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Formulation and Evaluation of Salicylic Acid Gel for Athlete's Foot

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ABSTRACT

Background: Athlete's foot (*tinea pedis*) is a common superficial fungal infection primarily caused by dermatophytes, particularly *Trichophyton* species. It is characterized by itching, scaling, inflammation, and discomfort. Effective treatment requires enhanced drug penetration into the infected stratum corneum along with improved patient compliance. Salicylic acid, a keratolytic agent with adjunct antifungal properties, facilitates the removal of infected keratinized tissue, thereby improving drug penetration and therapeutic efficacy. **Methods:** In the present study, salicylic acid topical gels were formulated using different gelling agents, namely Carbopol 940, hydroxypropyl methylcellulose (HPMC), and sodium carboxymethyl cellulose (CMC), by the dispersion method. The formulations were evaluated for physicochemical parameters including pH, viscosity, spreadability, homogeneity, and drug content. In vitro drug release studies were performed to assess drug release profiles. Fourier Transform Infrared (FTIR) spectroscopy was employed to investigate drug–excipient compatibility. **Results:** The Carbopol 940-based gel exhibited superior performance with optimal viscosity, uniform drug distribution, satisfactory spreadability, and sustained drug release. FTIR studies confirmed the absence of any significant interaction between salicylic acid and the selected excipients. All formulations followed zero-order release kinetics ($r^2 = 0.9966$) and demonstrated a non-Fickian (anomalous) drug release mechanism. **Conclusion:** The developed salicylic acid topical gel, particularly the Carbopol 940 formulation, demonstrated promising physicochemical properties and sustained drug release, indicating its potential as an effective, stable, and patient-friendly therapeutic option for the management of athlete's foot.

Keywords: Athlete's foot, salicylic acid, Carbopol 940, Hydroxypropyl methylcellulose, sodium carboxymethyl cellulose, topical gel.

INTRODUCTION :

Topical drug delivery systems (TDDS) represent an important approach for the localized administration of therapeutic agents through various routes, including dermal, ophthalmic, rectal, and vaginal applications. Among these, the skin serves as the most accessible and widely utilized route due to its large surface area and ease of application. TDDS offers several advantages, including avoidance of first-pass metabolism, reduced systemic side effects, and improved patient compliance[1].

Topical formulations are broadly classified into internal preparations, which are intended for application to mucous membranes, and external preparations, which are applied directly to the skin. In recent years, topical gels have gained significant attention owing to their favourable characteristics such as non-greasy texture, ease of application, enhanced drug release, and better patient acceptability[2].

Gels are semisolid systems composed of a three-dimensional cross-linked polymer network capable of entrapping a liquid phase. Their physicochemical properties are largely governed by the interaction between the polymer matrix and the solvent system, as well as the degree of cross-linking within the network [3] . According to the United States Pharmacopeia (USP), gels are defined as semisolid systems consisting of either small inorganic particles or large organic molecules dispersed in a liquid phase [4].

Structure of Skin and Topical Gel Systems

The skin, also known as the integumentary system, is the largest organ of the human body, covering approximately 2 m^2 and accounting for about 12–15% of total body weight. It serves as a primary protective barrier against environmental factors and plays a vital role in topical drug delivery [5] . Structurally, the skin is composed of three major layers: the epidermis, dermis, and hypodermis. The epidermis is the outermost layer and is primarily composed of keratinocytes arranged in distinct strata, namely the stratum

Basale, stratum spinosum, stratum granulosum, and stratum corneum. Among these, the stratum corneum is a highly keratinized layer measuring approximately 10–20 µm in thickness and acts as the principal barrier to drug penetration[6-8]. Beneath the epidermis lies the dermis, which consists of connective tissue rich in collagen and elastin fibres and contains blood vessels, nerves, and fibroblasts that provide structural and functional support [9] . The innermost layer, the hypodermis, is mainly composed of adipose tissue, which provides insulation and mechanical protection and facilitates drug absorption into systemic circulation during transdermal delivery[10].

Drug permeation through the skin occurs primarily via two pathways. The transepidermal route involves drug diffusion either through the keratinocytes (transcellular pathway) or through the lipid matrix between cells (intercellular pathway), the latter being the major route of dermal absorption. Alternatively, the transappendageal route enables drug transport through hair follicles and sebaceous glands, which is particularly significant for polar and high molecular weight compounds[11].

Topical gels are semisolid formulations designed for localized drug delivery with minimal systemic absorption. They are widely preferred due to their non-greasy nature, ease of application, enhanced spreadability, and improved drug release characteristicsv[12] .The process of percutaneous absorption involves the release of the drug from the formulation followed by its diffusion through the various layers of the skin to reach the target site [13] . Topical drug delivery systems offer several advantages, including avoidance of first-pass metabolism, reduced systemic toxicity, improved patient compliance, suitability for drugs with short biological half-lives, and enhanced therapeutic efficacy at lower doses[14]. However, they also have certain limitations, such as the potential for skin irritation or hypersensitivity reactions, limited permeability of certain drugs, unsuitability for drugs requiring high plasma concentrations, and difficulty in delivering large molecular weight compounds[15].

Gels exhibit several distinctive physicochemical properties, including swelling, which involves absorption of liquid leading to an increase in volume; syneresis, which refers to the expulsion of liquid upon standing; ageing, characterized by gradual structural reorganization; and the formation of a three-dimensional network structure. Additionally, gels demonstrate pseudoplastic or non-Newtonian flow behaviour, wherein viscosity decreases with increasing shear rate[16]. Gel-forming polymers are hydrophilic substances that absorb water and form a three-dimensional network, thereby facilitating controlled drug release and improving formulation stability [17]. These polymers can be classified into natural polymers (such as agar, alginate, and xanthan gum), semisynthetic polymers (such as hydroxypropyl methylcellulose and carboxymethyl cellulose), synthetic polymers (such as Carbopol, poloxamer, and polyvinyl alcohol), and inorganic agents (such as bentonite and aluminium hydroxide).

