

Formulation and Evaluation of Emulgel by Combining Miconazole Nitrate and Rosemary Oil for Treatment of Candidiasis and Dermatophytosis

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ABSTRACT

Superficial fungal infections such as candidiasis and dermatophytosis represent a major global dermatological concern, particularly in tropical and subtropical regions where humidity and temperature favor fungal proliferation. Despite the widespread availability of topical azole antifungal agents, therapeutic challenges including poor drug penetration, prolonged treatment duration, recurrence, and emerging resistance continue to compromise clinical outcomes. Miconazole nitrate, a broad-spectrum imidazole antifungal, exhibits potent activity against *Candida* species and dermatophytes through inhibition of ergosterol biosynthesis. However, its limited aqueous solubility and suboptimal dermal permeation restrict its therapeutic efficiency in conventional semisolid dosage forms.

Rosemary oil, obtained from *Rosmarinus officinalis*, contains bioactive terpenoids such as 1,8-cineole and α -pinene, which exhibit antifungal, anti-inflammatory, and skin permeation-enhancing properties. Incorporation of rosemary oil into an emulgel system provides dual benefits: synergistic antifungal activity and improved transdermal delivery of miconazole nitrate. Emulgel systems, combining the stability of emulsions with the rheological advantages of gels, offer enhanced drug release, superior spreadability, patient compliance, and prolonged residence time at the site of infection.

This review comprehensively discusses the epidemiology and pathophysiology of candidiasis and dermatophytosis, pharmacological profile of miconazole nitrate, therapeutic significance of rosemary oil, formulation strategies of emulgel systems, evaluation parameters, and stability considerations. The combination approach represents a promising advancement in topical antifungal therapy, potentially improving efficacy,

reducing recurrence, and enhancing patient adherence.

Keywords: Miconazole nitrate, Rosemary oil, Emulgel, Candidiasis, Dermatophytosis, Essential oils, Topical drug delivery, Antifungal therapy

I. INTRODUCTION

1.1 GLOBAL BURDEN OF SUPERFICIAL FUNGAL INFECTIONS

Superficial fungal infections are among the most common dermatological disorders worldwide. Epidemiological studies indicate that nearly 20–25% of the global population is affected by dermatophytic infections at any given time^[3]. These infections are particularly prevalent in regions with high humidity, overcrowding, and limited hygiene practices.

Candidiasis and dermatophytosis account for the majority of superficial fungal cases. While generally non-life-threatening, they significantly affect quality of life due to itching, discomfort, cosmetic concerns, and chronic recurrence^[1,3].

1.2 PATHOGENESIS OF CANDIDIASIS

Candidiasis is predominantly caused by *Candida albicans*, a dimorphic fungus capable of switching between yeast and hyphal forms, which enhances its invasiveness^[1]. The organism forms biofilms on epithelial surfaces, increasing resistance to antifungal therapy.

1.2.1 Virulence Factors

- Adhesins facilitating epithelial attachment
- Hydrolytic enzymes (proteases, phospholipases)
- Biofilm formation
- Morphological switching

These factors contribute to persistent infection and reduced susceptibility to azole drugs^[4].

1.2.2 Predisposing Conditions

- Diabetes mellitus

- Immunosuppression
- Broad-spectrum antibiotic use
- Prolonged corticosteroid therapy

In tropical climates, excessive sweating creates a moist environment conducive to fungal growth [3].

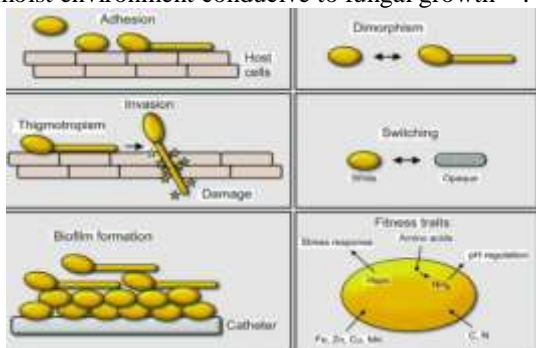


Fig.1.1 Pathogenesis of *Candida albicans*

1.3 PATHOGENESIS OF DERMATOPHYTOSIS

Dermatophytes are keratinophilic fungi belonging to genera *Trichophyton*, *Microsporum*, and *Epidermophyton*[3]. They infect keratinized tissues including skin, hair, and nails.

