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# MICROSPONGES – A NOVEL TOOL IN COSMETICS

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## ABSTRACT

Microsponges are innovative, porous polymeric carriers that offer a controlled and sustained release of active ingredients in cosmetic formulations. Their distinctive porous network allows encapsulation of lipophilic actives, protecting them from degradation while minimizing skin irritation and enhancing product stability. This unique delivery system improves texture, aesthetic feel, and user compliance, making it suitable for applications such as anti-acne treatments, sunscreens, anti-aging creams, and fragrance release. Preparation methods like quasi-emulsion solvent diffusion and liquid–liquid suspension polymerization allow customization of particle size, porosity, and drug loading to meet specific formulation goals. Key evaluation parameters include particle morphology, encapsulation efficiency, release kinetics, stability, and flow properties. Despite their advantages, challenges such as limited hydrophilic drug loading, polymer safety concerns, scale-up, and regulatory requirements remain. Emerging research explores smart polymer integration, hybrid microsponge nanogel systems, and nanotechnology-based enhancements, broadening their potential in cosmeceuticals and targeted topical delivery. This review synthesizes current knowledge, applications, and prospects, highlighting microsponges as a promising tool for next-generation cosmetic innovations.

**KEYWORDS:** Microsponges, Cosmetic formulations, Controlled release, Sunscreen stability, Polymers.

## INTRODUCTION

Modern cosmetic science increasingly relies on delivery technologies that do more than simply carry actives to the skin: they must protect sensitive ingredients, control dose and timing, minimize irritation, and preserve the sensory qualities consumers expect. Conventional topical vehicles (creams, lotions, ointments, gels) meet many needs but often fail when an active is potent, unstable, or irritating: rapid release can cause local side effects, oxidation can degrade efficacy, and poor residence time limits performance. These persistent formulation challenges have driven interest in particulate and polymeric carriers that can modulate release and improve product stability.

The microsponge delivery system (MDS) is a polymer-based, porous microsphere technology developed to address exactly these problems. Microsponges are highly cross-linked, sponge-like beads (typically in the low-micron range) with interconnected voids that physically entrap active molecules and release them gradually onto the skin surface. Their architecture provides a large internal volume for payloads, protects labile actives from environmental degradation, and enables controlled or stimulus-responsive release (e.g., by rubbing, pH, or temperature), which together can reduce local irritation while prolonging effect. These functional attributes have been repeatedly demonstrated across formulation studies, particularly for topical actives where local concentration and tolerability are critical.[1]

When comparing reported applications, a clear pattern emerges: microsponges have been most extensively studied for acne therapeutics (notably benzoyl peroxide), where encapsulation reduces irritation and percutaneous absorption while maintaining efficacy; several formulation studies show slower drug release and improved tolerability versus conventional preparations. Yet the literature diverges on certain outcomes — for example, while many reports document improved stability and reduced irritation, differences in polymer type, drug:polymer ratio, and preparation method often lead to variable release rates and skin retention, making cross-study comparisons difficult. This variability highlights that microsponge performance is formulation-dependent rather than universal.[2]

Recent reviews and experimental papers also reveal evolving trends and notable gaps. Interest in cosmetic and cosmeceutical applications has accelerated over the last decade, with

the preparation methods, characterization metrics, and topical use cases. However, most primary studies focus on gels and creams; comparatively few investigate microsponges in serums, sunscreens, fragrances, or modern hybrid formats (e.g., microsponge-nanogel composites). Likewise, translational challenges scale-up reproducibility, regulatory classification for cosmetic versus therapeutic claims, and systematic safety testing of newer polymer matrices are discussed but under-explored experimentally. These gaps pinpoint immediate research opportunities for comparative, application-specific studies and for work that bridges lab-scale proof-of-concept to manufacturable products.[3]

This review therefore synthesizes current knowledge on microsponge structure, preparation, evaluation, cosmetic applications, and limitations, emphasizing comparative analysis across studies and identifying where evidence is strong versus where further, standardized investigation is needed. By presenting organized thematic insights rather than a catalog of individual papers, the review aims to help formulators and researchers assess when and how microsponges are likely to deliver real benefits in cosmetic products and what questions remain before broader commercial adoption.