The selection of an appropriate polymer for topical formulations is based on several criteria, including suitable molecular weight, compatibility with the drug, non-toxic and biocompatible nature, ability to control drug release, and stability along with cost-effectiveness[18]. Gel formation occurs through various mechanisms, including chemical cross-linking involving covalent bonding between polymer chains, physical cross-linking through hydrogen bonding or temperature-induced gelation, and ionic cross-linking resulting from interactions between charged polymers and ions[19].

Various additives are incorporated into gel formulations to enhance their performance, including gelling agents such as Carbopol and HPMC, humectants such as glycerine and propylene glycol, and stabilizers such as EDTA, which acts as a chelating agent[20]. The quality and performance of gel formulations are evaluated using several parameters, including pH measurement, viscosity determination, spreadability, homogeneity, extrudability, skin irritation studies, stability testing, drug content analysis, and in-vitro drug diffusion studies[21-23].

METHODOLOGY

Pre-formulation Studies

1. Melting Point Determination

The melting point of salicylic acid was determined to assess the purity of the sample. A small quantity of the powdered drug was filled into a capillary tube sealed at one end. The tube was placed in a Thiele's melting point apparatus, and the temperatures at which the drug started and completed melting were recorded. The average of three determinations was reported[24].

2. UV Spectral Analysis (λmax Determination)

A solution of salicylic acid (100 µg/mL) was prepared in ethanol and scanned over the wavelength range of 200–400 nm using a UV–visible spectrophotometer (Shimadzu UV-1700), with phosphate buffer (pH 7.4) as the blank. The maximum absorbance (λmax) was determined and used for subsequent spectrophotometric analysis.

3. Solubility Studies

The solubility of salicylic acid was evaluated in various solvents, including distilled water, ethanol, methanol, polyethylene glycol 400 (PEG 400), and phosphate buffer (pH 7.4) at room temperature. An excess amount of drug was added to 10 mL of each solvent and shaken intermittently to achieve equilibrium. After 24 hours, the solutions were filtered, and the drug concentration was determined spectrophotometrically at 296 nm. All measurements were performed in triplicate, and the mean values were recorded[25].

4. Preparation of Salicylic Acid Gel

Gel Formulation Using Different Gelling Agents

A total of nine gel formulations were prepared using Carbopol 940, hydroxypropyl methylcellulose (HPMC), and sodium carboxymethyl cellulose (SCMC) as gelling agents. The required quantity of each gelling agent was dispersed in purified water and allowed to hydrate completely.

Salicylic acid was dissolved in ethanol and incorporated into the hydrated gel base. Excipients including methylparaben and propylparaben (as preservatives), propylene glycol, and polyethylene glycol 400 were added with continuous stirring. Triethanolamine was then added dropwise to adjust the pH and facilitate gel formation.

Evaluation of salicylic acid Gel

Appearance

The prepared gel formulations were assessed for various physical parameters like colour, oduor and washability.

Washability

Easiness in the removal of gel from the skin is known as washability.100 mg of gel was applied on the skin of six volunteers each person was trained to make scores for easiness in the removal of sample after one minute and the scores were based on the situation such as washable and not washable.

pH Measurement

The pH of gel was determined by using digital pH meter. 1 gm of gel was dissolved in 100 ml of distilled water. The pH of formulation was determined in triplicate and the average value for recorded.[26]

Viscosity

Viscosity was measured using a Brookfield Viscometer (Model LVDV II+ Pro) at room temperature using spindle number RV 6 at 10 rpm at 33±1°C.[27]

Spreadability

Spreadability was assessed by placing 1 g of gel between two glass slides each measuring 6 cm x 2cm.A consistent film was created and the air between the slides was released by letting a weight of 100gm on the slide for 5 minutes. The top slide was pulled by an 500gm weight while the bottom slide was secured. The change in diameter of gel was recorded as spreadability.[28]

Extrudability

Weighed quantity (20g) of gel was filled in collapsible aluminium tubes. The extrudability of the formulation was determined in terms of weights in grams required to extrude a 0.5cm ribbon of gel in 10 seconds.[29]

Homogeneity and Grittiness

Homogeneity and grittiness were measured by visual inspection as well as by taking a small quantity of gel and rubbing on the skin surface.[30]

Drug Content

100 mg of gel was dissolved in 100ml of phosphate buffer 7.4 solution and using magnetic stirrer for 1-2 hours and then it was filtered using phosphate buffer solution pH 7.4 as a blank, approximately diluted and spectrophometrically measured at 296 nm.

In-vitro Diffusion Studies

The release rate of the drug from the gel was studied using Franz diffusion cell with a cellophane membrane. The receptor compartment was filled with 100ml of phosphate buffer (pH 7.4) maintained at 37°C ± 0.5°C and stirred continuously at 600 rpm. At specific time intervals (15 min, 30 min, 1, 2, 3, 4, 5, 6 hours), 1ml samples were withdrawn and replaced with fresh buffer, and sink condition was maintained during the studies. The amount of drug released was determined spectrophotometrically.

Kinetic Analysis of Drug Release

Drug release data were analysed using various kinetic models, including zero-order, first-order, Higuchi, and Korsmeyer–Peppas models, to determine the release mechanism. The Korsmeyer–Peppas model was used to interpret the release exponent (n), where n = 0.45 indicates Fickian diffusion, 0.45–0.89 indicates non-Fickian (anomalous) transport, 0.89 corresponds to Case II (zero-order) transport, and >0.89 indicates super Case II transport. These models helped to characterize the drug release behaviour from the formulated gels.

Fourier Transform Infrared (FTIR) Analysis

The pure drug and selected formulations were subjected for FTIR analysis to check the compatibility/interaction between the drug and excipients. The samples were scanned over a range of 500-3500 cm^{-1} using Fourier transformer infrared spectrophotometer. Spectra were analysed for drug carrier interactions.

Antimicrobial Activity of Salicylic Acid Formulations Against *Candida albicans*

Procedure (Broth Microdilution Method)[31-34]

The antimicrobial activity of the prepared salicylic acid formulations against *Candida albicans* was evaluated using the broth microdilution method. Initially, all glassware and materials were sterilized, and the culture medium (such as Sabouraud dextrose broth) was prepared under aseptic conditions.

A fresh culture of *Candida albicans* was obtained and standardized to an appropriate inoculum density, typically matching 0.5 McFarland standard, to ensure uniform microbial concentration. Serial dilutions of each test sample, including salicylic acid formulations (F3, F6, F9) and pure salicylic acid, were prepared in sterile broth to obtain a range of concentrations.

