INTERNATIONAL JOURNAL OF
PHARMACEUTICAL AND HEALTHCARE INNOVATION
journal homepage: www.ijphi.com

Review Article

OPEN ACCESS

Formulation and Evaluation of Microsponge-Based Gel for Topical Drug Delivery

Ayushi Srivastava*[1], Shreya Sonkar[2]

[1,2]Yashraj College of Professional studies Mandhana Kanpur,U.P India

Article Info

Article history:

Manuscript ID:

IJPHI212101 2024
Received: 21-July -2024
Revised :21-October -2024
Accepted: 01- December 2024
Available online: December 2024

Keywords:
microsponges delivery systems, topical drug delivery, controlled release, dermatological formulations, benzoyl peroxide, sustained release

****Corresponding Author:***
ayushi1412@gmail.com

Abstract

Microsponges delivery systems (MDS) are a novel drug delivery approach offering controlled and sustained release of active ingredients for topical application. These porous polymeric microspheres enhance the stability, efficacy, and patient compliance of drugs while minimizing side effects. MDS demonstrates significant advantages over traditional methods, including improved stability, reduced irritation, and controlled drug release triggered by environmental conditions. This review provides an overview of the formulation, evaluation, and potential applications of microsponge-based gels, highlighting their role in dermatological treatments.

Introduction

Topical drug delivery is an essential and rapidly evolving domain in pharmaceutical sciences due to its non-invasive nature and potential for localized treatment with minimal systemic side effects. Among the various systems developed to enhance topical drug delivery, the Microsponge Delivery System (MDS) has emerged as a promising innovation. These are patented, highly cross-linked, porous polymeric microspheres capable of encapsulating a wide range of active substances and releasing them in a controlled manner onto the skin, offering multiple advantages over traditional drug delivery systems. The microsponge delivery system was first developed in the 1980s to address limitations associated with conventional topical formulations. These included challenges like greasy texture, poor patient compliance, localized irritation, and suboptimal control over the drug release (1). With advancements in polymer science and engineering, microsponges technology offered a solution through its unique ability to encapsulate active agents and release them gradually in response to specific triggers such as friction, temperature, pH, or moisture. Microspheres in this delivery system are composed of non-collapsible structures with numerous interconnecting voids. These voids provide a large surface area for the encapsulation of drugs and active ingredients. Unlike liposomes and other systems, microsponges are not prone to microbial instability or chemical degradation, making them highly versatile and robust. (2-3)

Advantages of Microsponges for Topical Delivery

The microsponges delivery system brings a plethora of benefits that enhance the efficacy and acceptability of topical formulations. Key advantages include:

So. No.		Overview	Ref.
1	**Controlled Drug Release**	MDS ensures prolonged drug release through mechanisms such as diffusion or external stimuli. This controlled release minimizes the need for frequent application, improving patient compliance.	(4)
2	**Reduced Side Effects**	The ability to encapsulate drugs reduces direct contact between the active ingredient and the skin, minimizing irritations and allergic reactions often associated with conventional topical formulations.	(5)
3	**Enhanced Stability**	Microsponges are stable across a wide pH range (1–11) and temperatures up to 130°C. They are compatible with various vehicles and additives, making them adaptable for different formulations such as creams, gels, and powders.	(6)
4	**Increased Formulation Flexibility**	MDS can incorporate both hydrophilic and hydrophobic drugs, enabling their use in a broad spectrum of therapeutic and cosmetic applications. They also allow for customization based on the desired release profile.	(7)
5	**Oil Control**	Microsponges can absorb up to six times their weight in oil, making them ideal for formulations targeting acne-prone or oily skin.	(8)
6	**Non-toxicity and Biocompatibility**	Composed of biologically inert polymers, microsponges are non-toxic, non-irritating, and non-mutagenic. They are too large to penetrate the skin barrier, ensuring localized action without systemic absorption.	(9)