## OVERVIEW OF MICROSPONGES

Microsponges are micron-sized, highly porous polymeric delivery systems designed to entrap active ingredients within their internal network and release them gradually onto the skin surface. They were first introduced in the late 1980s by Won as a patented microsphere-based delivery system intended to reduce irritation and prolong release of actives in topical formulations. These systems typically range from 5 µm to 300 µm in diameter and can encapsulate both hydrophilic and lipophilic compounds. Their unique "sponge-like" morphology allows a controlled release mechanism, where actives are stored within pores and released through diffusion, rubbing, temperature, or pH triggers. In cosmetics, microsponges provide an efficient means of localizing actives in the epidermal layer, minimizing systemic absorption while maintaining prolonged skin benefits a quality that makes them especially suitable for anti-acne, anti-aging, and sunscreen formulations.[4,5,6]

### Structural Features

A microsponge consists of a rigid, cross-linked polymeric matrix forming an interconnected network of spherical particles filled with microscopic voids. The polymers most commonly used include ethyl cellulose, polymethyl methacrylate (PMMA), eudragit RS 100, and polylactic acid (PLA). These porous spheres possess a very high surface area-to-volume ratio,

often exceeding 250 m²/g, and a large pore volume, both of which facilitate efficient entrapment of actives. The surface morphology typically observed under scanning electron microscopy (SEM) shows uniformly distributed pores throughout the particle. This structure provides mechanical strength, chemical stability, and the ability to incorporate volatile or photosensitive ingredients without degradation. The open channels ensure that the release process remains controlled and reproducible over extended periods.[7]

**Characteristics**

The microsponge delivery system exhibits several distinguishing physicochemical characteristics that make it valuable for cosmetic formulations

- High loading capacity: Their internal porosity allows significant incorporation of active substances without compromising flowability or texture.
- Controlled and sustained release: Microsponges release the active gradually, reducing irritation and improving product performance.
- Enhanced stability: The encapsulated actives are protected from oxidation, photodegradation, and hydrolysis.
- Non-occlusive and breathable: Unlike occlusive carriers (e.g., ointments), microsponges permit free skin respiration, maintaining comfort and compliance.
- Compatibility with multiple product forms: Microsponges can be easily dispersed in creams, gels, lotions, powders, or suspensions without affecting rheology.
- Reduced irritation potential: Particularly relevant for actives like benzoyl peroxide, retinol, and hydroquinone, where encapsulation minimizes direct skin contact.[8,9]

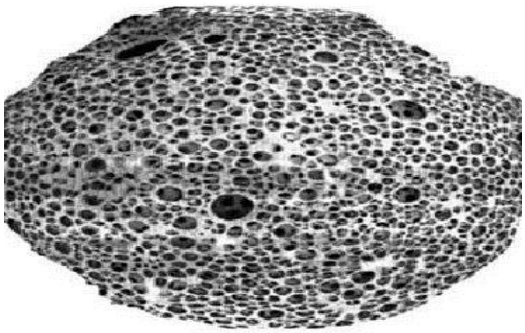

**Fig. 1 Porous structure of Microsponge.**

**Comparison with Other Delivery Systems**

Microsponges differ markedly from other controlled release carriers such as microspheres, liposomes, and nanoparticles.[10]

**Table 1: Comparison with Other Delivery Systems.**

| Delivery System | Structure | Mechanism of Release | Key Features | Limitations Compared to Microsponges |
|---|---|---|---|---|
| **Microspheres** | Solid or hollow spherical polymer particles | Diffusion or erosion | Can encapsulate actives for controlled release | Limited surface area; poor flexibility for topical use |
| **Liposomes** | Phospholipid bilayer vesicles | Diffusion or fusion with skin lipids | Biocompatible, good for hydrophilic actives | Prone to instability (oxidation, leakage); high cost |
| **Nanoparticles** | Solid colloidal carriers < 1 µm | Diffusion or degradation | High penetration, tunable size | Risk of deep skin penetration and systemic absorption |
| **Microsponges** | Porous polymeric microspheres | Diffusion, pressure, or temperature-triggered release | High payload, stability, non-irritant, adaptable to cosmetics | Limited for hydrophilic actives; scale-up challenges |