1.3.1 Mechanism of Infection

Dermatophytes produce keratinases and proteolytic enzymes that degrade keratin, enabling colonization of stratum corneum. The inflammatory response varies depending on fungal species and host immunity.

1.3.2 Clinical Forms

- Tinea corporis
- Tinea pedis
- Tinea cruris
- Tinea capitis

Chronic dermatophytosis and recurrent infections are increasingly reported due to antifungal resistance and incomplete treatment courses [4].

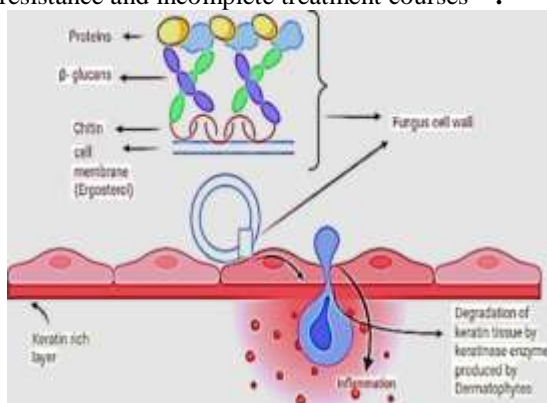


Fig.1.2 Pathogenesis of Dermatophytosis

1.4 LIMITATIONS OF CURRENT TOPICAL ANTIFUNGAL THERAPY

Although topical azoles remain first-line treatment, several limitations exist:

1. Poor penetration across stratum corneum barrier
2. Inadequate drug concentration at deeper infected layers
3. Greasy texture reducing patient compliance
4. Risk of resistance development

Conventional creams may undergo phase separation and exhibit inconsistent drug release profiles [10]. Therefore, innovative delivery systems are required.

1.5 PHARMACOLOGICAL PROFILE OF MICONAZOLE NITRATE

Miconazole nitrate is an imidazole derivative with broad-spectrum antifungal activity [5].

1.5.1 Mechanism of Action

It inhibits fungal cytochrome P450-dependent 14- α -demethylase, blocking conversion of lanosterol to ergosterol. Ergosterol depletion leads to membrane instability, increased permeability, and fungal cell death [6].

1.5.2 Physicochemical Limitations

- Poor water solubility
- High lipophilicity
- Limited dermal diffusion

These properties restrict effective topical delivery, necessitating formulation strategies such as emulgel systems [11].

1.6 RATIONALE FOR COMBINING ROSEMARY OIL

Rosemary oil extracted from *Rosmarinus officinalis* contains monoterpenes that exhibit antifungal and anti-inflammatory activities [7].

1.6.1 Antifungal Mechanism

Rosemary oil disrupts fungal cell membranes and interferes with intracellular metabolic pathways [7].

1.6.2 Penetration Enhancement Mechanism

Essential oils rich in terpenes disturb lipid packing of stratum corneum, increasing drug partitioning and diffusion [8,9,12]. This enhances dermal absorption of lipophilic drugs like miconazole.

1.7 NEED FOR ADVANCED DELIVERY SYSTEM

Given the limitations of conventional semisolids and the pharmacokinetic challenges of miconazole nitrate, an emulgel system offers:

- Improved drug solubilization
- Sustained release

- Enhanced penetration
- Better stability
- Patient-friendly texture

Emulgels provide a three-dimensional polymeric matrix that stabilizes emulsion droplets and controls drug release kinetics^[11,14].