Aliquots of these diluted samples were then transferred into sterile microtiter plate wells. To each well, a fixed volume of the standardized fungal inoculum was added. A positive control (containing broth and inoculum without drug) and a negative control (containing only broth) were also maintained to validate the results.

The microtiter plates were incubated at 35–37°C for 24–48 hours under suitable conditions. After incubation, the wells were visually examined for turbidity or microbial growth. The lowest concentration of the test sample that showed no visible growth was recorded as the minimum inhibitory concentration (MIC).

All experiments were performed under aseptic conditions, and the results were recorded carefully for comparison among different formulations.

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Table 1: Composition of Salicylic Acid Gel Formulations

Ingredients	F1	F2	F3	F4	F5	F6	F7	F8	F9
Drug	1gm	1gm	1gm	1gm	1gm	1gm	1gm	1gm	1gm
Carbopol 940	0.5gm	0.75gm	1gm	_	_	_	_	_	_
Hydroxypropyl methylcellulose	_	_	_	1gm	1.5gm	2gm	_	_	_
Sodium CMC	_	_	_	_	_	_	0.5gm	0.75gm	1gm
Alcohol	5ml	5ml	5ml	5ml	5ml	5ml	5ml	5ml	5ml
Triethylamine	Qs	Qs	Qs	Qs	Qs	Qs	Qs	Qs	Qs
Propylene glycol	5ml	5ml	5ml	5ml	5ml	5ml	5ml	5ml	5ml
Methylparaben	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Propylparaben	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
polyethylene glycol 400	5ml	5ml	5ml	5ml	5ml	5ml	5ml	5ml	5ml
Distilled Water	Qs	Qs	Qs	Qs	Qs	Qs	Qs	Qs	Qs

Table 2: Evaluation of prepared salicylic acid formulations.

Formulation code	Appearance	pH	Viscosity (Cps)	Spreadability (cm)	Extrudability (%)	Grittiness	Homogeneity	Drug Content (%)
F1	Whitish, smooth and uniform	6.1±0.2	1855±0.2	4.1±0.26	89.0	No	Excellent	94.53±0.02
F2	Whitish, smooth and uniform	5.9±0.2	1810±0.1	4.5±0.44	92.5	No	Excellent	87.98±0.04
F3	Whitish, smooth and uniform	6.1±0.1	1867±0.1	3.9±0.66	85.6	No	Excellent	95.63±0.07
F4	Whitish, less viscous	6.1±0.2	1276±0.3	3.9±0.86	92.5	No	Excellent	97.81±0.06
F5	White to off white, thin gel	5.9±0.2	1292±0.2	4.6±0.29	93.1	No	Excellent	95.63±0.05
F6	Whitish, less viscous	5.7±0.2	1198±0.1	4.7±0.85	92.7	No	Excellent	95.09±0.05
F7	Slightly whitish, smooth gel	5.7±0.1	1527±0.1	3.9±0.15	89.4	No	Excellent	98.37±0.02
F8	Colourless to slightly whitish, smooth gel	5.9±0.2	1592±0.2	3.8±0.19	82.9	No	Excellent	93.99±0.06
F9	Whitish, thick gel	5.4±0.1	1653±0.1	4.0±0.19	82.1	No	Excellent	97.81±0.03

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Table 3: Comparison of *In-vitro* release profile Salicylic acid gel (F1- F9).

Time(min)	Cumulative percentage of drug release								
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**
0	0	0	0	0	0	0	0	0	0
15	3.82514	1.27505	0.54645	1.45719	8.01457	3.27869	1.82149	1.0929	1.45719
30	5.74135	2.40437	0.74135	4.2459	10.1985	5.55191	4.24954	3.50638	3.87796
60	7.4153	4.25501	2.95082	10.1603	17.5774	6.86157	9.97632	9.23315	10.5246
120	9.82332	5.74499	6.28415	18.6812	25.561	10.5537	23.8306	23.0874	24.9399
180	16.8379	10.1749	7.42077	21.8925	28.7668	12.6138	33.3497	30.5829	32.0729
240	26.2896	13.898	10.1913	24.3151	32.1093	16.6812	35.4663	34.7031	34.5337
300	28.5902	14.6703	12.4262	28.0182	34.3497	19.1129	37.694	38.4226	37.6849
360	31.0036	19.0929	14.6557	33.7577	36.5792	21.8962	40.6594	40.1148	39.9235
420	32.867	21.1603	16.7013	37.4936	37.7049	25.4189	45.4718	42.7067	43.4408
480	35.0929	21.3643	18.377	42.4973	41.0273	28.0291	48.4627	47.8834	46.9709

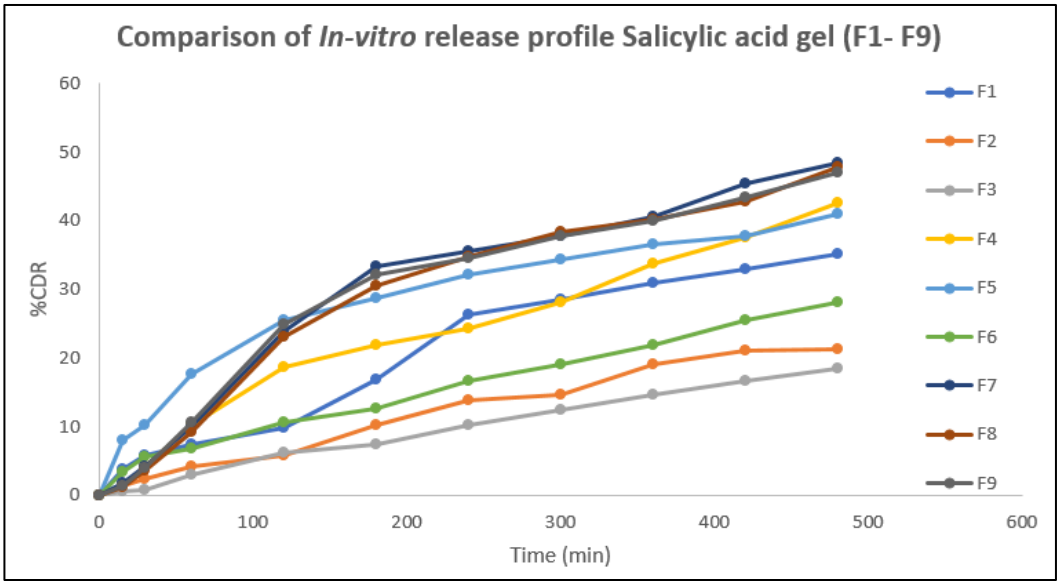

Fig 1: Comparison of *In-vitro* release profile Salicylic acid gel (F1- F9)

