RESEARCH PAPER

FORMULATION DESIGN AND OPTIMIZATION OF HYDROGEL CONTAINING TERBINAFINE HYDROCHLORIDE

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ABSTRACT

The present study aimed to formulate and optimize a hydrogel containing Terbinafine Hydrochloride, a potent antifungal agent, to enhance topical delivery, immediate drug release, and therapeutic efficacy. Terbinafine Hydrochloride, an allylamine derivative, blocks squalene epoxidase in the ergosterol synthesis pathway to successfully treat superficial fungal infections. However, its lipophilicity and low permeability hinder its absorption through the skin. To address these issues, water-soluble polymer-based hydrogels were formulated as an easy-to-use alternative to overcome problems of sustained release, permeation of the drug, and stability.

Polymers such as Carbopol 940, HPMC, Chitosan, Xanthan Gum, HPMC E15, HPMC K100, Guar Gum, etc., were used to formulate a number of hydrogels (F1 to F31). The prepared hydrogels were tested for parameters such as pH, viscosity, spreadability, content of drug, swelling index, entrapment efficiency, and appearance. FT-IR and DSC studies confirmed drug-polymer compatibility and thermal stability. SEM analysis revealed a porous, uniform surface structure favourable for drug diffusion. In vitro drug release and permeation studies were conducted using the Franz diffusion cell with phosphate buffer (pH 7.4) as the medium.

The results indicated that all formulations had time-dependent release. Among these, formulations F8, F10, F11, F24, F29, and F31 had superior permeation efficiency (>90 µg/cm² at 60 min). Among these, formulation F8 had the best physicochemical properties, higher content, and maximum drug permeation and release, thus showing its promise. The accelerated stability results for the formulation (maintained at 40 ± 2 °C and 75 ± 5% RH for 3 months) indicated that the formulation had minimal changes in the release and permeation of the drug. Additionally, the formulation remained transparent, had viscosity, and a pH.

The hydrogel system that was developed showed effective and controlled release of the drug, reduced the frequency of drug administration, and improved skin permeation, thus showing that it is better than the conventional formulation. The biocompatibility of the polymers used in the formulation makes it safe and effective in improving the efficiency of the drug.

The present investigation demonstrates the potential of using the hydrogel system for the delivery of Terbinafine Hydrochloride as a novel, stable, and efficient topical antifungal agent. Further studies would be directed toward the in vivo studies, kinetic studies, long-term stability, and the feasibility of scaling up, along with the use of stimuli-responsive hydrogels for the site-specific and immediate release of the drug. This investigation demonstrates the conclusion that the optimized hydrogel formulations, especially F8, could prove to be a promising approach for the improved topical antifungal treatment.

Keywords: Hydrogel, Topical Drug Delivery, Antifungal Therapy, Hydrophilic polymers, Biocompatibility, Patient Compliance

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INTRODUCTION

Hydrogels are 3D, hydrophilic polymer networks that absorb large amounts of water while maintaining structure [1]. Their soft, moist, and biocompatible nature makes them ideal for wound dressings and dermatological uses [2,3]. Made from natural or synthetic materials, synthetic hydrogels offer greater stability, strength, and tunable properties [4]. Hydrogels, being the result of polymerization and cross-linking, have a structure that enables swelling without dissolving, thus offering precise control over their properties [5,6].

Hydrogels can be classified according to their source, responsiveness, structure, and application. According to their source, hydrogels can be natural (chitosan, alginate, biocompatible, and biodegradable), synthetic (PVA, PEG, PAM, durable, and stable), or composite (chitosan-PVA, having the advantages of both). According to their responsiveness, smart hydrogels react to stimuli, for example, temperature, pH, light, or enzymes, for controlled drug release. According to their structure, they may be amorphous, sheet/film, or sprayable, for various types of wounds. Their application includes wound healing, cosmetics, transdermal products, and pharmaceutical or medical use [7,8].

Hydrogels are highly water-retentive (up to 99%) and provide a moist environment conducive to healing. Hydrogels are biocompatible, flexible, and soft, which enables them to mold snugly onto the skin. Hydrogels are permeable to facilitate exchange of gases, nutrients, and drugs. Swell ability and mechanical properties are variable. Many are adhesive or bio adhesive, improving drug retention, and their transparency permits easy wound monitoring. Additionally, hydrogels are tunable in degradation and responsiveness and are biodegradable, eliminating the need for removal [4,9].

Topical hydrogels are hydrophilic, biocompatible, and non-greasy, and they moisturize, heal, and release medications in a controlled fashion [10,11]. They offer cooling, soothing, and transparent films that are best suited for wounds, burns, and cosmetics [12,13]. Despite their benefits, hydrogels are also limited in that they lack mechanical strength, can only be used to carry limited amounts of medication, have poor shelf life, are prone to dehydration, and are expensive to make [16,17].

Skin Structure [18]: The epidermis protects the body with keratinocytes and melanocytes, the dermis provides strength and nourishment through collagen and vessels, and the hypodermis offers insulation and cushioning with its fatty tissue.

Administration Routes [19]: Topical, transdermal, ocular, vaginal, rectal, injectable, and oral.
Drug Release Mechanisms [20]: Diffusion-, chemical-, or swelling-controlled (mainly diffusion).
Hydrogels vs Normal Gels [21,22]: Hydrogels have higher water content, better biocompatibility, and controlled release, while normal gels offer stronger adhesion and faster, immediate drug release.

MATERIALS AND METHODS

Materials:

Terbinafine HCl (antifungal, R.S. Scientific) was incorporated into a hydrogel matrix using polymers—guar gum, chitosan, xanthan gum, Carbopol 940, HPMC K-100, HPMC E-15, and PVP K-90. Borax acted as a cross-linker, glycerine as a plasticizer, and triethanolamine for pH adjustment. Benzalkonium chloride served as a surfactant and antimicrobial agent, optimizing the hydrogel's stability, texture, and therapeutic performance.