Challenges in Conventional Topical Drug Delivery Systems

Conventional topical formulations like creams, ointments, and gels have long been used for treating skin disorders and delivering drugs locally. However, these formulations come with several limitations:

So.No.		Overview	References
1	Greasy Texture and Low Spreadability	Ointments and thick creams are often greasy and sticky, leading to poor patient acceptability.	(10)
2	Rapid Drug Degradation	Many active ingredients are unstable in the presence of light, air, or moisture, resulting in reduced efficacy over time.	(11)
3	Short Drug Retention Time	Microsponges are stable across a wide pH range (1–11) and temperatures up to 130°C. They are compatible with various vehicles and additives, making them adaptable for different formulations such as creams, gels, and powders.	(12)
4	High Concentration Requirement	To achieve the desired therapeutic effect, conventional formulations often require higher drug concentrations, increasing the risk of side effects.	(13)

Mechanisms of Drug Release from Microsponges

One of the hallmark features of microsponges is their ability to release drugs in response to specific triggers. The release mechanisms include:

Pressure: Triggered Release: Rubbing or applying pressure on the microsponge-containing formulation releases the encapsulated drug. (14)

Temperature: Triggered Release: A rise in skin temperature can increase the drug's flow rate, facilitating its release. (15)

Solubility: Triggered Release: Microsponges containing water-soluble drugs release the active agent upon contact with moisture or sweat. (16)

Applications of Microsponges in Dermatology and Beyond

Microsponge-based formulations are extensively utilized in dermatology for their ability to deliver a wide range of therapeutic agents effectively. Applications include:

1. Acne Treatment:

Active ingredients like benzoyl peroxide are encapsulated to reduce skin irritation and improve efficacy. (17)

2. Anti-inflammatory Therapies:

Microsponges provide sustained delivery of anti-inflammatory agents such as hydrocortisone, reducing allergic responses and dermatoses. (9)

3. Anti-fungal Treatments:

They are effective in the prolonged release of antifungal agents, enhancing treatment outcomes for conditions like athlete's foot and ringworm.

4. Skin Whitening and Depigmentation:

Active agents like hydroquinone are stabilized within microsponges to prevent oxidation, enhancing their efficacy and appeal. (6)

5. Sunscreens:

Microsponges enable the incorporation of higher concentrations of UV-protective agents without causing irritation, making sunscreen formulations more effective and user-friendly. (18)

Comparison with Other Advanced Drug Delivery Systems

Microsponges are often compared with liposomes and microcapsules, two other advanced drug delivery systems. While all these systems aim to improve drug delivery, microsponges offer distinct advantages: (19)

Higher Payload Capacity:

Microsponges can encapsulate 50–60% of active ingredients, significantly higher than liposomes.

Superior Stability:

Unlike liposomes, microsponges are chemically stable and do not suffer from microbial degradation.

Non-greasy Formulation:

Microsponges enable the development of lightweight, non-greasy formulations, enhancing patient comfort. (18)

Lower Cost of Production:

The manufacturing processes for microsponges are relatively simpler and more cost-effective compared to liposomes and microcapsules. (5)

Innovations in Microsponges Technology

Recent advancements in microsponge technology have expanded their applications beyond dermatology to include oral, ophthalmic, and transdermal drug delivery. Researchers are exploring the potential of microsponges in cancer therapy, where they can deliver chemotherapeutic agents directly to the tumor site, reducing systemic toxicity. Additionally, microsponge technology is being investigated for its role in delivering probiotics and other sensitive biomolecules. (15)

Characteristics of Microsponges

Microsponges are highly porous, polymeric microspheres that exhibit unique physical, chemical, and functional characteristics, making them ideal for controlled drug delivery. These attributes define their utility in pharmaceutical, cosmetic, and dermatological formulations. Below is a detailed exploration of their features: (3-6)