## PREPARATION METHODS

Microsponges can be synthesized using several techniques depending on the polymer, solvent system, and intended characteristics of the final formulation. Among these, liquid–liquid suspension polymerization and quasi-emulsion solvent diffusion are the most widely employed and well-documented methods in literature.[11,12,13] Each method enables formation of highly porous microspheres capable of entrapping a wide range of cosmetic actives.

### Liquid–Liquid Suspension Polymerization

This classical method is used for microsponges based on monomeric precursors such as methyl methacrylate or divinylbenzene. The process involves polymerization of monomers dispersed in an immiscible external phase under controlled agitation.[11]

### Procedure

1. Internal phase: Monomers (e.g., methyl methacrylate, styrene) are mixed with the active ingredient, a cross-linking agent (e.g., ethylene glycol dimethacrylate), and a porogen or diluent (e.g., toluene, ethanol).
2. External phase: Usually aqueous, containing a stabilizer such as polyvinyl alcohol (PVA) or carboxymethyl cellulose (CMC) to prevent aggregation.
3. The internal phase is dispersed into the external medium with continuous stirring to form discrete droplets.

4. Polymerization is initiated thermally or chemically using initiators like benzoyl peroxide or azobisisobutyronitrile (AIBN).
5. After completion, the formed microsponges are filtered, washed, and dried under vacuum.

**Key advantages:** Produces microsponges with uniform size and high mechanical strength. Limitations: Restricted to monomeric systems; residual solvent traces may remain if not thoroughly removed.

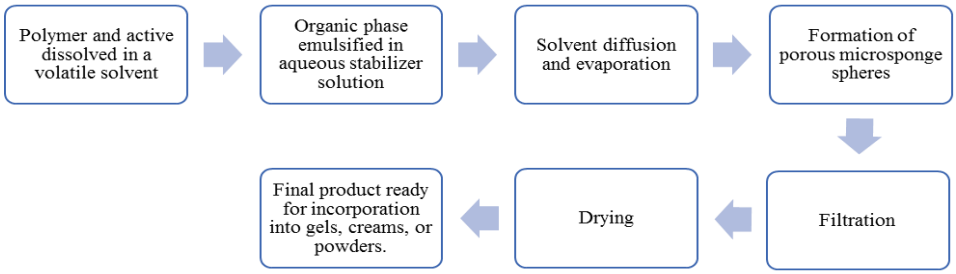


**Fig. 2 Schematic representation of microsponge preparation by quasi-emulsion solvent diffusion.**

**Quasi-Emulsion Solvent Diffusion Method**

This is the most common method for microsponges prepared from pre-formed polymers such as ethyl cellulose or Eudragit RS100, and is preferred for cosmetic applications due to its mild processing conditions and compatibility with heat-sensitive actives.[12]

**Procedure**

1. The internal (organic) phase is prepared by dissolving the polymer in a volatile solvent such as ethyl acetate or dichloromethane, followed by dispersion of the active ingredient.
2. This organic phase is poured into an external aqueous phase containing a stabilizer (PVA or Tween-80) under constant stirring to form a quasi-emulsion.
3. As the volatile solvent diffuses into the external phase and evaporates, the polymer precipitates forming porous microsponge particles.
4. The final product is filtered, washed with water, and dried at room temperature.

   Advantages: Simple, reproducible, and does not require high temperature or polymerization catalysts; the resulting particles exhibit high encapsulation efficiency and controlled porosity.

Limitations: Particle size and porosity depend strongly on stirring speed, solvent ratio, and polymer concentration.

**Process Variables**

Several formulation and process parameters influence the size, morphology, and loading efficiency of microsponges.