Method:

Pre- formulation Studies [23,24]: During this study experiments were conducted to gather the physical and chemical properties of drug and excipients before going to the formulation development.

Calibration Curve of Terbinafine Hydrochloride using Ultra- Violet (UV) Spectrophotometer: A stock solution of Terbinafine HCl (0.1 mg/ml) was prepared in phosphate buffer (pH 7.4) and sonicated for 10 min [25]. From this, a secondary stock (10 µg/ml) was made. Aliquots of 1–7 ml were diluted to 10 ml with buffer, and absorbance was measured at 223 nm using a UV spectrophotometer to construct the calibration curve [26,27].

Drug Excipients compatibility study [28,29]: It is conducted mainly to predict the potential incompatibility, and to provide justification for the selection of excipients in the formulation. An incompatibility may result in changes in physical, chemical, microbiological or therapeutic properties of the dosage form. There is always the possibility of drug- polymer interaction in any formulation.

FT- IR SPECTROSCOPY [30,31]: FT-IR spectroscopy was used to confirm the drug's identity and check compatibility between Terbinafine Hydrochloride and polymers (Carbopol-940, Guar Gum, Chitosan, Xanthan Gum, HPMC-K100, HPMC-E15). Pure drug, polymers, and their physical mixtures were mixed with KBr, compressed into disks, and scanned over 4000–400 cm^{-1}. The spectra were compared to detect any shifts or changes indicating drug–polymer interactions.

Differential Scanning Calorimetry (DSC) Study [32,33]: The instrument was calibrated with Indian standard. Accurately weighted 5mg of sample were placed in an open, flat bottom, Aluminium sample pans. Thermograms were obtained by heating the sample at a constant rate of 10 C/min. A dry purge of Nitrogen gas (20ml/min) was used for all runs samples heated from 35-400 C.

Preparation of Hydrogel [34]: The simple dispersing method was employed for the preparation of terbinafine hydrochloride hydrogel. Initially, the selected polymer was dispersed in distilled water, followed by the addition of the required amount of terbinafine hydrochloride. To this mixture, glycerine, borax solution, and a surfactant were added with continuous stirring at 1000 RPM for 2 hours. The final volume was made up with distilled water. Stirring was continued until the formulation began to thicken, after which the gel was neutralized by the dropwise addition of 50% (w/w) triethanolamine until a transparent gel was formed. The amount of triethanolamine was adjusted to obtain the desired pH. The prepared gels were then stored at room temperature for 24 hours to stabilize.

Table 1: Formulation Table of Hydrogel Containing Terbinafine Hydrochloride

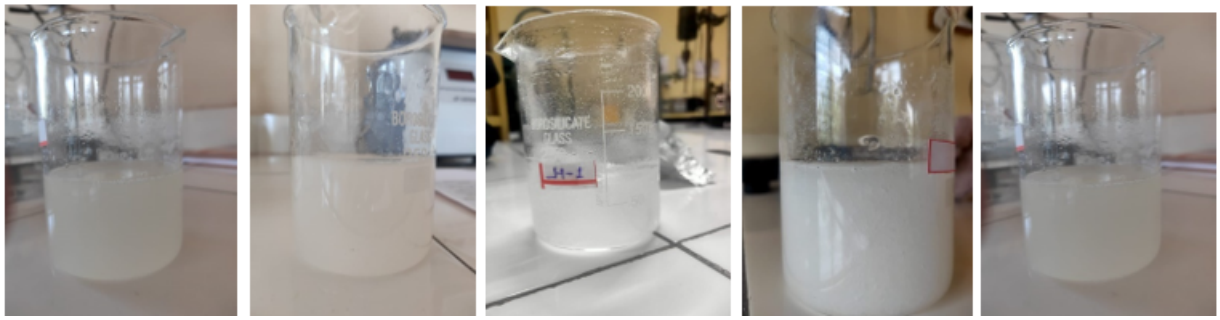
Materials	Terbinafine Hydrochloride (mg)	Carbopol 940 (g)	Guar Gum (g)	Xanthan Gum (g)	Chitosan (g)	HPMC K- 100 (g)	HPMC E-15 (g)	Borax Solution (ml)	Glycerine (ml)	PVP K-90 (%)	Benzalkonium Chloride (%)	Triethanolamine (ml)
F-1	1	1						7.5	10	1	0.01	q.s.
F-7	1	0.5	0.5					7.5	10	1	0.01	q.s.
F-8	1	0.5		0.5				7.5	10	1	0.01	q.s.
F-9	1	0.5			0.5			7.5	10	1	0.01	q.s.
F-10	1	0.5				0.5		7.5	10	1	0.01	q.s.
F-11	1	0.5					0.5	7.5	10	1	0.01	q.s.
F-22	1	0.33	0.33	0.33				7.5	10	1	0.01	q.s.
F-23	1	0.33	0.33		0.33			7.5	10	1	0.01	q.s.
F-24	1	0.33	0.33			0.33		7.5	10	1	0.01	q.s.
F-25	1	0.33	0.33				0.33	7.5	10	1	0.01	q.s.
F-26	1	0.33		0.33	0.33			7.5	10	1	0.01	q.s.
F-27	1	0.33		0.33		0.33		7.5	10	1	0.01	q.s.
F-28	1	0.33		0.33			0.33	7.5	10	1	0.01	q.s.
F-29	1	0.33			0.33	0.33		7.5	10	1	0.01	q.s.
F-30	1	0.33			0.33		0.33	7.5	10	1	0.01	q.s.
F-31	1	0.33				0.33	0.33	7.5	10	1	0.01	q.s.