II. ADVANCED TOPICAL DRUG DELIVERY SYSTEMS AND FORMULATION STRATEGIES FOR MICONAZOLE-ROSEMARY OIL EMULGEL

2.1 STRUCTURE AND BARRIER FUNCTION OF HUMAN SKIN

The human skin acts as a protective barrier preventing microbial invasion and excessive transepidermal water loss. It consists of three primary layers:

1. Epidermis
2. Dermis
3. Hypodermis

Among these, the stratum corneum (outermost epidermal layer) is the principal barrier to topical drug permeation.

2.1.1 Stratum Corneum Architecture

The stratum corneum follows a “brick and mortar” model where:

- Corneocytes = bricks
- Intercellular lipid bilayers = mortar

These lipid bilayers (composed of ceramides, cholesterol, and fatty acids) are highly ordered and restrict drug diffusion^[9].

Drug permeation through skin follows Fick’s first law of diffusion:

$$J = \frac{D \cdot K \cdot \Delta C}{h}$$

Where:

- J = Flux
- D = Diffusion coefficient
- K = Partition coefficient
- ΔC = Concentration gradient
- h = Membrane thickness

Improving D and K is essential for enhancing transdermal absorption, which can be achieved using penetration enhancers such as essential oils^[8,9].

2.2 LIMITATIONS OF CONVENTIONAL TOPICAL DOSAGE FORMS

Traditional semisolid formulations (creams, ointments, gels) exhibit several limitations:

- Phase separation
- Greasy texture
- Poor spreadability
- Limited drug penetration
- Instability during storage

Conventional creams often fail to maintain uniform drug distribution and may show variable drug release kinetics^[10].

Moreover, hydrophobic drugs like miconazole nitrate show poor dispersion in aqueous gel systems, leading to suboptimal therapeutic concentration at infection sites^[5,11].

2.3 EMULGEL: CONCEPT, DESIGN AND SCIENTIFIC BASIS

2.3.1 Definition and Rationale

An emulgel is a biphasic delivery system where an emulsion (O/W or W/O) is incorporated into a gel matrix using suitable gelling agents such as Carbopol 940^[11].

The system combines:

- Solubilization capacity of emulsions
- Structural stability of gels

This hybrid approach improves stability and enhances drug release.

2.3.2 Advantages of Emulgel System

1. Suitable for hydrophobic drugs
2. Enhanced drug loading capacity
3. Improved patient compliance
4. Non-greasy and easily washable
5. Controlled drug release
6. Increased residence time at site of application

Emulgel systems demonstrate superior stability compared to traditional emulsions due to polymeric network stabilization^[11,14].

2.4 ROLE OF ROSEMARY OIL IN SKIN PERMEATION ENHANCEMENT

Rosemary oil derived from *Rosmarinus officinalis* contains terpenes such as 1,8-cineole and α -pinene.

2.4.1 Mechanism of Penetration Enhancement

Terpenes enhance drug permeation by:

- Disrupting lipid bilayer organization
- Increasing lipid fluidity
- Extracting intercellular lipids
- Enhancing drug partition into stratum corneum

This increases both diffusion coefficient (D) and partition coefficient (K) as per Fick’s law^[8,9,12].

2.4.2 Synergistic Antifungal Action

Rosemary oil exhibits intrinsic antifungal activity by:

- Causing membrane leakage
- Disrupting fungal mitochondrial function
- Inducing oxidative stress

Studies report enhanced zone of inhibition when essential oils are combined with azole antifungals^[7].

2.5 SELECTION OF FORMULATION COMPONENTS

2.5.1 Oil Phase

Oil phase typically includes:

- Liquid paraffin
- Rosemary oil
- Miconazole nitrate

Oil phase dissolves hydrophobic drug effectively^[5].

2.5.2 Surfactants and Emulsifiers

Surfactants such as Tween 80 are selected based on Hydrophilic-Lipophilic Balance (HLB) value to ensure stable O/W emulsion formation^[12].

Improper HLB selection may result in:

- Creaming
- Coalescence
- Phase inversion

2.5.3 Gelling Agents

Carbopol 940 is widely used due to:

- High viscosity
- Good clarity
- Skin compatibility
- Pseudoplastic rheology

Carbopol gels exhibit optimal viscosity at pH 5.5–6.5^[13,14].