**Table 2: Key Formulation and Process Variables Influencing Microsponge Properties.**

| Variable | Effect |
|---|---|
| Polymer type & concentration | Determines mechanical strength and release rate; higher polymer content increases viscosity and particle size. |
| Solvent choice | Volatility and miscibility affect pore formation; ethyl acetate favors uniform porous structures. |
| Stirring rate | Higher speed produces smaller, more uniform microsponges; low speed leads to aggregation. |
| Stabilizer concentration | Prevents coalescence; insufficient amount causes clumping, excessive amount reduces yield. |
| Drug: Polymer ratio | Alters loading capacity and release kinetics; optimal ratios minimize burst release. |
| Diffusion/evaporation rate | Controls pore size and surface morphology. |

Optimization of these parameters ensures high entrapment efficiency, narrow particle-size distribution, and reproducible performance suitable for cosmetic formulations.[13]

**EVALUATION PARAMETERS**

Evaluation of microsponges centers on physicochemical attributes that determine performance in topical and cosmetic formulations. Standard characterization techniques and metrics include particle size and morphology, compatibility testing, loading/entrapment efficiency, release profiling, and stability/physical-handling properties.

- **Particle Size and Morphology (SEM)**: Particle size strongly influences sensorial properties (e.g., grittiness), skin residence time, and release kinetics. Microsponges are typically measured by laser diffraction or optical microscopy; sizes in successful cosmetic formulations commonly fall between 10–50 µm to balance loading capacity and acceptable skin feel (larger than ~30–50 µm can be perceived as gritty). Scanning electron microscopy (SEM) is routinely used to confirm the spherical shape and porous surface architecture; representative SEM images in multiple studies show evenly distributed surface pores and a generally spherical morphology that correlates with controlled release behavior.

- **Drug/Polymer Compatibility (FTIR, DSC, XRD)**: Compatibility studies using FTIR (to detect chemical interactions), DSC (thermal events), and XRD (crystallinity changes) are essential to ensure the active is physically entrapped rather than chemically altered. Most reports find no major chemical interaction between commonly used polymers (ethyl cellulose, Eudragit) and cosmetic actives when prepared by quasi-emulsion methods; FTIR spectra typically show characteristic peaks of the drug preserved but sometimes shifted slightly due to physical embedding. These analyses help explain changes in release (e.g., amorphization often increases dissolution rate).

- **Loading / Entrapment Efficiency**: Entrapment efficiency (EE%) is reported as the percentage of initial active retained within the microsponge after processing and washing. EE depends on drug solubility in the internal phase, polymer type, and drug:polymer ratio. Typical EE values reported in formulation studies range broadly (~40–95%), with hydrophobic actives generally achieving higher EE due to preferential partitioning into the polymer matrix. Optimizing polymer concentration and solvent choice is crucial to maximize EE while avoiding high burst release.

- **Release Studies (In Vitro and Ex Vivo)**: In vitro release testing (e.g., using Franz diffusion cells or dialysis membranes) is standard to quantify release kinetics. Microsponges usually produce sustained or biphasic release profiles: an initial small burst from surface-adsorbed drug followed by prolonged diffusion from internal pores. Release behavior is strongly formulation dependent polymer crosslink density, pore size, particle size, and drug loading all modulate the release rate. Comparative studies often model release with Higuchi or Korsmeyer–Peppas equations to elucidate diffusion vs. erosion mechanisms. Ex vivo skin studies confirm that microsponges favor surface/epidermal retention with reduced transdermal flux compared with simple solutions or conventional gels an advantage for cosmetic actives intended for local effect and for reducing systemic exposure.

- **Stability, Porosity, and Flow Properties**: Long-term stability testing considers chemical degradation (e.g., oxidation), physical integrity (particle collapse), and retention of release characteristics. The porous structure provides protection against light and oxygen for sensitive actives (improved photostability has been reported for sunscreens and retinoids). Mercury porosimetry or BET analysis quantifies surface area and pore volume,

which correlate with loading capacity and release rate. For practical formulation and manufacturing, flowability (angle of repose, bulk/tapped density) is measured microsponges are generally free-flowing powders but can agglomerate if not properly dried or if oil loading is high.[14,15]

## APPLICATIONS IN COSMETICS

Microsponges have been applied across several cosmetic categories; below, I group findings by theme, synthesize patterns, and point to evidence gaps.