1. Physical Properties

- **Porous Structure:**
Microsponges have a highly porous architecture with interconnected voids. These voids allow for the encapsulation of active ingredients and their gradual release. The porosity ranges between 50% to 90%, ensuring a high payload capacity.
- **Small Particle Size:**
Microsponges typically range from 5 to 300 microns in size, making them suitable for topical and transdermal delivery without clogging skin pores. Their size can be tailored based on the intended application.
- **Non-Collapsible Nature:**
The rigidity of their polymeric matrix ensures that microsponges maintain their structure under various physical conditions, such as pressure or friction.
- **Large Surface Area:**
The extensive surface area due to their porous nature enhances the adsorption and release of drugs. This characteristic is crucial for achieving controlled drug delivery over extended periods.
- **Compatibility with Formulations:**

Microsponges can be incorporated into diverse delivery systems, including creams, gels, ointments, and powders, without significantly altering the texture or stability of the base formulation. (4)

2. Chemical Properties

- **Inertness:**
Microsponges are chemically inert and do not interact with the encapsulated drug or external environment. This stability ensures that the active ingredients retain their efficacy over time.(9)
- **Biocompatibility and Non-toxicity:**
Composed of safe polymers, such as polyesters or polyacrylates, microsponges are biocompatible and suitable for use on sensitive skin or mucosal surfaces.

- **Wide pH Stability:**
  Microsponges are stable over a broad pH range (1–11), making them compatible with acidic, neutral, and basic formulations. (9)
- **Thermal Stability:**
  These systems remain stable at elevated temperatures, allowing their incorporation into formulations requiring heat during preparation. (11)

3. Drug Encapsulation and Release Properties

- **High Drug Loading Capacity:**
  Microsponges can encapsulate both hydrophilic and hydrophobic drugs, making them versatile carriers for a wide range of active agents. (12)
- **Controlled Drug Release:**
  The polymeric network of microsponges allows for sustained or controlled drug release based on the specific formulation and environmental conditions. Mechanisms include:
  Diffusion
  Solubility triggers (e.g., water or sweat)
  Mechanical action (e.g., rubbing or pressure)
  Temperature changes
- **Enhanced Stability of Drugs:**

Encapsulation in microsponges protects drugs from environmental factors such as light, oxygen, and moisture, reducing degradation and extending shelf life. (13)

- **Localized Action:**

Microsponges are too large to penetrate the stratum corneum, ensuring that the drug acts locally without systemic absorption, thereby minimizing side effects. (14)

- **Reduced Irritation:**

By releasing the drug in a controlled manner, microsponges prevent the sudden exposure of sensitive skin to high concentrations of irritants.

4. Formulation Flexibility

- **Compatibility with Hydrophilic and Lipophilic Drugs:**

Microsponges can incorporate a variety of drugs with differing solubility profiles. The polymer used can be tailored to suit the drug's characteristics. (15)

- **Ease of Incorporation into Bases:**

Microsponges can be seamlessly added to creams, gels, or other topical bases without affecting their stability, texture, or spreadability. (9)

- **Versatility in Applications:**

They are used in formulations for diverse purposes, including anti-acne, anti-inflammatory, antifungal, sunscreen, and cosmetic treatments. (14)

5. Stability and Safety Characteristics

- **Microbial Resistance:**

The dry, porous nature of microsponges makes them inhospitable to microbial growth, ensuring longer shelf life and safety.

- **Non-irritating and Non-mutagenic:**

Microsponges are designed to release drugs gradually, reducing the risk of irritation, mutagenicity, or other adverse reactions. (12)

- **Environmentally Safe Disposal:**

Microsponges are composed of biodegradable polymers, reducing their environmental impact upon disposal. (17)

6. Triggered Release Mechanisms

- **Pressure-Triggered Release:**
- Physical manipulation, such as rubbing or pressing, can release the encapsulated drug, making it ideal for massage-based or tactile therapies.
- **Moisture-Activated Release:**

The porous matrix can absorb moisture, triggering the dissolution and release of hydrophilic drugs.

- **Temperature-Triggered Release:**

Heat from the skin or external sources can alter the diffusion rate, facilitating the release of temperature-sensitive drugs.