(A total of **41 formulations** were prepared using single polymers, combinations of two polymers, and combinations of three polymers, maintaining a total polymer weight of **1 g** in each formulation. Only those formulations that successfully formed hydrogels were included in the formulation tabl



Evaluation of Hydrogel Containing Terbinafine Hydrochloride: Evaluation of the formulated product is performed to check the quality of the product and to optimize the process and product.

Fig 1: Different Hydrogel Formulation



Production yield [35, 36]:

Production Yield (%) = (Weight of hydrogel / Total weight of solid raw materials used) × 100

Viscosity [36]: Remove air bubbles from the hydrogel and let it equilibrate at 25 ± 1 °C. Transfer ~100 mL into a beaker. Using spindle No. 64 on the viscometer (set at 12 RPM), immerse it fully without touching the beaker. After 30–60 s of stabilization, record the viscosity in centipoise (cP).

pH [37,38]: Calibrate the pH meter with buffers pH 7.0 and 4.0. Rinse and blot electrode. Place 10–20 g hydrogel in a beaker, stir gently, insert electrode, wait for a stable reading (30–60 s), and record pH.

% Drug Content [39,40]: Prepare drug standards (1–10 µg/mL) in ethanol–water, measure absorbance at λmax, and plot calibration curve (y = mx + c). Weigh 1 g drug-loaded hydrogel, immerse in 50 mL ethanol–water, shake, filter, and measure absorbance. Determine drug content using the calibration curve.

Drug content (mg)= (Concentration (mg/mL) ×Volume (mL) × Dilution Factor)/ 1000

% Drug Content= (Amount of drug extracted from hydrogel/Theoretical drug amount loaded) ×100

% Entrapment Efficiency [41,42]: Prepare drug standards (1–10 µg/mL) in DCM, measure absorbance at λmax, and plot calibration curve. Weigh 1 g drug-loaded hydrogel, add DCM, shake 30 min, filter, and determine drug content using the UV calibration curve. **% Entrapment Efficiency = (*A*-*B*)/ A× 100**

A = Amount of drug present in hydrogel (mg) ; B = Amount of drug extracted from hydrogel (mg)

Swelling index [43,44]: Swelling Index (SI)= Weigh 1 g dry hydrogel (Wi), immerse in PBS (pH 7.4) for 24 h at room temp/37 °C, blot gently, weigh swollen hydrogel (Wf).

(Wf- Wi)/ Wi ×100

Spread ability [45,46]: Place hydrogel on the lower glass plate, cover with another plate, apply **10 g weight for 15 s**, remove it, and measure the spread distance.

Spreadability (S)= M×L/T

Where: M = weight apply on the plate (g); L = length moved by the plate (cm); T = time taken in seconds

***In- Vitro* Drug Release [47, 48]:** Hydrate a membrane in PBS pH 5.5 for 30 min and mount in a diffusion cell. Fill the receptor with PBS at 34 °C, stirring at 50 rpm. Apply hydrogel on the donor side, cover to prevent evaporation. At set intervals, withdraw 5 mL, replace with fresh PBS at 32 °C, filter, and analyze drug release at 223 nm using UV-Vis.

***In- Vitro* Drug Permeation [49,50]:** Hydrate a synthetic membrane in PBS pH 6.8 for 30 min and mount it in a diffusion cell. Fill the receptor with PBS at 37 ± 0.5 °C, stirring at 50 rpm. Apply 0.5–1 g hydrogel to the donor side. At set intervals, withdraw 5 mL samples, replace with fresh PBS, filter, and measure drug release at 223 nm using UV-Vis with a calibration curve.

Scanning Electron Microscopy (SEM) [51,52]: The morphology of hydrogel was examined using a scanning electron microscope (SEM-EDAX: Jeol 6390LA) operating at 20 kV. Dried hydrogel was coated with gold– palladium alloy for 45 s under an argon atmosphere before observation. SEM photograph was recorded at magnification of ×75- ×3000.

Differential Scanning Calorimetry (DSC) [53,54]: A small amount of pure drug and physical mixture was sealed in aluminum pans and heated at 10°C/min under nitrogen. The thermograms were recorded to detect thermal events (e.g., melting points) indicating drug–excipient compatibility.