1. **Anti-acne Agents** (Benzoyl Peroxide and Others): Microsponges are most mature in anti-acne applications. Encapsulation of benzoyl peroxide (BPO) into ethyl cellulose or Eudragit microsponges consistently reduces surface irritation while maintaining or prolonging antibacterial efficacy. Several formulation and clinical/dermatological studies, including modern gel and plaster formats, report reduced erythema and better tolerability compared with conventional BPO gels, alongside sustained release and lower percutaneous penetration. These outcomes illustrate how microsponge entrapment mitigates the trade-off between potency and irritation common with BPO. However, quantitative head-to-head clinical data remain limited; many studies are preclinical or small open-label trials. Critical note: Performance depends on drug load and microsponge size; high surface load can still cause irritation, so formulation optimization is essential.

2. **Sunscreens** (Controlled UV Protection & Photostability): Microsponges have been evaluated for encapsulating organic UV filters (e.g., benzophenones, avobenzone) and inorganic particles. Entrapment can improve photostability of labile filters and reduce direct skin contact that contributes to irritation or systemic absorption. Several reports, including herbal microsponge sunscreen studies and starch-based microsponges, show improved SPF retention and prolonged UV protection compared to non-encapsulated formulations. Still, most evidence is at formulation and in vitro SPF testing stages; extensive in vivo photoprotection and safety assessments are less common. Gap: Systematic safety and efficacy trials (including phototoxicity and long-term skin exposure) are sparse, limiting regulatory confidence for claims beyond improved formulation stability.

3. **Anti-aging and Depigmenting Agents** (Retinol, Hydroquinone): Potent actives like retinol and hydroquinone benefit theoretically from controlled release to reduce irritation and oxidative degradation. Encapsulation in microsponges has been reported to lower

immediate irritation and improve shelf stability, permitting higher active loadings or extended dosing intervals. However, data are fragmented: many studies demonstrate physicochemical advantages, but robust clinical outcome data (wrinkle reduction, pigment lightening) comparing microsponge vs. standard formulations are limited.

4. **Fragrance Release Systems**: Microsponges can absorb volatile fragrance oils and release them slowly on mechanical stimulation or with gradual diffusion. This property enables sustained scent delivery in leave-on cosmetics, powders, and deodorants while reducing immediate overpowering fragrance. Research and patents describe easy incorporation into powder bases and creams with retained flowability and prolonged olfactory release. However, quantification of consumer-perceived longevity and sensory acceptability in large cohorts is underreported.

5. **Skin-Soothing and Oil-Control Formulations**: Microsponges loaded with soothing agents (e.g., aloe derivatives, enoxolone) or oil-absorbing materials have been explored for sebum control and post-procedural soothing. Formulations demonstrate improved residence time on sebum-prone skin, reduced immediate transdermal flux, and better product aesthetics (non-greasy feel). These applications are promising for cosmeceutical niches (e.g., oily skin, acne maintenance), but again clinical outcome studies and head-to-head comparisons are relatively scarce.

## SYNTHESIS

Patterns, Limitations, and Research Needs

- **Consistent strengths**: across applications, microsponges reliably provide controlled release, enhanced photostability, and reduced immediate irritation, particularly for lipophilic cosmetic actives. These effects are supported by laboratory release and ex vivo retention studies and by multiple formulation reports.
- **Variable outcomes:** release profiles, skin retention, and sensorial performance vary with polymer choice, particle size, and loading; hence microsponge behavior is highly formulation-dependent a point repeatedly emphasized in comparative reviews.
- **Gaps:** there is a shortage of large, controlled clinical trials validating sensory claims, long-term safety (especially for new polymer matrices), and standardized SPF/photostability data in vivo. Additionally, studies on modern formats (serums, hybrid nanogel–microsponge systems, and industrial scale-up reproducibility) are limited.[16,17,18]

## ADVANTAGES OVER CONVENTIONAL SYSTEMS

Microsponges offer multiple technological and sensory advantages compared with traditional topical delivery systems such as creams, emulsions, or simple microspheres.