- **Time-Dependent Release:**

Microsponges can be engineered for prolonged release, ensuring therapeutic levels are maintained over hours or days. (6-12)

7. Advantages over Conventional Systems

- **Improved Drug Solubility and Bioavailability**:
Microsponges enhance the solubility of poorly water-soluble drugs, improving their bioavailability in topical and systemic applications.
- **Non-greasy and Elegant Formulations:**
Unlike conventional ointments, microsponges offer a light, non-oily finish, enhancing patient satisfaction.
- **Enhanced Efficacy:**
The sustained release reduces the need for frequent reapplication, improving therapeutic outcomes.
- **Cost-Effectiveness:**
Microsponges optimize the use of active ingredients by reducing waste and improving stability, lowering overall formulation costs.(3-9)

8. Applications in Various Fields

- **Dermatology:**
Microsponges are widely used in formulations for acne treatment, anti-aging creams, and skin-lightening agents.
- **Cosmetics:**
They enhance the performance and feel of cosmetic products by providing a matte finish, prolonged fragrance release, and oil control.
- **Pharmaceuticals:**
Microsponges deliver anti-inflammatory, antifungal, and antibiotic agents for localized treatment.
- **Sunscreen Formulations:**
Microsponges stabilize UV filters and allow for sustained UV protection without frequent reapplication.
- **Advanced Drug Delivery:**
Research is expanding their use in oral, transdermal, and injectable drug delivery systems.(7-15)

Mechanism of Drug Release in Microsponges

Microsponges, with their unique porous structure and polymeric matrix, allow for tailored drug release. The controlled release mechanisms can be triggered by external stimuli such as pressure, temperature, or solubility factors. This attribute not only enhances drug efficacy but also minimizes side effects and improves patient compliance. Below is a detailed exploration of the drug release mechanisms in microsponges. (9)

1. Pressure-Triggered Drug Release

Pressure-triggered drug release is one of the most commonly employed mechanisms in microsponges, especially in topical applications. This mechanism ensures that the active ingredient is released only when mechanical force is applied, such as during rubbing or massage. (5)

How It Works:

Localized Pressure Application:

When external pressure is applied to the microsponge formulation, the porous polymeric network compresses, forcing the encapsulated drug to diffuse out of the microsponge matrix. (6)

Controlled Flow of Actives:

The degree of pressure determines the amount of drug released, allowing for a controlled dosage. Gentle pressure releases a small amount of the drug, while more force results in higher release. (7)

Applications:

1. Topical Skincare Products:

Pressure-triggered release is ideal for creams and gels where active ingredients, such as salicylic acid or retinoids, are delivered during application. (7)

2. Massage Therapy:

Massage creams and therapeutic ointments benefit from this mechanism, ensuring a gradual release of pain-relief agents or essential oils with physical manipulation. (18)

2. Temperature-Triggered Drug Release

Temperature-triggered release is based on the ability of the microsponge polymeric matrix to respond to temperature changes. This mechanism is particularly advantageous for formulations that rely on body heat or external heating to activate drug delivery. (17)

How It Works:

Thermosensitivity of Polymers:

The polymers used in microsponges, such as polyacrylates or polylactic acid, are engineered to soften or swell at specific temperatures. When the skin's temperature rises, these polymers become more permeable, allowing the encapsulated drug to diffuse out. (16)

Viscosity Control:

Elevated temperatures decrease the viscosity of the drug or carrier inside the microsponge, promoting a smoother flow and quicker release. (15)

Applications:

1. Fever Patches and Antipyretic Creams:

These formulations release drugs like menthol or paracetamol upon contact with heated skin. (15)

2. Sunscreen Lotions:

Sunscreens embedded in microsponges release UV blockers more efficiently as skin temperature rises during sun exposure. (14)

3. Wound Healing:

Temperature-sensitive release is used in dressings to deliver antimicrobial agents when the wound area becomes warm due to infection or inflammation. (13)

