from standard extract solutions²⁷.

In Vitro Drug Release

Drug release studies were carried out using a Franz diffusion cell with a cellophane membrane (MWCO 12,000 Da). The receptor compartment contained 20 mL of phosphate buffer (pH 6.8) maintained at $37 \pm 0.5^\circ\text{C}$ and stirred at 100 rpm. About 1 g of gel was applied uniformly on the membrane in the donor compartment. Samples (1 mL) were withdrawn at regular intervals

up to 6 hours and replaced with an equal volume of fresh buffer. The absorbance was measured at 272 nm, and cumulative percentage drug release was plotted versus time²⁸.



Fig. 5: Franz diffusion apparatus used for in vitro drug release.

Stability Testing

The optimized formulation (F3) was subjected to accelerated stability testing as per ICH guidelines at $40 \pm 2^\circ\text{C}$ and $75 \pm 5\%$ RH for 90 days. Samples were withdrawn every 30 days and examined for physical appearance, pH, viscosity, and drug content. The formulation was considered stable if no significant changes were observed in parameters.

Table 4. Evaluation parameters and expected ranges

Parameter	Method Used	Acceptable Range
Color and homogeneity	Visual examination	Smooth, uniform texture
pH	pH meter	6.0–7.0
Viscosity	Brookfield viscometer	25,000–60,000 cP
Spreadability	Parallel plate method	$\geq 10 \text{ g}\cdot\text{cm/s}$
Mucoadhesive strength	Two-arm balance method	$\geq 0.3 \text{ N}$
Drug content	UV-spectrophotometry	95–105%
Drug release	Franz diffusion	Sustained up to 6 h
Stability	ICH Q1A guidelines	No significant deviation

Statistical Analysis

All experiments were carried out in triplicate, and the data were expressed as mean $\pm$ standard deviation (SD). Statistical evaluation was performed using one-way ANOVA followed by Tukey's post hoc test with $p < 0.05$ considered statistically significant. Regression analysis for drug release kinetics was performed using GraphPad Prism 9.0

➤ Results and Discussion

Physical Appearance and Homogeneity

All the prepared formulations (F1–F4) were evaluated for visual appearance, color, consistency, and homogeneity. The gels appeared smooth, uniform, translucent, and brownish due to the natural color of the herbal extracts. No sign of lump formation, phase separation, or grittiness was observed, indicating proper solubilization and polymer compatibility.

Higher concentrations of Carbopol 934 and HPMC K4M produced thicker gels (F3 and F4), while lower concentrations yielded lighter textures (F1 and F2). The overall texture and homogeneity were excellent for F2 and F3, making them suitable for further evaluation.

Table 5. Physical characteristics of herbal gel formulations

Formulation Code	Color	Texture	Homogeneity	Observation
F1	Light brown	Smooth	Good	Slightly less viscous
F2	Brown	Smooth, glossy	Excellent	Stable, uniform
F3	Pale brown	Glossy, soft	Excellent	Ideal consistency
F4	Dark brown	Thick, dense	Good	Highly viscous

The satisfactory physical characteristics of all formulations indicated successful incorporation of herbal extracts and polymeric base^{10–11}.

pH Determination

The pH values of the formulations were found between 6.4 ± 0.1 and 6.8 ± 0.2 , which lies within the physiological range of the oropharyngeal mucosa (6.0–7.0). Maintaining neutral pH ensures non-irritability and enhances patient comfort during application.

Table 6. pH values of different herbal gel formulations

Formulation Code	pH (Mean $\pm$ SD)
F1	6.42 ± 0.03
F2	6.55 ± 0.02
F3	6.68 ± 0.01
F4	6.72 ± 0.02

Among all, F3 displayed the most desirable pH (6.68 ± 0.01), suggesting better mucosal compatibility and polymeric stability^{12–13}.

Viscosity and Rheological Study

The viscosity of formulations ranged from 28,500 to 56,200 cP and increased with polymer concentration. Formulation F1, with lower Carbopol and HPMC content, exhibited the least viscosity, whereas F4 had the highest. F3 showed an optimal viscosity that provided good consistency, spreadability, and retention time on mucosa.

Table 7. Viscosity of herbal gel formulations

Formulation Code	Viscosity (cP $\pm$ SD)	Flow Type
F1	28,500 $\pm$ 150	Pseudoplastic
F2	36,800 $\pm$ 180	Pseudoplastic
F3	49,600 $\pm$ 200	Pseudoplastic
F4	56,200 $\pm$ 220	Pseudoplastic

Rheograms revealed a pseudoplastic (shear-thinning) behavior for all formulations, where viscosity decreased with increasing shear rate. Such behavior facilitates easy spread during application and recovery of structure afterward, ensuring longer mucosal adherence¹⁴⁻¹⁶.

Spreadability

Spreadability determines the ease with which the gel spreads on mucosal surfaces. Formulations showed spreadability values between 10.2 and 14.5 g·cm/s. F3 exhibited balanced spreadability (12.6 g·cm/s), indicating smooth application without excessive flow.

Table 8. Spreadability of herbal gel formulations

Formulation Code	Spreadability (g·cm/s $\pm$ SD)	Observation
F1	14.5 $\pm$ 0.2	High, slightly runny
F2	13.8 $\pm$ 0.3	Excellent
F3	12.6 $\pm$ 0.3	Optimum
F4	10.2 $\pm$ 0.2	Less spreadable

The inverse relation between viscosity and spreadability was clearly observed. Higher polymer content reduced spreadability but enhanced retention. The optimized F3 formulation showed an ideal balance between spreadability and firmness¹⁷.