2.6 METHOD OF PREPARATION

The formulation generally involves:

2.6.1 Step 1: (Oil Phase Preparation) Drug dissolved in oil phase containing rosemary oil.

2.6.2 Step 2: (Aqueous Phase Preparation) Surfactant dissolved in purified water.

2.6.3 Step 3: (Emulsion Formation) Oil phase added to aqueous phase with continuous stirring.

2.6.4 Step 4: (Gel Base Preparation) Carbopol dispersed in water and neutralized with triethanolamine.

2.6.5 Step 5: (Emulgel Incorporation) Emulsion mixed into gel base with homogenization.

Proper homogenization ensures uniform droplet distribution and improved stability^[11].

2.7 PHYSICOCHEMICAL EVALUATION OF EMULGEL

2.7.1 pH Measurement

Skin-compatible pH prevents irritation and ensures polymer stability^[13].

2.7.2 Rheological Evaluation

Rheology determines:

- Flow behavior
- Spreadability
- Application ease

Emulgels typically exhibit pseudoplastic behavior (shear-thinning), improving spread under stress while maintaining viscosity at rest^[14].

2.7.3 Spreadability Test

Spreadability is evaluated using slip and drag method^[15].

Higher spreadability ensures uniform application over infected skin

2.7.4 Drug Content Uniformity

Uniform drug distribution ensures consistent therapeutic efficacy and complies with pharmacopeial standards^[16].

2.8 STABILITY STUDIES

Stability evaluation is conducted according to ICH Q1A(R2) guidelines^[19].

Test conditions:

- 25°C ± 2°C / 60% RH
- 40°C ± 2°C / 75% RH

Parameters monitored:

- Phase separation
- pH variation
- Viscosity changes
- Drug degradation

Stability determines commercial feasibility.

III. FORMULATION DEVELOPMENT AND OPTIMIZATION OF MICONAZOLE-ROSEMARY OIL EMULGEL

3.1 PREFORMULATION STUDIES

Preformulation studies are essential to understand physicochemical characteristics of the drug and excipients before formulation development.

3.1.1 Organoleptic Properties

Miconazole nitrate appears as a white to off-white crystalline powder with characteristic odor and slight bitterness^[5]. Rosemary oil possesses a strong aromatic fragrance due to volatile terpenes.

3.1.2 Solubility Analysis

Miconazole nitrate is poorly soluble in water but freely soluble in organic solvents and

lipophilic media ^[5]. Therefore, incorporation into oil phase improves solubilization.

Solubility studies are performed in:

- Water
- Ethanol
- Propylene glycol
- Liquid paraffin

This determines appropriate vehicle selection.

3.2 COMPATIBILITY STUDIES

Compatibility between drug and excipients is evaluated using:

- FTIR spectroscopy
- Differential scanning calorimetry (DSC)

No significant shift in characteristic peaks confirms absence of drug–excipient interaction. This ensures formulation stability and therapeutic integrity ^[11].

3.3 OPTIMIZATION OF EMULSION PARAMETERS

3.3.1 Oil-to-Water Ratio

Oil phase concentration influences:

- Droplet size
- Viscosity
- Drug release rate

Higher oil content increases drug solubilization but may reduce spreadability.

3.3.2 Surfactant Concentration

Proper Hydrophilic–Lipophilic Balance (HLB) selection ensures stable oil-in-water emulsion [12]. Insufficient surfactant causes coalescence, while excess surfactant may irritate skin.

3.3.3 Homogenization Speed and Time

High-speed homogenization reduces droplet size, enhancing:

- Stability
- Surface area
- Drug release

Smaller droplets improve diffusion rate according to Fick's principle ^[8].

3.4 GEL BASE OPTIMIZATION

Carbopol concentration (0.5–2%) significantly affects:

- Viscosity
- Spreadability
- Drug release

Optimal concentration ensures pseudoplastic flow behavior ^[14].