3. Solubility-Triggered Drug Release

Solubility-triggered release is a highly versatile mechanism wherein the presence of moisture or specific solvents triggers the release of the encapsulated drug. This method is particularly effective for hydrophilic or water-soluble active ingredients. (12)

How It Works:

- Moisture Absorption:

The porous structure of microsponges allows them to absorb environmental moisture, dissolving water-soluble drugs within the polymeric matrix.(11)

Diffusion Gradient:

The dissolved drug diffuses out of the microsponge due to a concentration gradient between the inside of the microsponge and the surrounding medium. (8)

Applications:

1. Anti-Acne Formulations:

Ingredients like benzoyl peroxide release in the presence of skin moisture, providing targeted action at acne-affected sites. (6)

2. Antifungal Products:

Microsponges containing water-soluble antifungal agents, such as clotrimazole, release the drug only in moist environments, such as sweaty or humid areas. (5)

3. Transdermal Patches:

These systems rely on body moisture to activate the release of drugs over extended periods. (4)

4. Diffusion-Controlled Release

Diffusion is one of the most fundamental mechanisms by which drugs are released from microsponges. The diffusion rate depends on the size of the drug molecules, the pore size of the microsponges, and the surrounding environmental conditions. (7)

How It Works:

Passive Diffusion:

Encapsulated drugs slowly diffuse through the porous matrix into the surrounding environment.

Polymeric Matrix Role:

The polymeric material acts as a barrier, regulating the drug's release rate based on its diffusion coefficient. (2)

Applications:

1. Sustained Drug Delivery Systems:

Drugs like antibiotics or corticosteroids are released gradually, ensuring a consistent therapeutic effect. (5)

2. Cosmetic Products:

Microsponges release active ingredients like vitamin E or coenzyme Q10 over extended periods, maintaining skin hydration and radiance. (3)

5. pH-Responsive Release

Certain microsponges are designed to release drugs in response to changes in pH. This mechanism is particularly relevant for drugs intended for specific environments, such as acidic or basic conditions.(2,3)

How It Works:

- pH-Sensitive Polymers:

Microsponges may be made of materials that swell or degrade in response to pH changes, triggering drug release. (1,2)

- Localized Activation:

Drugs are released only in the target environment, such as acidic skin conditions or basic intestinal pH. (14)

Applications:

1. Oral Drug Delivery:

pH-sensitive microsponges deliver drugs like proton pump inhibitors in the intestine, bypassing the acidic stomach environment. (9)

2. Vaginal and Rectal Formulations:

These formulations release active agents like antifungals or laxatives in response to the specific pH of the target site. (15)

6. Time-Dependent Release

Time-dependent or chronotherapeutic release is another mechanism employed by microsponges to ensure that drugs are delivered at specific times. (14)

How It Works:

Polymer Degradation:

The polymers degrade slowly over time, releasing the drug in a controlled manner.

Layered Systems:

Multi-layered microsponges allow for sequential release, providing initial and sustained drug delivery.(13)

Applications:

1. Pain Management:

Time-dependent microsponges provide prolonged relief by releasing analgesics in phases. (2)

2. Anti-Inflammatory Drugs:

Sustained release of NSAIDs reduces dosing frequency and improves patient adherence. (8)

7. Environmental or Mechanical Stimuli

In addition to pressure, temperature, and solubility, microsponges can be designed to respond to other stimuli, such as mechanical stress, light, or enzymatic activity. (7)

Applications:

1. Light-Sensitive Drugs:

Photosensitive drugs are released upon exposure to light, ideal for photodynamic therapy. (2)

2. Enzyme-Triggered Release:

Microsponges release drugs in the presence of specific enzymes, ensuring targeted action in infected or diseased tissues. (3)