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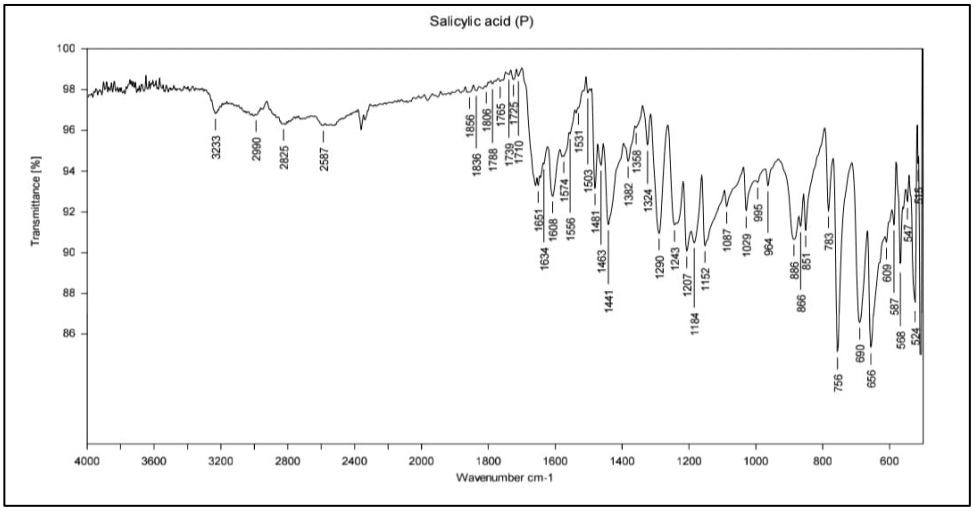

Fig. 2: FTIR of pure Salicylic Acid

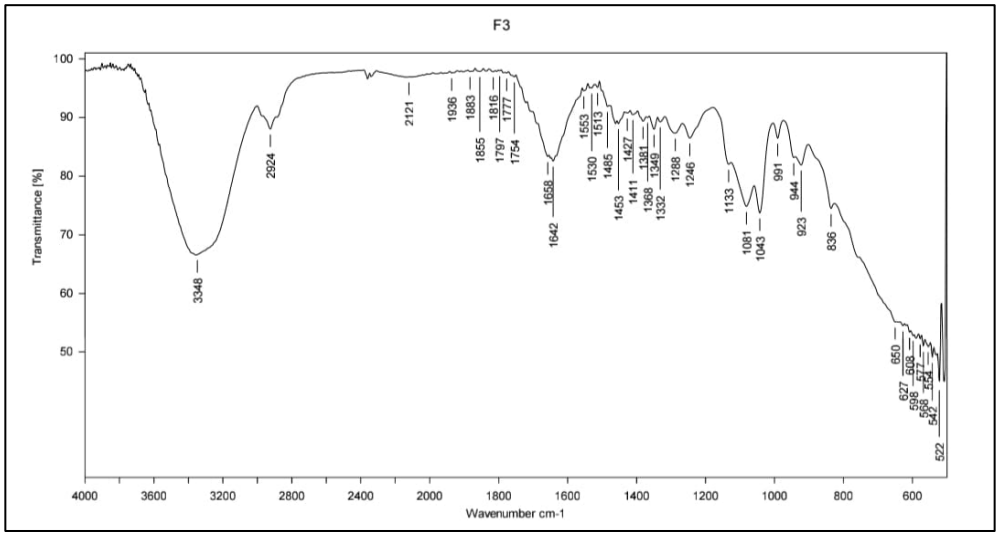

Fig.3: FTIR spectra of salicylic acid gel formulations (F3)