RESULTS AND DISCUSSION

- **FT-IR Study:**

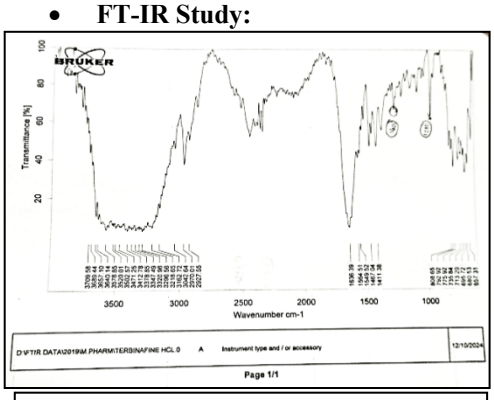


Fig 2: FT-IR Spectra of Terbinafine

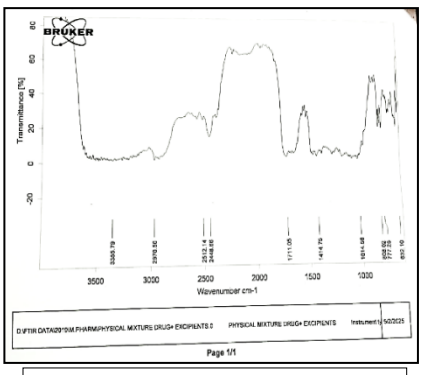


Fig 3: FT-IR Spectra of Physical

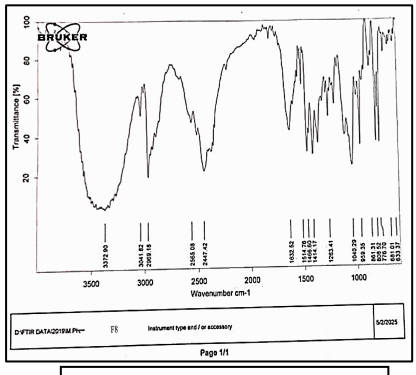


Fig 4: FT-IR Spectra of

The FTIR spectrum of Terbinafine Hydrochloride shows characteristic peaks for N–H/O–H (3709–3300 cm^{-1}), C–H (2965–2827 cm^{-1}), C=C/C=N (1655 cm^{-1}), and C–N (1234–1000 cm^{-1}), confirming its functional groups and The physical mixture with excipients shows similar peaks (3355–3370, 2910–2846, 1711, 1441, 1014, and 900–600 cm^{-1}), indicating no significant chemical interaction and confirming the drug's structural integrity.

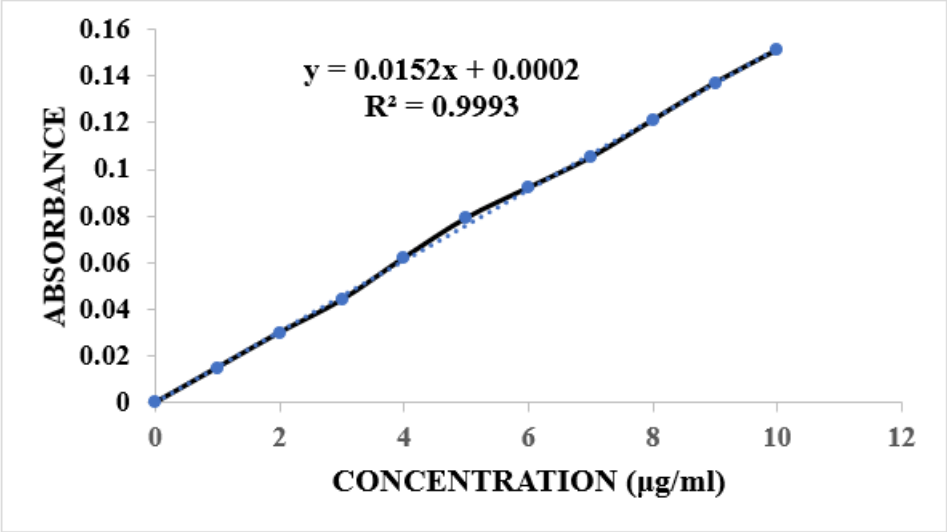


Fig 6: DSC Study of Terbinafine Hydrochloride

Table 2: Concentration and Absorbance Obtained for Calibration Curve of Terbinafine Hydrochloride (pH 7.4)

SL. NO.	CONCENTRATION (µg/ml)	ABSORBANCE
1	0	0
2	2	0.03
3	4	0.062
4	6	0.092
5	8	0.121
6	10	0.151

The calibration curve of Terbinafine Hydrochloride in PBS (pH 7.4) showed excellent linearity (y = 0.0152x + 0.0002, R2 = 0.9993) conforming Beer-Lambert's law and the accuracy of the UV Spectroscopic method for quantitative analysis and drug release studies.