3.5 FINAL OPTIMIZED FORMULATION CHARACTERISTICS

An optimized miconazole–rosemary oil emulgel should demonstrate:

- Smooth texture
- No phase separation
- Uniform drug distribution
- Acceptable pH (5.5–6.5) ^[13]
- Good spreadability ^[15]

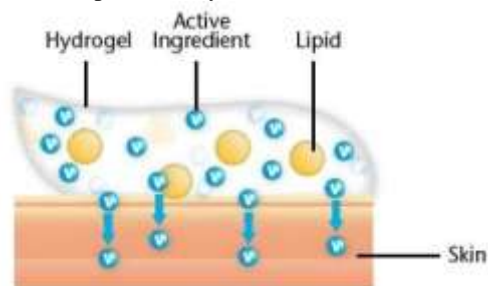


Fig. 3.1 Structure of Emulgel

IV. PHYSICOCHEMICAL EVALUATION

4.1 PHYSICAL EXAMINATION

Formulation should be:

- Homogeneous
- Creamy white
- Free from grittiness
- Free from phase separation

Visual stability is critical for patient acceptance ^[10].

4.2 pH MEASUREMENT

Measured using calibrated digital pH meter.

Acceptable pH range: 5.5 – 6.5 to prevent irritation and maintain skin compatibility ^[13].

4.3 RHEOLOGICAL STUDY

Rheological analysis using Brookfield viscometer determines flow behavior.

Emulgels typically exhibit pseudoplastic (shear-thinning) flow, meaning viscosity decreases with increased shear stress, aiding easy application while maintaining stability at rest ^[14].

4.4 SPREADABILITY

Spreadability (S) is calculated as:

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

Where:

- M = Weight applied
- L = Length moved by glass slide
- T = Time taken

Higher spreadability ensures uniform application over infected skin ^[15].

4.5 DRUG CONTENT DETERMINATION

Drug content is determined by dissolving a known quantity of emulgel in suitable solvent followed by UV spectrophotometric analysis. Content uniformity must comply with pharmacopeial standards ^[16].

V. STABILITY STUDIES AND SHELF-LIFE DETERMINATION OF MICONAZOLE-ROSEMARY OIL EMULGEL

5.1 INTRODUCTION TO STABILITY TESTING

Stability testing is a critical component in the development of pharmaceutical dosage forms to ensure that the product maintains its physical, chemical, microbiological, therapeutic, and toxicological integrity throughout its shelf life. For topical semisolid formulations such as emulgels, stability evaluation becomes particularly important because they contain:

- Oil phase
- Aqueous phase
- Surfactants
- Gelling agents
- Volatile essential oils

These multiphase systems are inherently susceptible to instability phenomena such as:

- Phase separation
- Creaming
- Coalescence
- Polymer degradation
- Oxidation of essential oils
- Drug degradation

Therefore, systematic stability studies must be conducted according to International Council for Harmonisation (ICH) Q1A(R2) guidelines ^[19].

5.2 OBJECTIVES OF STABILITY STUDIES

The primary objectives of stability testing include:

1. Determination of shelf life
2. Establishment of appropriate storage conditions
3. Evaluation of degradation pathways
4. Assessment of packaging compatibility
5. Monitoring of physical integrity

For miconazole-rosemary oil emulgel, stability studies ensure that:

- Miconazole nitrate retains antifungal potency

- Rosemary oil does not oxidize or evaporate significantly
- Emulsion droplets remain uniformly dispersed
- Gel matrix retains viscosity

5.3 TYPES OF STABILITY STUDIES

According to ICH Q1A(R2) ^[19], stability studies are categorized into:

6.3.1 Long-Term Stability Study

Conducted under normal storage conditions.

Typical condition:

- $25^{\circ}\text{C} \pm 2^{\circ}\text{C} / 60\% \text{RH} \pm 5\%$

Duration:

- 12 months or more

Purpose:

To evaluate product stability under recommended storage conditions.