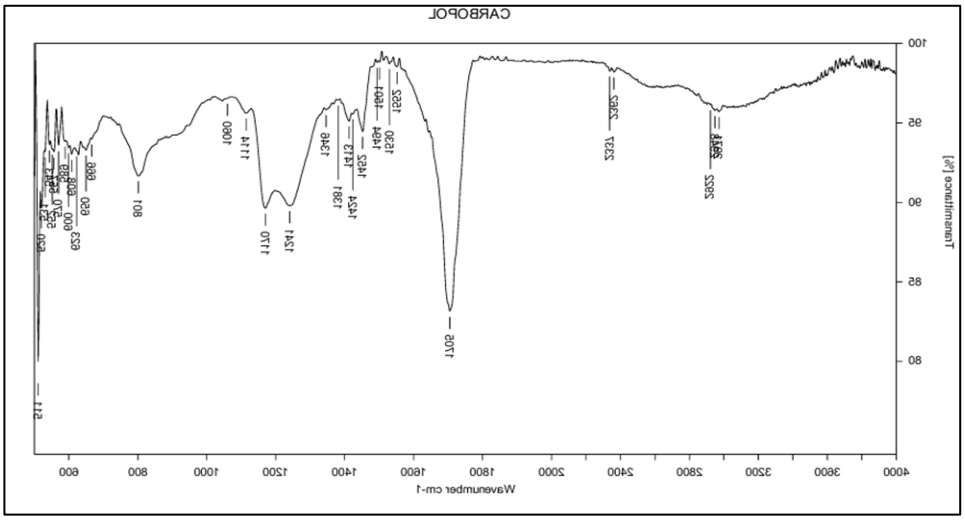

Fig 4: FTIR spectra of Carbopol940

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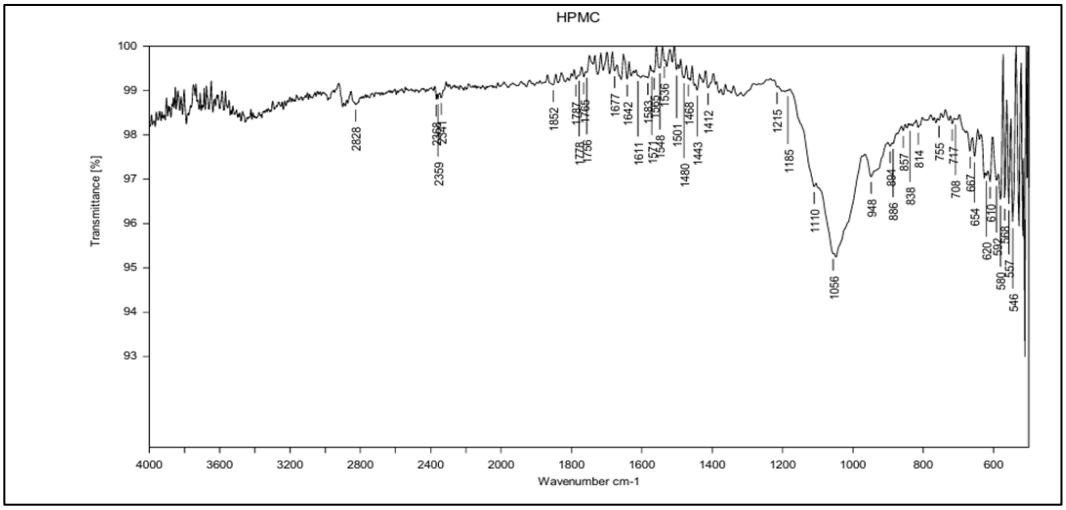

Fig 5: FTIR spectra of HPMC

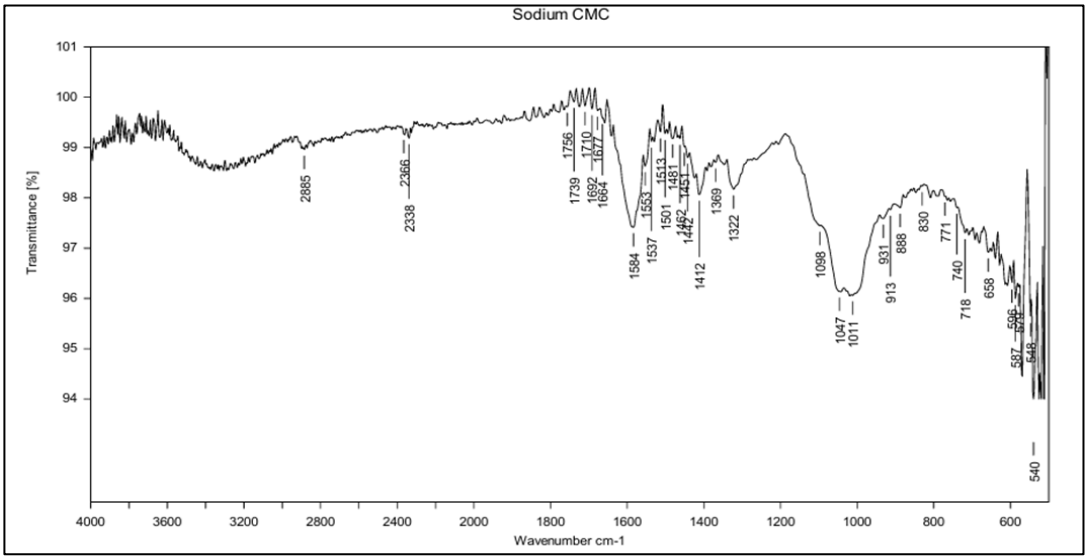

Fig 6: FTIR spectra of Sodium CMC

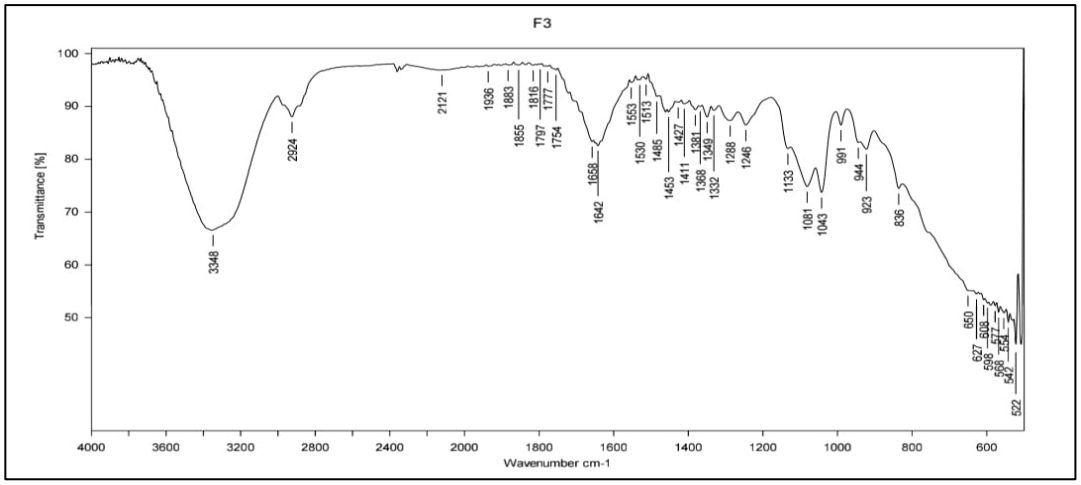

Fig.7: FTIR spectra of salicylic acid gel formulations (F3)