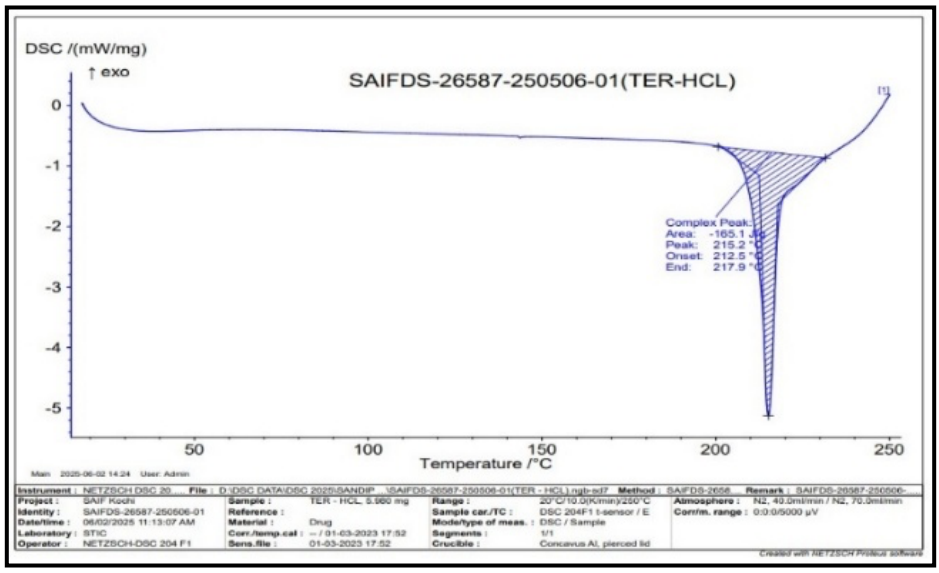


Fig 10: In- Vitro Release Profile of Different Formulation

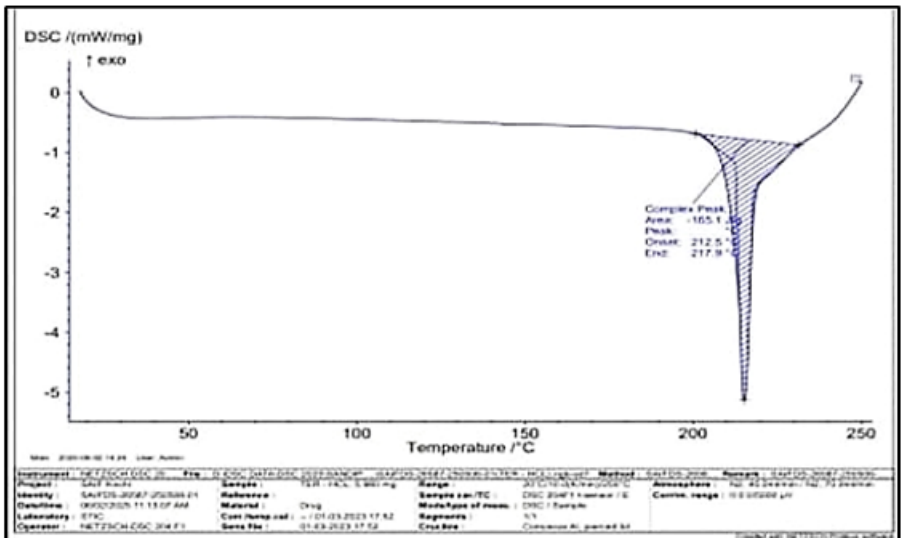


Fig 7: DSC Study of Drug- Polymer Physical Mixture

Differential Scanning Calorimetry (DSC):

The DSC thermogram of pure Terbinafine Hydrochloride shows a sharp endothermic peak at 215.2°C, confirming its crystalline nature. The drug–polymer mixture shows a similar peak with minor variations, indicating no significant interaction and retained thermal stability.

Results & Discussion of Evaluation tests of Hydrogel:

FORMULATION CODE	% PRODUCTION YIELD	VISCOSITY (cP)	pH	% DRUG CONTENT
F1	96.79	42000	6.4	92.41
F7	95.61	39250	6.7	72.94
F8	98.57	33750	6.1	94.11
F9	95.25	24500	5.7	79.94
F10	95.43	29000	5.8	76.42
F11	95.88	29750	5.3	84.16
F22	95.04	32750	5.9	68.79
F23	95.6	28250	5.7	87.59
F24	96.41	29250	5.3	92.05
F25	97.33	19250	5.8	70.44
F26	96.5	18750	5.7	77.27
F27	97.11	21250	5.9	62.81
F28	96.85	24000	5.4	70.1
F29	98.25	19000	6.1	67.33
F30	97.26	20500	6.1	77.88
F31	98.51	24500	6.3	75.09

Table 3: Characterization of Hydrogel Containing Terbinafine Hydrochloride

Production Yield: 95.04–98.57%; high yields (>95%) indicate efficient formulation. F8 (98.57%) shows best yield;minor losses seen in F22, F9, F10.
Viscosity: 18,750–42,000 cP; higher viscosity (F1) due to more polymer/cross-linking; lower values (F25–F29) indicate looser networks affecting spreadability and retention.
pH: 5.3–6.7; all within dermally acceptable range (5.0–7.0).
Drug Content: 62.81–94.11%; F8 and F1 show best incorporation, while low values (F27, F22, F29) may result from poor solubilization or degradation.

Scanning Electron Microscopy (SEM):

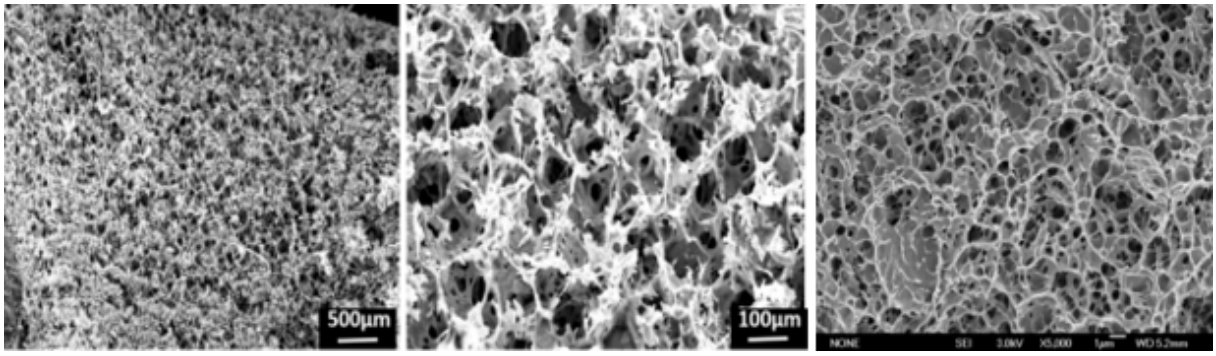


Fig 8: SEM images of Hydrogel Formulation

Left (500 µm): Shows a highly porous, interconnected hydrogel structure aiding fluid absorption. **Middle (100 µm):** Reveals uniform, sponge-like pores supporting drug loading and sustained release. **Right (1 µm, 5000×):** Displays fine porous matrix enhancing surface area and bioavailability.

Table 4: Evaluation Parameters of Hydrogel Containing Terbinafine Hydrochloride

FORMULATION CODE	% ENTRAPMENT EFFICIENCY	PHYSICAL CHARACTERISTICS	SWELLING INDEX	SPREAD ABILITY
F1	84.19	TRANSPARENT, SMOOTH	20.4	6.4
F7	83.12	TRANSPARENT, SMOOTH	23.5	6.06
F8	95.53	TRANSPARENT, SMOOTH	24.3	6.53
F9	74.34	TRANSPARENT, SMOOTH	16.8	5.4
F10	70.41	TRANSPARENT, SMOOTH	21.1	5.6
F11	70.51	TRANSPARENT, SMOOTH	31.4	5.8
F22	70.88	TRANSPARENT, SMOOTH	20.9	6.06
F23	69.48	TRANSPARENT, SMOOTH	29.5	5.66
F24	80.43	TRANSPARENT, SMOOTH	19.6	5.8
F25	70.17	TRANSPARENT, SMOOTH	17.6	5.2
F26	71.5	TRANSPARENT, SMOOTH	16.9	5.06
F27	71.33	TRANSPARENT, SMOOTH	12.9	5
F28	71.47	TRANSPARENT, SMOOTH	16.9	4.6
F29	73.25	TRANSPARENT, SMOOTH	29.6	5.86
F30	74.29	TRANSPARENT, SMOOTH	26.1	5.73
F31	69.33	TRANSPARENT, SMOOTH	24.5	3.73