6.3.2 Accelerated Stability Study

Conducted under elevated temperature and humidity conditions.

Typical condition:

- $40^{\circ}\text{C} \pm 2^{\circ}\text{C} / 75\% \text{RH} \pm 5\%$

Duration:

- 3–6 months

Purpose:

To predict long-term stability and identify potential degradation.

6.3.3 Intermediate Stability Study

If significant change occurs under accelerated conditions, intermediate testing is performed at:

- $30^{\circ}\text{C} \pm 2^{\circ}\text{C} / 65\% \text{RH} \pm 5\%$

5.4 PARAMETERS EVALUATED DURING STABILITY STUDY

5.4.1 Physical Stability

Physical parameters include:

- Color
- Odor
- Homogeneity
- Phase separation
- Liquefaction
- Syneresis

Essential oils such as rosemary oil are prone to oxidation, which may cause color change or odor alteration. Absence of visible phase separation indicates stable emulsion droplets ^[11].

5.4.2 pH Evaluation

pH must remain within 5.5–6.5 to ensure skin compatibility ^[13].

Significant pH change may indicate:

- Drug degradation
- Polymer breakdown
- Hydrolysis reactions

pH is measured at predetermined intervals (0, 1, 3, 6 months).

5.4.3 Viscosity Measurement

Viscosity is measured using Brookfield viscometer [14].

Changes in viscosity may occur due to:

- Polymer chain breakdown
- Water loss
- Emulsion instability

Stable pseudoplastic flow behavior indicates preserved gel structure.

VI. THERAPEUTIC SIGNIFICANCE AND COMPARATIVE ADVANTAGE

6.1 ADVANTAGES OVER CONVENTIONAL CREAM

Compared to marketed miconazole cream, emulgel offers:

- Better penetration (due to terpenes) [8,9]
- Sustained drug release [11]
- Improved spreadability [15]
- Reduced greasiness [10]

6.2 SYNERGISTIC MECHANISM

Miconazole:

- Inhibits ergosterol synthesis [6]

Rosemary oil:

- Disrupts fungal membrane
- Enhances permeation
- Reduces inflammation [7]

Combination enhances overall therapeutic outcome.

6.3 PATIENT COMPLIANCE

Non-greasy texture, pleasant aroma, easy application improve adherence to therapy.

6.4 CLINICAL RELEVANCE

Emulgel system may:

- Reduce recurrence
- Shorten treatment duration
- Improve patient satisfaction

Further clinical trials are required to confirm large-scale efficacy.

VII. FUTURE PERSPECTIVES

7.1 ADVANCEMENT TOWARD NANO-STRUCTURED EMULGEL SYSTEMS

Although conventional emulgel systems significantly improve the delivery of hydrophobic antifungal agents, further enhancement can be achieved by developing nanoemulgel systems. Reduction of droplet size to the nanometer range increases surface area, enhances thermodynamic stability, and improves drug penetration across the stratum corneum barrier. Nano-sized globules also

reduce gravitational separation and creaming, thereby improving long-term stability.

Future research may focus on:

- Nanoemulsion-based emulgel systems
- Optimization of droplet size using high-pressure homogenization
- Incorporation of advanced polymers for sustained release

Such advancements could further improve dermal bioavailability of miconazole nitrate.

7.2 SYNERGISTIC PHYTOCHEMICAL-SYNTHETIC COMBINATION THERAPY

The combination of miconazole nitrate with rosemary oil represents a promising phytochemical-synthetic hybrid approach. Rosemary oil derived from *Rosmarinus officinalis* not only enhances permeation but also exhibits intrinsic antifungal and anti-inflammatory properties.

Future investigations should explore:

- Quantitative synergy studies
- Determination of fractional inhibitory concentration (FIC) index
- Combination index modeling

Understanding molecular synergy may help reduce required azole concentration, thereby minimizing resistance development.