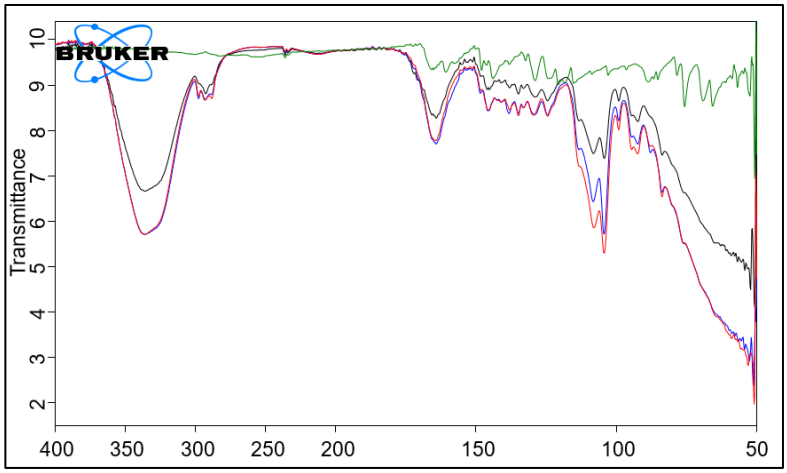

Fig 8: Comparison of formulations F-3, F-6, F-9 with pure drug

Table 4: Result of Antimicrobial assay against candida albicans

Sl. No	Sample Name	Test	MIC (mg/ml)	Technique
1	Salicylic acid F3 (Carbopol 940)	Antimicrobial assay against *Candida albicans*	0.625	Broth Microdilution
2	Salicylic acid F6 (HPMC)	Antimicrobial assay against *Candida albicans*	2.50	Broth Microdilution
3	Salicylic acid F9 (SCMC)	Antimicrobial assay against *Candida albicans*	1.25	Broth Microdilution
4	Pure Salicylic acid	Antimicrobial assay against *Candida albicans*	0.313	Broth Microdilution

Discussion:

Topical preparations are applied to the skin to achieve either local or systemic therapeutic effects. Dermal and transdermal delivery systems offer several advantages, including avoidance of first-pass hepatic metabolism, prevention of gastric degradation, and reduced dosing frequency. Among these, topical gels are considered safe and effective for the treatment of skin disorders. Compared to creams and ointments, gels are non-greasy, provide faster drug release, and improve patient compliance due to their cooling and soothing properties. They are widely used for the delivery of analgesic, anti-inflammatory, antifungal, and dermatological agents.

Salicylic acid is classified as a Biopharmaceutics Classification System (BCS) Class I drug, exhibiting high solubility and permeability. It belongs to the group of β-hydroxy acids (BHAs) and acts as a keratolytic agent by softening and promoting the removal of the outer keratinized layer of the skin. It is also a precursor and metabolite of acetylsalicylic acid (aspirin).

Following systemic absorption, salicylic acid undergoes extensive hepatic metabolism, primarily through conjugation with glycine and glucuronic acid, enhancing its solubility and renal excretion. At higher doses, metabolic pathways may become saturated, leading to drug accumulation and potential toxicity. Therefore, incorporation of salicylic acid into topical gel formulations is advantageous, as it ensures localized drug action while minimizing systemic exposure and associated adverse effects.

Topical salicylic acid gels are widely used in the management of various dermatological conditions, including acne, dandruff, psoriasis, seborrheic dermatitis, corns, calluses, and warts.

Melting Point Determination

The melting point of salicylic acid was determined using a Thiele's melting point apparatus as an initial indicator of purity. The drug exhibited a melting point of 158 °C, indicating good purity, physical stability, and suitability for formulation development.

Solubility Studies

Salicylic acid, a BCS Class I drug, exhibited high solubility and permeability. The saturation solubility was found to be 2.4 mg/mL in water and 10 mg/mL in 0.2 M KH_2PO_4, which is consistent with reported values. The enhanced solubility in slightly basic medium supports previous findings that weakly acidic drugs show improved solubility at higher pH due to ionization[35,36]. Therefore, phosphate buffer (pH 7.4) was selected to simulate physiological conditions.

Evaluation of Salicylic Acid Gel

General Appearance

All gel formulations were clear, homogeneous, and free from particulate matter, indicating uniform dispersion of the drug and excipients. Similar observations have been reported in topical gel formulations, where homogeneity ensures consistent drug distribution and therapeutic efficacy[37]. The smooth texture and easy washability further indicate good patient acceptability.

pH Measurement

The pH of all formulations (5.7–6.2) was within the normal skin pH range (5.5–6.5), suggesting compatibility with skin and minimal irritation potential. Previous studies have emphasized that maintaining formulation pH close to skin pH enhances tolerability and reduces irritation[38].

Viscosity

Carbopol 940-based formulations showed higher viscosity compared to HPMC and sodium CMC formulations. This is attributed to the highly cross-linked structure of Carbopol, which imparts greater thickening efficiency. Similar findings have been reported, where Carbopol-based gels exhibited superior viscosity and stability compared to cellulose derivatives[39,40].

Spreadability

The spreadability of the gels decreased with increasing polymer concentration due to increased viscosity. This inverse relationship between viscosity and spreadability has been well documented in topical formulations [41]. Adequate spreadability is essential to ensure uniform drug application and patient compliance.

Extrudability

All formulations showed good extrudability (82.1–93.1%), indicating suitable consistency for application. Previous studies have reported that optimal extrudability is critical for patient convenience and dosage accuracy in semisolid formulations[42].

Drug Content

Drug content ranged from 87.98% to 98.37%, indicating uniform drug distribution. Similar uniformity has been reported in well-formulated topical gels, reflecting efficient mixing and formulation stability [43].

In-vitro Diffusion Studies

Drug release studies showed that sodium CMC formulations exhibited the highest release, followed by HPMC and Carbopol 940. The decrease in drug release with increasing polymer concentration is attributed to the increased viscosity and diffusion barrier. These findings are in agreement with previous reports indicating that polymer type and concentration significantly influence drug release from gel systems[44,45]. Formulation F7 (sodium CMC) demonstrated the highest release and was selected as the optimized formulation.

Kinetic Study

The release data best fitted zero-order kinetics, indicating a constant drug release rate. Higuchi model fitting confirmed diffusion-controlled release, while Korsmeyer–Peppas analysis indicated a non-Fickian (anomalous) mechanism (n = 0.8559–0.9978), suggesting combined diffusion and polymer relaxation. Similar release patterns have been widely reported for polymeric gel systems[46,47].

FTIR Studies

FTIR analysis confirmed the absence of significant drug–excipient interactions, as characteristic peaks of salicylic acid were retained in all formulations. This indicates chemical stability and compatibility of the drug with selected polymers. Comparable results have been reported in earlier studies, where no significant spectral shifts indicated stable formulations[48,49].