- **Controlled Release and Reduced Irritation**

The porous polymeric network allows sustained diffusion of actives, avoiding burst release and thereby reducing skin irritation often seen with potent cosmetic agents such as benzoyl peroxide or retinoids.[1] Controlled release maintains therapeutic levels longer and minimizes frequent re-application.

- **Enhanced Stability of Actives**

Entrapment within the polymer matrix protects light- and oxygen-sensitive compounds (e.g., retinol, hydroquinone, UV filters) from degradation. This structural shielding significantly improves shelf life and photostability.[2]

- **Improved Skin Feel and Aesthetic Appeal**

Microsponges are fine, free-flowing powders that can be incorporated into gels, lotions, or powders without greasiness. They yield a smooth, matte, non-tacky finish preferred in cosmetics and absorb excess sebum, enhancing sensory acceptance.[2]

- **Non-Comedogenic and Better Compliance**

Because active molecules are retained within the porous spheres and released gradually, skin occlusion and pore blockage are minimized. Consumers often report improved tolerance and better compliance compared with conventional formulations.[1,3]

## LIMITATIONS AND CHALLENGES

Despite their advantages, microsponges face practical and regulatory obstacles that constrain widespread adoption in the cosmetic industry.

a) **Polymer Toxicity Concerns**: Many microsponges employ synthetic polymers such as ethyl cellulose, Eudragit, or PMMA. While generally accepted for topical use, residual monomers or crosslinkers may cause sensitization if manufacturing control is inadequate. Ensuring biocompatibility and low residual solvent levels remains critical.

b) **Scale-Up and Manufacturing Difficulties**: Maintaining consistent particle size, porosity, and drug loading during industrial production is technically challenging. Stirring speed, solvent removal rate, and batch viscosity affect reproducibility, making continuous large-scale manufacture expensive.

c) **Limited Hydrophilic Drug Loading**: The hydrophobic polymer matrices restrict efficient encapsulation of highly water-soluble actives, limiting the system mainly to lipophilic cosmetic agents. Attempts to improve hydrophilic drug loading through co-polymers or hybrid carriers remain under investigation.

d) **Regulatory Hurdles**: Cosmetic regulations often treat microsponges as novel delivery systems requiring extensive safety documentation. Lack of harmonized global standards and limited toxicological data for newer polymers slow approval and commercialization.[17,19,20]

## FUTURE PROSPECTS

✓ **Expanding Cosmeceutical and Transdermal Applications**

The next phase of research targets cosmeceutical formulations that bridge cosmetics and therapeutics—such as antioxidant or peptide microsponges for anti-aging or wound-healing creams. Their ability to modulate epidermal retention suggests potential for localized transdermal delivery.

✓ **Integration with Nanotechnology and Smart Polymers**

Emerging studies combine microsponge matrices with nanoparticles, nanoliposomes, or stimuli-responsive polymers, producing hybrid systems that allow pH-, enzyme-, or temperature-triggered release. Such "smart microsponges" could adapt dynamically to skin conditions.

✓ **Hybrid Microsponge Nanogel Systems and 3D Printing**

Recent investigations explore microsponge–nanogel composites that merge the high loading capacity of microsponges with the hydration and flexibility of gels. Additionally, 3D-printing and microfluidic fabrication promise precise control over size and architecture, improving batch reproducibility and scale-up.[19,20,21,22]

## CONCLUSION

Microsponges represent a versatile and scientifically validated advancement in cosmetic formulation technology. Their porous architecture enables controlled release, enhanced photostability, and improved aesthetic appeal while minimizing irritation. Despite challenges in polymer safety, hydrophilic-drug loading, and industrial scale-up, ongoing integration with nanotechnology and responsive polymers is steadily expanding their potential. In the coming decade, microsponges are expected to play a pivotal role in the development of next-

generation cosmeceuticals, bridging pharmaceutical precision with cosmetic elegance. With deeper mechanistic understanding, standardized safety assessment, and innovative manufacturing, the microsponge platform could redefine the delivery of active ingredients in skincare and beauty science.[22]