Entrapment Efficiency: 69.33–95.53%; F8 (95.53%) shows best encapsulation, indicating strong polymer–drug compatibility. Low EE (<72%) in F23–F31 may be due to poor interaction or drug loss. **Physical Traits:** All formulations are transparent and smooth, confirming uniformity and good quality. **Swelling Index:** 12.9–31.4; optimal range (20–25) supports balanced release. F11 and F29 show high swelling; F27 lowest.

Spreadability: 3.73–6.53 g·cm/s; F8 (6.53) and F1 (6.4) show best spreadability; lower in F31 and F28 due to higher viscosity.

TIME (MIN)	F1	F7	F8	F9	F10	F11	F22	F23
0	0	0	0	0	0	0	0	0
10	20.25	21.27	23.32	18.2	19.2	16.16	20.25	21.27
20	28.44	28.44	39.69	28.44	35.6	27.41	30.48	36.62
30	38.67	37.64	56.06	37.64	47.9	40.71	41.74	48.9
40	54.01	47.87	69.36	48.9	63.2	55.03	56.06	63.22

50	76.52	62.2	88.79	62.2	70.4	71.4	75.49	74.47
60	90.84	79.59	98	87.77	86.8	88.79	83.68	85.72

***In- Vitro* Release Study: *In- Vitro* Release Data of different Formulation of Hydrogel Containing Terbinafine Hydrochloride:**

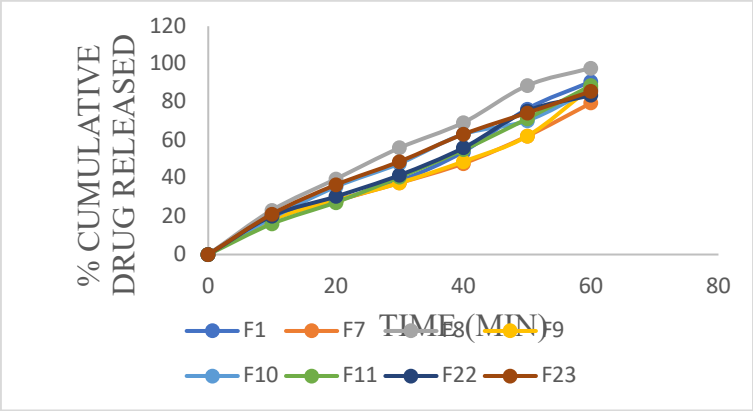


Fig 9: In- Vitro Release Profile of Different Formulation

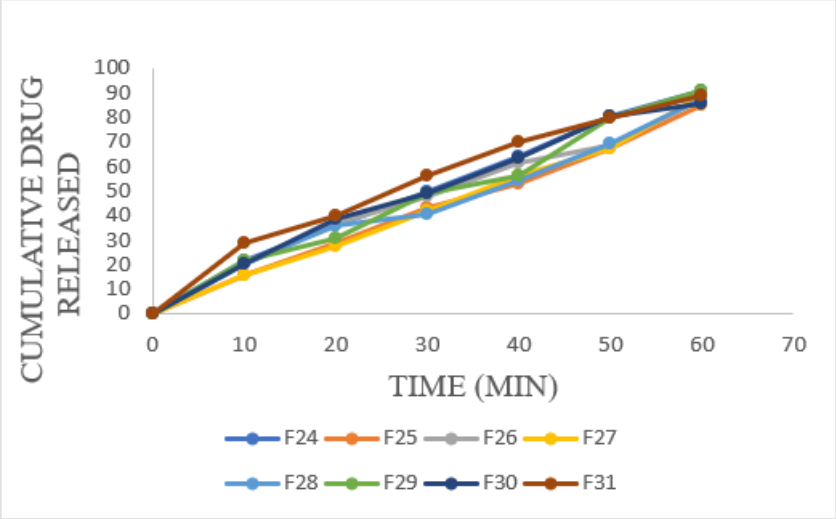


Fig 10: *In- Vitro* Release Profile of Different Formulation

TIME (MIN)	F24	F25	F26	F27	F28	F29	F30	F31
0	0	0	0	0	0	0	0	0
10	21.27	15.44	20.25	15.44	20.3	21.27	20.25	28.44
20	35.6	28.44	36.62	27.41	35.6	30.48	38.67	39.69
30	49.92	42.76	47.87	41.74	40.8	48.9	48.9	56.06
40	64.24	52.99	61.17	56.06	54	56.06	63.22	69.71
50	80.61	67.31	68.33	67.31	69.4	79.59	80.61	79.59
60	90.84	84.7	87.77	88.79	87.8	90.84	85.72	88.79

***In-Vitro* Release:** All formulations show time-dependent drug release. F8 exhibits the highest release (98 µg/cm² at 60 min), followed by F1, F24, F29 (~90 µg/cm²). F11 shows slow initial but sustained release. F8 demonstrates rapid, efficient diffusion—ideal for quick transdermal action; F1 and F11 suit sustained release. F24 and F29 also perform

well due to good hydration and diffusion, while F25, F27, and F31 show controlled or burst release patterns .