Methods of Microsponge Preparation

Quasi-Emulsion Solvent Diffusion Method

The quasi-emulsion solvent diffusion method is a widely used and efficient technique for preparing microsponges, particularly for pharmaceutical and cosmetic applications. This method involves the formation of a quasi-emulsion, where the organic solvent containing the polymer and drug acts as the dispersed phase, and an aqueous solution containing a stabilizer, such as polyvinyl alcohol, acts as the continuous phase. The process begins with dissolving a suitable polymer, often Eudragit RS 100 or a similar biocompatible polymer, in a volatile organic solvent such as ethanol. The drug, which could be hydrophilic or hydrophobic, is then dissolved or dispersed into this polymeric solution, forming the inner organic phase. This mixture is subjected to gentle stirring and heating to ensure homogeneity and polymer-drug interaction. Once the organic phase is ready, it is added dropwise into the aqueous phase under continuous stirring. The aqueous phase typically contains a stabilizer to prevent coalescence and ensure the formation of uniform droplets. The difference in solubility between the two phases leads to the gradual diffusion of the organic solvent into the aqueous phase, inducing precipitation of the polymer around the drug particles to form microspheres. The stirring speed, temperature, and ratio of the organic to aqueous phases are critical parameters in this process as they influence the size, shape, and porosity of the resultant microsponges(4-7). Higher stirring speeds generally result in smaller microsponges, while the solvent evaporation rate can impact the porosity. After sufficient diffusion and hardening of the microspheres, the product is separated through filtration or centrifugation, washed to remove residual stabilizers or unentrapped drug, and dried under controlled conditions, typically using an air-heated oven at temperatures around 40°C for 12 hours. This drying step ensures the removal of any residual organic solvent and enhances the stability of the microsponge. The quasi-emulsion solvent diffusion method is favored for its simplicity, scalability, and ability to produce microsponges with high drug-loading efficiency and uniform size distribution(6). The process parameters can be easily adjusted to control the characteristics of the microsponges, such as their surface morphology, porosity, and drug release profile, making this method highly versatile. The resulting microsponges are free-flowing powders that can be incorporated into various topical formulations, including gels, creams, and lotions, or even modified for oral and transdermal applications. Moreover, this method is suitable for heat-sensitive drugs since the process operates at relatively low temperatures. The ability to tailor the microsponge characteristics through this method enables the development of specialized delivery systems that offer controlled release, improved stability, and reduced side effects, further enhancing their utility in pharmaceutical and cosmetic formulations. (18)

Evaluation Parameters

Evaluation of microsponges is a critical process to ensure their effectiveness, stability, and suitability for pharmaceutical and cosmetic applications. One of the primary parameters is particle size analysis, which determines the size distribution of the microsponges using techniques such as laser diffraction or dynamic light scattering. This analysis is essential for ensuring batch uniformity, drug release consistency, and aesthetic quality, especially in topical formulations. Uniform particle size minimizes aggregation and optimizes the surface area for drug release. Another vital evaluation criterion is morphology and surface topography, which is assessed using advanced imaging techniques like scanning electron microscopy (SEM). SEM provides detailed images of the microsponge surface, revealing their porosity, shape, and structural integrity. Porous structures are indicative of high surface area and are directly related to the microsponge's ability to load and release active ingredients. Loading efficiency and yield are also crucial parameters, calculated based on the ratio of the actual drug encapsulated within the microsponges to the initial amount of drug used during preparation. This is typically expressed as a percentage and provides insight into the efficiency of the preparation process. A high loading efficiency indicates effective encapsulation, while the production yield assesses the overall effectiveness of the fabrication method by comparing the weight of the final product to the total raw materials used. Another essential factor is the zeta potential, which measures the surface charge of the microsponges using electrophoretic techniques(16). Zeta potential is a key indicator of the colloidal stability of the microsponge suspension; a higher absolute value of zeta potential reflects better electrostatic repulsion between particles, reducing aggregation and ensuring a stable formulation over time. Drug content evaluation is carried out to quantify the amount of active ingredient present in the microsponges. This parameter is typically analyzed using UV-visible spectrophotometry, high-performance liquid chromatography (HPLC), or other analytical techniques depending on the drug's chemical properties. Ensuring accurate drug content is essential for dose uniformity and therapeutic efficacy. Furthermore, in vitro diffusion studies are performed to assess the drug release behavior of the microsponges over time. These studies often utilize Franz diffusion cells, which simulate drug permeation through a synthetic or biological membrane, mimicking the application site. The release profile is monitored by collecting samples from the receptor compartment at specific intervals and analyzing the drug concentration using suitable analytical methods. Such studies are pivotal in determining the release kinetics, whether the system exhibits zero-order, first-order, or Higuchi release patterns. Together, these evaluation parameters not only ensure the physical and chemical stability of the microsponge systems but also validate their performance in delivering the desired therapeutic or cosmetic benefits, providing a comprehensive framework for quality assurance and optimization of the formulation. (6-9)