Antimicrobial Activity [50-52]

The antimicrobial activity of the developed formulations against *Candida albicans* showed noticeable variation, primarily influenced by the type of polymer used in the formulation. This indicates that the choice of polymer plays a critical role in modulating the release and availability of salicylic acid, thereby affecting its antifungal efficacy.

Pure salicylic acid demonstrated the lowest minimum inhibitory concentration (MIC) value of 0.313 mg/ml, confirming its highest antifungal activity. This can be attributed to the absence of any polymeric matrix, allowing immediate availability and direct interaction of the drug with the fungal cells.

Among the formulated systems, F3 containing Carbopol 940 exhibited superior activity (MIC = 0.625 mg/ml) compared to other formulations. This enhanced activity may be due to the hydrophilic nature and excellent swelling properties of Carbopol, which facilitate better drug release and diffusion. Additionally, Carbopol forms a uniform gel matrix that may improve drug dispersion and contact with microbial cells.

F9 containing sodium carboxymethyl cellulose (SCMC) showed moderate antimicrobial activity with an MIC of 1.25 mg/ml. The relatively higher MIC compared to F3 suggests a comparatively slower drug release, possibly due to higher viscosity or stronger polymer-drug interactions that limit immediate drug availability.

F6 formulated with hydroxypropyl methylcellulose (HPMC) exhibited the least antifungal activity (MIC = 2.50 mg/ml). This reduced efficacy may be attributed to the formation of a more viscous gel barrier, which can retard drug diffusion and delay its release into the surrounding medium, thereby reducing its effective concentration against the microorganism.

The observed differences in antimicrobial activity can be explained by several formulation factors, including variations in drug release profiles, polymer-drug interactions, and the viscosity and diffusion characteristics of each system. Polymers that allow rapid hydration and swelling tend to enhance drug diffusion, while highly viscous systems may hinder drug mobility.

Overall, Carbopol 940-based formulation demonstrated better performance among the tested polymers, suggesting that it is a more suitable candidate for enhancing the antifungal efficacy of salicylic acid in topical formulations.

REFERENCES

1. Shivam, Goswami M, Patel VM. A brief review on topical drug delivery system and gel. *Int J Pharm Res Appl*. 2022;7(1):271–8.
2. Bani KS, Bhardwaj K. Topical drug delivery therapeutics, drug absorption and penetration enhancement techniques. *J Drug Deliv Ther*. 2021;11(4):105–10.
3. Ahmed M, Ali M. Semisolid dosage form: topical gel formulation – a review. *World J Pharm Res*. 2016;5(12):1256–68.
4. Suhonen MT, Bouwstra JA, Urtti A. Chemical enhancement of percutaneous absorption in relation to stratum corneum structural alterations. *J Control Release*. 1999;59:149–61.
5. Lopez-Ojeda W, Sharma S. Anatomy, skin (integument) [Updated 2022 Oct 17]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 [cited 2024 Mar 17].
6. Blanpain C, Fuchs E. Epidermal homeostasis: a balancing act of stem cells in the skin. *Nat Rev Mol Cell Biol*. 2009;10:207–17.
7. Bin BH, Joo YH, Lee AY, Shin SS, Cho EG, Lee TR. Novel inhibitory effect of N-(2-hydroxycyclohexyl) valiolamine on melanin production in a human skin model. *Int J Mol Sci*. 2014;15:12188–95.
8. Bin BH, Kim ST, Bhin J, Lee TR, Cho EG. The development of sugar-based anti-melanogenic agents. *Int J Mol Sci*. 2016;17:583.
9. Souto EB, Fangueiro JF, Fernandes AR, Cano A, Sanchez-Lopez E, Garcia ML, et al. Physicochemical and biopharmaceutical aspects influencing skin permeation and role of SLN and NLC for skin drug delivery. *Heliyon*. 2022;8:e08938.
10. Lai-Cheong JE, McGrath JA. Structure and function of skin, hair and nails. *Medicine (Abingdon)*. 2021;49:337–42.
11. Ramadon D, McCrudden MT, Courtenay AJ, Donnelly RF. Enhancement strategies for transdermal drug delivery systems: current trends and applications. *Drug Deliv Transl Res*. 2021;12:758–91.
12. Almoshari Y. Novel hydrogels for topical applications: an updated comprehensive review based on source. *Gels*. 2022;8(174):2–24.