7.3 Overcoming Antifungal Resistance

Emerging azole resistance among dermatophytes and *Candida* species is a growing concern. Novel formulation strategies may help:

- Increase localized drug concentration
- Prolong residence time
- Reduce subtherapeutic exposure

Combination with essential oils may disrupt fungal efflux pump mechanisms and enhance membrane permeability, potentially overcoming resistance pathways.

Future molecular-level research should focus on:

- Gene expression analysis of resistant strains
- Membrane integrity assays
- Biofilm disruption studies

7.4 CLINICAL TRANSLATION AND HUMAN TRIALS

While preclinical and in vitro data are promising, large-scale randomized clinical trials are required to confirm:

- Comparative efficacy vs. marketed creams
- Reduction in recurrence rate
- Safety in long-term use
- Patient satisfaction and adherence

Clinical endpoints may include:

- Time to symptom resolution
- Mycological cure rate
- Recurrence rate after 3–6 months

Such trials would establish clinical superiority and facilitate regulatory approval.

7.5 SCALE-UP AND INDUSTRIAL MANUFACTURING

For commercial viability, formulation must be adaptable to industrial-scale production. Challenges include:

- Maintaining droplet size distribution
- Controlling viscosity during bulk manufacturing
- Ensuring uniform distribution of volatile rosemary oil

Quality-by-Design (QbD) approaches can optimize critical process parameters and ensure batch-to-batch consistency.

7.6 STABILITY ENHANCEMENT STRATEGIES

Given the volatile and oxidation-prone nature of essential oils, future research may explore:

- Microencapsulation of rosemary oil
- Incorporation of natural antioxidants
- Use of air-tight laminated packaging

Advanced stability modeling based on ICH Q1A(R2) guidelines will further strengthen regulatory compliance.

7.7 PERSONALIZED DERMATOLOGICAL THERAPY

Emerging precision medicine approaches may enable:

- Tailored antifungal therapy based on fungal strain
- Customized drug concentration
- Targeted combination therapy

Integration of formulation science with microbiological diagnostics may enhance therapeutic outcomes.

VIII. CONCLUSION

Superficial fungal infections such as candidiasis and dermatophytosis remain prevalent worldwide and significantly impact quality of life. Conventional topical antifungal creams, although widely used, often suffer from limitations including poor penetration, inconsistent drug release, greasiness, and reduced patient compliance.

Miconazole nitrate is a well-established broad-spectrum antifungal agent that acts by

inhibiting ergosterol biosynthesis and compromising fungal cell membrane integrity. However, its hydrophobic nature and limited dermal permeability necessitate an improved delivery system.

Rosemary oil extracted from *Rosmarinus officinalis* provides dual therapeutic benefits. It exhibits intrinsic antifungal and anti-inflammatory activity while functioning as a natural penetration enhancer by disrupting the lipid organization of the stratum corneum. The terpene components increase diffusion and partition coefficients, facilitating enhanced drug permeation.

The emulgel system serves as an advanced hybrid delivery platform that combines the solubilization capacity of emulsions with the rheological and stability advantages of gels. This system ensures:

- Improved drug solubility
- Sustained release profile
- Enhanced dermal penetration
- Increased residence time
- Better patient compliance

Comprehensive evaluation including physicochemical characterization, *in vitro* drug release, antifungal testing, *in vivo* safety assessment, and stability studies as per ICH guidelines [19] supports the feasibility of the miconazole–rosemary oil emulgel formulation.

The synergistic interaction between synthetic antifungal drug and natural essential oil offers a promising strategy to enhance therapeutic efficacy and potentially reduce resistance development. While current evidence indicates significant advantages over conventional semisolid formulations, further clinical validation is essential to establish long-term safety and effectiveness.

In conclusion, the formulation of miconazole nitrate and rosemary oil in an emulgel matrix represents a scientifically rational, technologically advanced, and therapeutically promising approach for the management of candidiasis and dermatophytosis. Continued research focusing on nano-optimization, resistance modulation, and clinical translation may position this formulation as a next-generation topical antifungal therapy.

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