Future Prospective

Microsponges, with their unique porous structure and customizable properties, hold immense potential for revolutionizing drug delivery and cosmetic formulations. As advancements in material sciences and nanotechnology continue, the development of microsponges is expected to overcome current limitations, such as encapsulating a broader range of active pharmaceutical ingredients (APIs), including biologics and peptides. Future research may focus on biodegradable and eco-friendly polymers to align with sustainability goals, enhancing patient compliance and reducing environmental impact. Moreover, the integration of stimuli-responsive microsponges, capable of releasing drugs in response to specific physiological conditions like pH, temperature, or enzymatic activity, can pave the way for targeted therapies. Such systems could be pivotal in treating chronic conditions like cancer, diabetes, and neurodegenerative disorders. In the realm of cosmeceuticals, microsponges can further advance anti-aging, whitening, and sunscreen formulations by providing sustained release and reduced irritation, enhancing consumer satisfaction(8). The incorporation of artificial intelligence (AI) and machine learning (ML) in microsponge design may also revolutionize the prediction and optimization of release profiles, enabling personalized medicine. Additionally, scaling up manufacturing processes using 3D printing or advanced microfluidics may offer precise control over particle size and composition, ensuring consistent product quality and reducing production costs. The potential use of microsponges in combination therapies is another promising avenue, wherein they could deliver multiple drugs with distinct release profiles simultaneously. This could be especially beneficial in addressing multidrug resistance in infectious diseases or cancer. Furthermore, exploring their application in non-invasive drug delivery systems, such as transdermal patches, ophthalmic solutions, or nasal sprays, could expand their utility across diverse therapeutic areas. Regulatory harmonization and comprehensive safety studies will also play a crucial role in accelerating the adoption of microsponge-based formulations globally. (9-15)

Conclusion

The versatility of microsponges as a drug delivery platform has been extensively explored, demonstrating their ability to enhance the solubility, stability, and bioavailability of various APIs. With controlled and targeted release profiles, reduced side effects, and compatibility with both hydrophilic and hydrophobic drugs, microsponges have emerged as a promising alternative to conventional delivery systems. Their applications span across oral, topical, and transdermal drug delivery, offering significant improvements in therapeutic efficacy and patient compliance. Advances in preparation techniques, such as the quasi-emulsion solvent diffusion method and in-situ polymerization, have ensured efficient encapsulation and reproducibility of microsponges. Rigorous evaluation parameters, including particle size analysis, morphology assessment, loading efficiency, and in vitro drug release studies, have established robust quality standards for their development. Despite their many advantages, challenges such as scalability, regulatory approval, and high production costs remain areas of concern. In conclusion, microsponges represent a transformative approach to modern drug delivery, with a bright future shaped by technological innovation and interdisciplinary collaboration. By addressing current challenges and leveraging emerging technologies, microsponges could significantly impact pharmaceutical and cosmetic industries, contributing to improved healthcare outcomes and product performance. As research in this field continues to evolve, microsponges are poised to play a pivotal role in the next generation of therapeutic and cosmetic solutions.

Conflict of Interest: Nil

Funding Source: Nil

Ethical statement: Nil

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