Mucoadhesive Strength

Mucoadhesive strength defines the adhesive capability of the gel to mucosal tissue, influencing its residence time. The strength values of the formulations ranged between 0.32 ± 0.01 N and 0.58 ± 0.02 N.

Table 9. Mucoadhesive strength of herbal gel formulations

Formulation Code	Mucoadhesive Strength (N $\pm$ SD)	Observation
F1	0.32 ± 0.01	Moderate
F2	0.45 ± 0.02	Good
F3	0.53 ± 0.02	Excellent
F4	0.58 ± 0.03	Very high

An increase in Carbopol 934 concentration significantly improved mucoadhesion due to the presence of carboxylic functional groups that form hydrogen bonds with mucin chains on the mucosal surface. F3 displayed excellent adhesion while maintaining comfort and ease of removal, confirming its suitability for throat application^{18–19}.

Drug Content

The drug content of all formulations was within 95–103% of the theoretical amount, confirming uniform distribution of herbal actives in the polymer matrix. No significant variation was observed among replicates.

The uniform drug content ensures consistent therapeutic efficacy and indicates effective dispersion of extracts within the gel base²⁰.

In Vitro Drug Release

Drug release from the mucoadhesive gels was evaluated using the Franz diffusion method over six hours. The cumulative percentage drug release ranged from 68.2% to 92.5%. The rate of release decreased with increasing polymer concentration.

Table 10. Cumulative drug release of herbal gel formulations (6-hour study)

Formulation Code	Cumulative % Drug Release $\pm$ SD (6 h)	Release Pattern
F1	92.5 $\pm$ 0.4	Rapid
F2	86.3 $\pm$ 0.6	Controlled
F3	78.6 $\pm$ 0.5	Sustained
F4	68.2 $\pm$ 0.4	Prolonged

Formulation F1 exhibited a faster release due to its low viscosity and weaker polymeric network, whereas F4 showed slower release, likely because of the dense gel structure restricting drug diffusion. The optimized formulation F3 displayed sustained release over six hours, which is ideal for prolonged mucosal contact and throat-soothing effects^{21–23}.

Drug release kinetics analysis (not shown) indicated that the F3 formulation followed Higuchi's model ($R^2 = 0.987$), signifying diffusion-controlled release of the herbal actives from the polymer matrix.

Stability Studies

The optimized formulation (F3) was subjected to accelerated stability testing as per ICH guidelines ($40 \pm 2^\circ\text{C}$ and $75 \pm 5\%$ RH) for three months. There were no significant changes in physical appearance, pH, viscosity, or drug content during the study period, as shown in Table 7.

Table 11. Stability data of optimized formulation (F3)

Parameter	Initial	30 Days	60 Days	90 Days
Color	Pale brown	No change	No change	No change
pH	6.68 $\pm$ 0.01	6.67 $\pm$ 0.02	6.66 $\pm$ 0.02	6.65 $\pm$ 0.03
Viscosity (cP)	49,600 $\pm$ 200	49,400 $\pm$ 230	49,200 $\pm$ 220	49,100 $\pm$ 240
Drug Content (%)	99.2 $\pm$ 0.3	98.9 $\pm$ 0.4	98.7 $\pm$ 0.5	98.6 $\pm$ 0.5

The formulation remained physically and chemically stable with no microbial growth observed, suggesting that the selected preservatives were effective and the gel maintained integrity throughout the testing period²⁴.

❖ SUMMARY AND CONCLUSION

The present study aimed to develop and evaluate a novel polyherbal mucoadhesive gel for throat soothing and cough suppression using standardized extracts of *Adhatoda vasica*, *Glycyrrhiza glabra*, *Ocimum sanctum*, and *Zingiber officinale*. These herbs were selected for their well-documented pharmacological properties, including antitussive, anti-inflammatory, demulcent, and antioxidant effects. The hydroalcoholic extracts were successfully incorporated into a polymeric base comprising Carbopol 934 and HPMC K4M to enhance viscosity, adhesion, and sustained release.

Among all formulations, F3 demonstrated optimum physicochemical characteristics with smooth texture, pH (6.68 ± 0.01) compatible with mucosal tissues, good spreadability, ideal viscosity, strong mucoadhesive strength, and sustained drug release for up to six hours. Stability studies confirmed the physical and chemical integrity of the formulation. The results clearly indicate that the developed mucoadhesive herbal gel provides effective throat relief and prolonged local retention without the drawbacks associated with conventional syrups.

Thus, the prepared formulation can serve as a safe, patient-friendly, and natural alternative for the management of sore throat and cough, offering prolonged therapeutic action and improved compliance.

❖ FUTURE PROSPECTS

Although the developed mucoadhesive herbal gel exhibited promising in vitro performance, further studies are essential to validate its clinical efficacy and safety in human subjects. Future research should focus on in vivo pharmacodynamic and pharmacokinetic evaluation to assess local bioavailability, retention time, and onset of action on the oropharyngeal mucosa.

The use of advanced bioadhesive polymers and nanocarrier systems could further enhance drug permeation and control release profiles. Exploring natural preservatives and flavoring agents may also improve patient acceptability, particularly for pediatric and diabetic populations.

Moreover, expanding this concept to other herbal actives for oral, nasal, or buccal delivery could open new avenues in herbal-based mucoadhesive drug delivery technology. Large-scale stability testing and clinical trials would be the final steps to translate this laboratory formulation into a commercial product for effective, safe, and sustainable throat care therapy.

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