13. Parihar N, Saini M, Soni SL, Sharma V. Emulgel: a topical preparation. *Asian J Pharm Res Dev*. 2020;8(3):196–201.
14. Abitha MH, Mathew F. Recent advances in topical gel formulation. *World J Pharm Res*. 2024;13(21):1184.
15. Sharma J, Agrawal D, Sharma AK, Khandelwal MK, Aman S. New topical drug delivery system pharmaceutical organogel: a review. *Asian J Pharm Res Dev*. 2022;10(1):75–8.
16. Shelke SJ, Shinkar DM, Saudagar RB. Topical gel: a novel approach for development of topical drug delivery system. *Int J PharmTech Res*. 2013;5(3):2739–63.
17. Singh V, Singh PK, Sharma PK, Srivastava PK, Mishra A. Formulation and evaluation of topical gel of aceclofenac containing piperine. *Indo Am J Pharm Res*. 2013;3(7):5266–80.
18. Labarre D, Ponchel G, Vauthier C. Biomedical and pharmaceutical polymers. London (UK): Pharmaceutical Press; 2010.
19. Cevc G, Schatzlein A, Blume G. Transdermal drug carriers: basic properties, optimization and transfer efficiency in case of epicutaneously applied peptides. *J Control Release*. 1995;36:3–16.
20. Saroha K, Singh S, Aggarwal A, Nanda S. Transdermal gels – an alternative vehicle for drug delivery. *Int J Pharm Chem Biol Sci*. 2013;3(3):495–503.
21. Tahsildar AG, Shankar DM, Saudagar RB. Hydrogel – a novel technique for preparation of topical gel. *World J Pharm Pharm Sci*. 2013;2(6):4520–41.
22. Thorat SP, Rane SI. Formulation and in vitro evaluation of lecithin (soya and egg) based aceclofenac organogels. *J Pharm Res*. 2010;3(6):1438–41.
23. Patel HK, Shah DP. A review on microemulsion-based gel: an innovative approach for topical delivery of hydrophobic drug. *World J Pharm Res*. 2018;7(7):344–9.
24. Taylor M, Gonzalez M, Porter R. Pathways to inflammation: acne pathophysiology. Eur J Dermatol. 2011;21(3):323–33.
25. Gordon RD. More than skin deep: advances in transdermal technologies are opening up new avenues of exploration. Pharm Technol Eur. 2005;17(11):60–6.
26. Alberti I, Grenier A, Kraus R, Raus H, Carrara DN. Expert Opin Drug Deliv. 2005;2(5):935-950.
27. Guo R, Du X, Zhang R, Deng L, Dong A, Zhang J. Bioadhesive film formed from a novel organic-inorganic hybrid gel for transdermal drug delivery system. Eur J Pharm Biopharm. 2011;79(3):574-583.
28. Renata CV, Tatiele K, Silvia GS. Drug transport across skin. In: Muro S, editor. Drug delivery across physiological barriers. Boca Raton (FL): Taylor and Francis Group LLC; 2016. p.132–4
29. Das S, Haldar PK, Pramanik G. Formulation and evaluation of herbal gel containing Clerodendrum infortunatum leaves extract. Int J PharmTech Res. 2011;3(1):140–3
30. Khullar R, Kaur D, Minocha S, Saini S, Seth N. Formulation and evaluation of mefenamic acid emulgel for topical delivery. Saudi Pharm J. 2012;20(1):63–7.
31. Clinical and Laboratory Standards Institute (CLSI). **Reference method for broth dilution antifungal susceptibility testing of yeasts; Approved standard—4th ed.** CLSI document M27. Wayne, PA: CLSI; 2017.
32. Pfaller MA, Diekema DJ. Progress in antifungal susceptibility testing of *Candida* spp. by use of Clinical and Laboratory Standards Institute broth microdilution methods. **J Clin Microbiol.** 2012;50(9):2846–56. doi:10.1128/JCM.00937-12.
33. Rex JH, Pfaller MA, Walsh TJ, Chaturvedi V, Espinel-Ingroff A, Ghannoum MA, et al. Antifungal susceptibility testing: practical aspects and current challenges. **Clin Microbiol Rev.** 2001;14(4):643–58. doi:10.1128/CMR.14.4.643-658.2001.
34. Balouiri M, Sadiki M, Ibnsouda SK. Methods for in vitro evaluating antimicrobial activity: A review. **J Pharm Anal.** 2016;6(2):71–9. doi:10.1016/j.jpha.2015.11.005.
35. Amidon GL, Lennernäs H, Shah VP, Crison JR. A theoretical basis for a biopharmaceutic drug classification: the correlation of in vitro drug product dissolution and in vivo bioavailability. *Pharm Res.* 1995;12(3):413–420. doi:10.1023/A:1016212804288
36. Dressman JB, Amidon GL, Reppas C, Shah VP. Dissolution testing as a prognostic tool for oral drug absorption: immediate release dosage forms. *Eur J Pharm Sci.* 1998;6(4):265–271. doi:10.1016/S0928-0987(97)10034-3
37. Barry BW. Dermatological formulations: percutaneous absorption. *Drugs Pharm Sci.* 1983; 18:1–480. doi:10.1201/9780203750333
38. Ali SM, Yosipovitch G. Skin pH: from basic science to basic skin care. *Acta Derm Venereol.* 2013;93(3):261–267. doi:10.2340/00015555-1531
39. Rowe RC, Sheskey PJ, Quinn ME. *Handbook of Pharmaceutical Excipients.* 6th ed. London: Pharmaceutical Press; 2009.
40. Aulton ME, Taylor KMG. *Aulton's Pharmaceutics: The Design and Manufacture of Medicines.* 5th ed. Elsevier; 2018. doi:10.1016/C2015-0-05084-3
41. Mutimer MN, Riffkin C, Hill JA, Glickman ME, Cyr GN. Modern ointment bases: evaluation of properties. *J Pharm Pharmacol.* 1956;8(1):63–74. doi:10.1111/j.2042-7158.1956.tb12173.x
42. Allen LV. Pharmaceutical dosage forms and drug delivery systems. 10th ed. Lippincott Williams & Wilkins; 2014.
43. Indian Pharmacopoeia Commission. *Indian Pharmacopoeia.* Ghaziabad: IPC; 2018.
44. Siepmann J, Peppas NA. Higuchi equation: derivation, applications, use and misuse. *Adv Drug Deliv Rev.* 2011;63(3):163–174. doi: 10.1016/j.addr.2011.01.002
45. Dash S, Murthy PN, Nath L, Chowdhury P. Kinetic modelling on drug release from controlled drug delivery systems. *Acta Pol Pharm.* 2010;67(3):217–223.

46. Higuchi T. Mechanism of sustained-action medication: theoretical analysis of rate of release of solid drugs dispersed in solid matrices. *J Pharm Sci.* 1963;52(12):1145–1149. doi:10.1002/jps.2600521210
47. Korsmeyer RW, Gurny R, Doelker E, Buri P, Peppas NA. Mechanisms of solute release from porous hydrophilic polymers. *Int J Pharm.* 1983;15(1):25–35. doi:10.1016/0378-5173(83)90064-9
48. Stuart B. *Infrared Spectroscopy: Fundamentals and Applications.* Wiley; 2004. doi:10.1002/0470011149
49. Silverstein RM, Webster FX, Kiemle DJ. *Spectrometric Identification of Organic Compounds.* 7th ed. Wiley; 2005. doi:10.1002/0471705128
50. EUCAST. **Method for the determination of broth dilution minimum inhibitory concentrations of antifungal agents for yeasts.** EUCAST Definitive Document E.DEF 7.3.2; 2020.
51. Odds FC. Synergy, antagonism, and what the chequerboard puts between them. **J Antimicrob Chemother.** 2003;52(1):1. doi:10.1093/jac/dkg301.
52. Ghannoum MA, Rice LB. Antifungal agents: mode of action, mechanisms of resistance, and correlation of these mechanisms with bacterial resistance. **Clin Microbiol Rev.** 1999;12(4):501–17.

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