TIME (MIN)	F1	F7	F8	F9	F10	F11	F22	F23
0	0	0	0	0	0	0	0	0
10	15.26	12.63	20.52	15.26	17.89	10	17.89	17.89
20	25.79	23.15	33.68	23.15	31.05	23.15	28.42	31.05
30	36.31	31.05	49.47	31.05	44.21	38.94	38.94	44.21
40	52.1	44.21	65.26	46.84	54.73	52.1	54.73	57.36
50	73.15	54.73	83.68	60	67.89	67.89	70.52	70.52
60	83.68	78.42	94.21	81.05	83.68	86.31	81.05	83.68

***In- Vitro* Drug Permeation Study: *In- Vitro* Permeation Data of Different Formulations of Hydrogel Containing Terbinafine Hydrochloride**

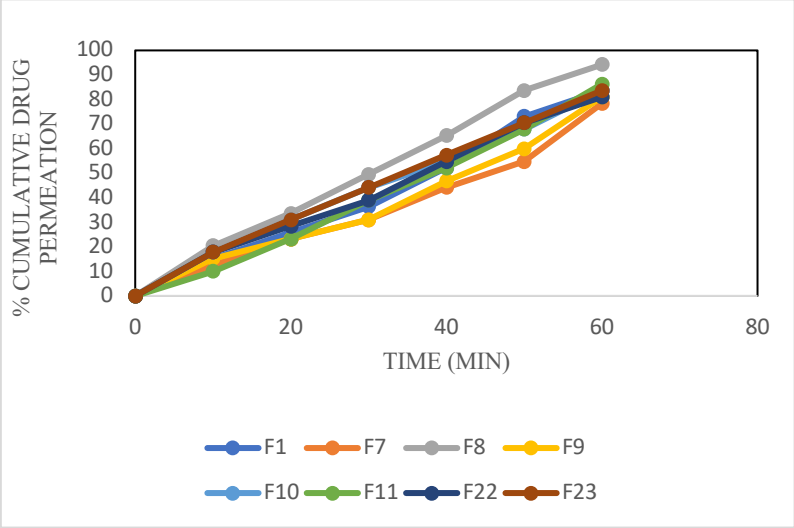


Fig 11: *In- Vitro* Permeation Profile of Different Formulation

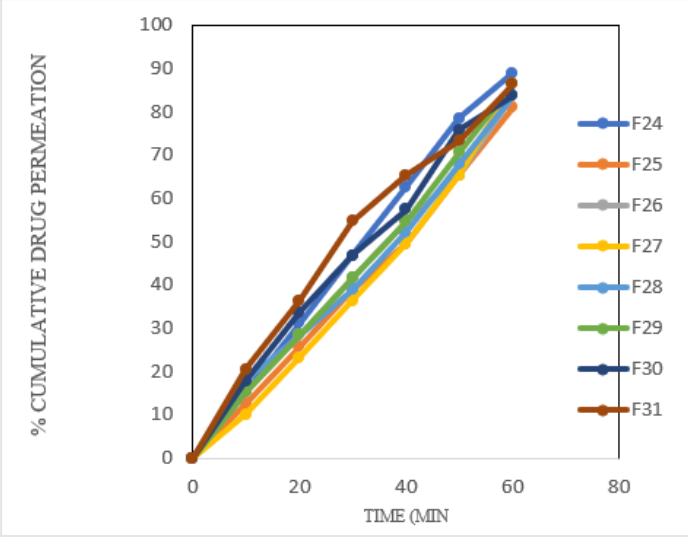


Fig 12: In- Vitro Drug Permeation Profile of Different Hydrogel

TIME (MIN)	F24	F25	F26	F27	F28	F29	F30	F31
0	0	0	0	0	0	0	0	0
10	15.26	12.63	15.26	10	17.89	15.26	17.89	20.52
20	31.05	25.79	28.42	23.15	28.42	28.42	33.68	36.31
30	46.84	38.94	41.57	36.31	38.94	41.57	46.84	54.73
40	62.63	49.47	54.73	49.47	52.1	54.73	57.36	65.26
50	78.42	65.26	65.26	65.26	67.89	70.52	75.79	73.15
60	88.94	81.05	83.68	86.31	83.68	86.31	83.68	86.31

***In-Vitro* Permeation:** All the formulations are showing time-dependent permeation following Fick's law. F8, F10, F11, F28, and F31 are showing the highest permeation (~90 units at 60 minutes), whereas F7 and F25 are showing lower permeation. Replicate formulations are showing good reproducibility. Optimized formulations F8, F10, F31 can be taken for further studies.

Accelerated Stability Study: Accelerated stability tests are performed to check the stability and shelf life of pharmaceutical formulations under stress conditions. As per ICH guidelines Q1A(R2), standard conditions for accelerated stability tests are set to be $40 \pm 2°C$ temperature and $75 \pm 5\%$ relative humidity (RH) in a controlled humidity chamber.

FORMULATION CODE	F8	F8 (After 3 Months of Storing)
VISCOSITY (cP)	33750	32750
pH	6.1	5.9
% DRUG CONTENT	94.11	92.41
% ENTRAPMENT EFFICIENCY	95.53	94.19
PHYSICAL CHARACTERISTIC	Transparent, Smooth	Transparent, Smooth
SWELLING INDEX	24.3	24.5
SPREAD ABILITY	6.53	6.4

Table 5: Comparisons of the Evaluation Parameters of Optimized Formulation of Hydrogel Containing Terbinafine Hydrochloride

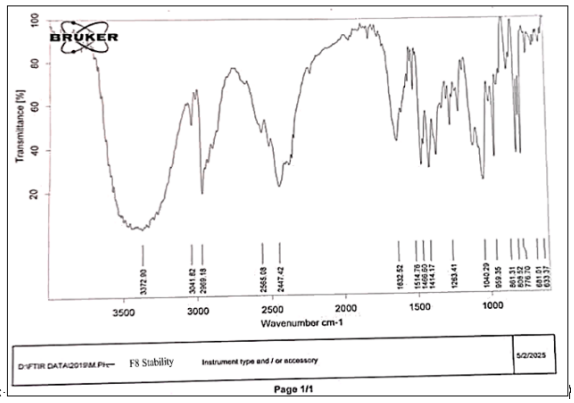


Fig 13: FT-IR Spectra of F8 Formulation After 3 Months of Storing

FT-IR Study

FTIR spectra of F8 (fresh and 3-month stored) show identical peaks at 3312, 3044, 2929, and 1632 cm^{-1}, confirming no drug–excipient interaction or degradation. Consistent fingerprint peaks (900–600 cm^{-1}) indicate preserved functional groups and chemical stability of Terbinafine Hydrochloride.