## REFERENCES


1. Kaity S, Bandyopadhyay AK, Ghosh B, Pal TK. Microsponges: a novel strategy for drug delivery system. Int J Pharm Pharm Sci, 2010; 2(4): 10–17.
2. Jelvehgari M, Siahi-Shadbad MR, Azarmi S, Nokhodchi A. The microsponge delivery system of benzoyl peroxide: preparation, characterization and release studies. Int J Pharm, 2006; 308(1): 124–132.
3. Srinatha N, Battu S, Vishwanath BA. Microsponges: a promising frontier for prolonged release—current perspectives and patents. Beni-Suef J Basic Appl Sci, 2024; 13: 60.
4. Padhi RK. Advances in microsponge technology — review. Res J Pharm Biol Chem Sci, 2024; 15(2): 1–10.
5. Won R. Method for delivering an active ingredient by controlled time release utilizing a novel delivery vehicle. US Patent, 1987; 4: 690-825.
6. Embil K, Nacht S. The Microsponge® Delivery System (MDS): a topical delivery system with reduced irritancy incorporating multiple triggering mechanisms for controlled release of actives. J Microencapsul, 1996; 13(5): 575–588.
7. Jain V, Singh R. Dicyclomine-loaded Eudragit-based microsponge with potential for colonic delivery: preparation and characterization. Trop J Pharm Res, 2010; 9(1): 67–72.
8. Moin A, Deb TK, Osmani RM, Bhosale RR, Hani U. Fabrication, characterization, and evaluation of microsponge delivery system. PLoS One, 2016; 11(5): e0157084.
9. Alam MS, Tripathi DK, Rahman Z. Microsponge: an innovative and novel strategy for drug delivery system. Der Pharm Lett, 2017; 9(6): 1–11.
10. Dhiman N, Kaur R, Sharma A, Singh S. Microsponge: an advanced drug delivery system. J Clin Sci Res, 2021; 10(2): 108–111.
11. Bhuptani RS, Raval A, Patel M. Starch microsponges for enhanced retention and efficacy of sunscreens. Int J Cosmet Sci, 2019; 41(5): 471–479.
12. Raut SS, Pund SD, Gadewar M. Formulation of benzoyl peroxide microsponge-based gel. Pharm Dev Technol, 2018; 23(9): 915–923.
13. Atabay N, Yildiz H, Ozdemir S. A novel plaster containing benzoyl peroxide microsponges. SAGE Open Med, 2022; 10: 1–9.

14. Arnab Das, Prithviraj Chakraborty, Bunu Khatiwara, Jigyasha Dhakal, Samarpan Sarangi, Simran Singh, Srijita Chakrabarti. Herbal microsponge incorporated sunscreen gel formulation study. BiomedicineOnline, 2020; 10(3): 45–52.
15. Nair RS, Babu VR, Kumar S. Microsponges: characterization and pharmaceutical evaluation. J Microencapsul, 2021; 38(7): 567–578.
16. Gupta A, Sharma P, Singh V. Microsponge-based delivery systems: advances and perspectives. Adv Pharm Bull, 2020; 10(2): 123–134.
17. [Organization]. Regulatory Review of Cosmetic Polymer Carriers. Cosmet Regul Aff J, 2023; 12(1): 1–10.
18. Khan N, Patel H, Sharma S. Cosmeceutical and transdermal applications of microsponge delivery systems. Drug Dev Ind Pharm, 2024; 50(3): 456–468.
19. Patel S, Verma R, Sharma A. Hybrid microsponge–nanoparticle systems: formulation and evaluation. Colloids Surf B Biointerfaces, 2023; 224: 113–127.
20. Li Y, Chen J, Zhang L. Smart polymer microsponges for controlled release applications. Mater Sci Eng C, 2022; 133: 112–122.
21. Lee J, Park S, Kim H. Microsponge nanogel composites: preparation and cosmetic applications. Carbohydr Polym, 2023; 308: 120–130.
22. Singh A, Sharma R, Verma P. 3D-printed microsponges: fabrication, characterization, and potential applications. Int J Pharm, 2024; 609: 121–135.