Viscosity: Slight decrease (33750→32750 cP), indicating stable gel structure.

pH: Minor drop (6.1→5.9), still skin-compatible.
Drug Content: Slight reduction (94.11→92.41%), within acceptable limits.
Entrapment Efficiency: Small decrease (95.53→94.19%), maintaining good retention.
Physical Traits: Transparent, smooth, no phase change.
Swelling Index: Slight rise (24.3→24.5), stable hydration.
Spreadability: Minimal drop (6.53→6.4), no impact on usability.

TIME (MIN)	F8	F8 (After 3 months)
0	0	0
10	23.32	20.25
20	39.69	31.05
30	56.06	46.84
40	69.36	62.63
50	88.79	78.42
60	98	90.84

Table 6: Comparisons of *In- Vitro* Release Data for Stability of Optimized Formulation of Hydrogel Containing Terbinafine Hydrochloride

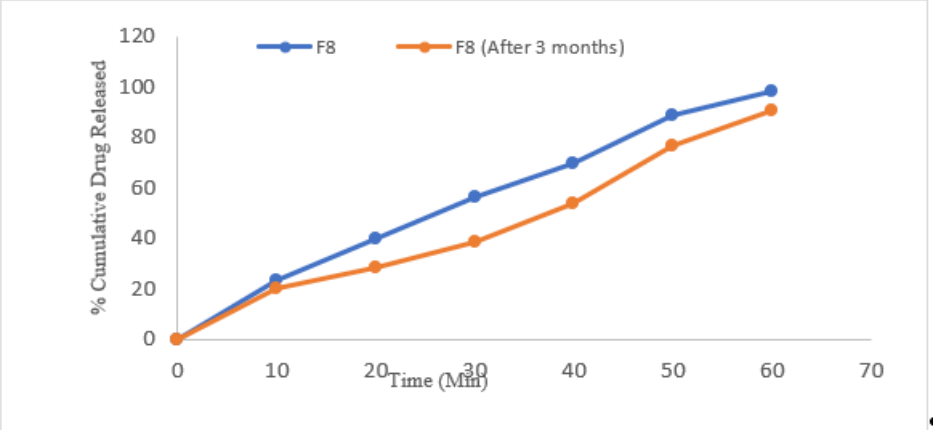


Fig 14: In-Vitro Drug Release Data for Stability Study

***In-Vitro* Drug Release:** F8 showed 98% release initially and 90.84% after 3 months, indicating minor changes but stable performance.

TIME (MIN)	F8	F8 (After 3 Months)
0	0	0
10	20.52	15.26
20	33.68	28.44
30	49.47	38.67
40	65.26	54.01
50	83.68	76.52
60	94.21	88.94

Table 7: Comparisons of *In- Vitro* Permeation Data for Stability of Optimized Formulation of Hydrogel Containing Terbinafine Hydrochloride

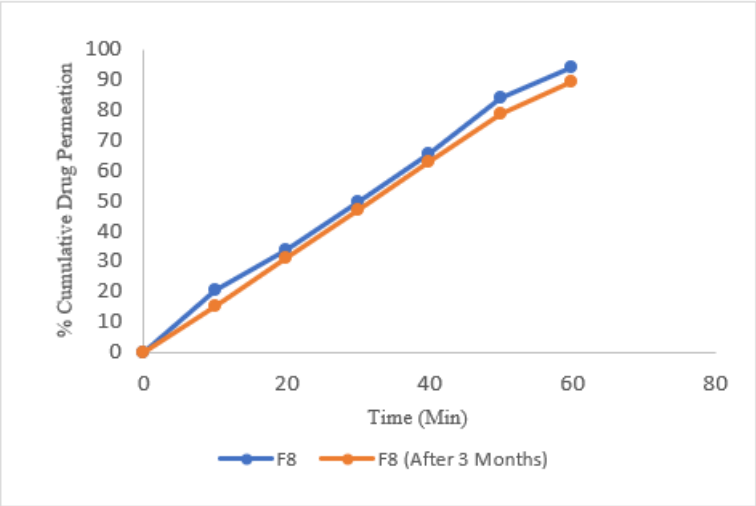


Fig 15: In- Vitro Drug Permeation Data for Stability Study

***In-Vitro* Permeation:** F8 showed slight permeation drop (94.21%→88.94%) after 3 months, indicating minor changes but stable performance.

Conclusion: The study developed stable Terbinafine Hydrochloride hydrogels with suitable pH, viscosity, and spreadability for topical use. *In vitro* studies showed time-dependent release, with F8, F10, F11, F24, F29, and F31 achieving >90 µg/cm² permeation at 60 min. These optimized formulations showed excellent stability, bioavailability, and patient-friendly properties, making them promising for effective antifungal therapy.

Future Prospect: Future work includes *in vivo* evaluation for efficacy and safety, kinetic modelling of drug release, long-term stability studies, and assessment of scale-up feasibility. Further, developing smart or stimuli-responsive hydrogels could enhance advanced antifungal therapy.

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