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Development of herbal *Nelumbinis semen* microsphere: A review on formulation strategies and characterization techniques

Azra Turuk[1]*, Madan Pomaje[2], Pritam Chaudhari[3], Ashwini Patil[4]

[1]Research Scholar, Department of Pharmaceutics, Govindrao Nikam College of Pharmacy Sawarde, Maharashtra, India

[2, 3 ,4]Associate Professor, Department of Pharmaceutics, Govindrao Nikam College of Pharmacy Sawarde, Maharashtra, India

***Name of Department:** Department of Pharmaceutics, Govindrao Nikam College of Pharmacy Sawarde, Maharashtra, India

Abstract

The *Nelumbinis Semen*, derived from the seeds of *Nelumbo nucifera*, contains a rich profile of therapeutic compounds such as flavonoids, alkaloids, polysaccharides, proteins, and vital minerals. These constituents contribute to various pharmacological actions, including antioxidant, anti-inflammatory, neuroprotective, and immunomodulatory effects. Their extensive use in traditional medicine has led to growing interest in their application within modern pharmaceutical systems. Microsphere-based delivery provides an advanced strategy to enhance the therapeutic efficiency of herbal agents. Encapsulation of *Nelumbinis semen* within polymeric microspheres helps preserve sensitive phytoconstituents, improves bioavailability, and ensures controlled, sustained release. This study highlights the importance of optimized formulation design, robust preparation methods, and comprehensive characterization in developing effective microspheres. With improved release control and patient adherence, *Nelumbinis Semen*-loaded microspheres offer a promising platform for next-generation herbal drug delivery.

Keywords: *Nelumbinis semen*, Phytoconstituents, Polymeric encapsulation, Microspheres, Novel drug delivery system (NDDS).

Introduction

The dried, mature reproductive units of *Nelumbo nucifera*, an important aquatic plant long used in traditional medical systems and health-promoting diets, are represented by lotus seeds, also known as *Nelumbinis Semen*. A wide range of bioactive substances, such as flavonoids, alkaloids, polysaccharides, proteins, and vital minerals, are concentrated in these seeds and contribute to their acknowledged medicinal potential. Lotus seeds are now prominent candidates in contemporary nutraceutical and pharmaceutical research due to their proven antioxidant, anti-inflammatory, neuroprotective, and rejuvenating properties. Their phytoconstituents' versatility supports their traditional use in immune system augmentation,

mental relaxation, digestive health regulation, and the treatment of chronic inflammatory diseases. Lotus seeds are becoming increasingly recognized as viable natural agents for creating innovative formulations and cutting-edge medication delivery systems as the market for plant-based medicines continues to expand.

Fig. no. 1: Lotus seed

Taxonomic Classification of Lotus seed *(Nelumbinis semen)*

- **Kingdom:** Plantae
- **Clade:** Tracheophytes
- **Clade:** Angiosperms
- **Clade:** Eudicots
- **Order:** Proteales
- **Family:** Nelumbonaceae
- **Genus:** *Nelumbo*
- **Species:** *Nelumbo nucifera* Gaertn.

The formal scientific name for the lotus plant, which includes its flowers, leaves, rhizomes, and seeds, is *Nelumbo nucifera*. However, *Nelumbinis semen*, a pharmacognostic term commonly employed in herbal and pharmaceutical sciences, especially refers to the dried mature seeds collected from this plant. *Nelumbinis semen* focuses on a single plant portion recognized for its functional, nutritional, and therapeutic qualities, whereas *Nelumbo nucifera* describes the entire species within botanical nomenclature. As a result, although they are related, the two words have different meanings; one refers to the entire plant, while the other recognizes its medicinally significant seeds.

Nomenclature of Lotus seed *(Nelumbinis semen)*

Botanical Name: *Nelumbo nucifera* Gaertn.

Family: Nelumbonaceae

Common Name (English): Lotus seed / Sacred lotus seed

Ayurvedic Name:

✓ *Makhana*

✓ *Padma-beeja*

Traditional Chinese Medicine (TCM) Name: *Nelumbinis semen* (*Lián Zǐ*)

Pharmacognostic Name: *Nelumbinis semen*

Plant Part Used: Seeds (fully mature and dried)

Drug Source: Natural plant origin

Synonyms

- ✓ Lotus nut
- ✓ Lotus kernel
- ✓ *Semen Nelumbinis* (Latinized)
- ✓ *Nelumbo nucifera* seeds

Description

The dried, fully developed reproductive organs of *Nelumbo nucifera* are called lotus seeds, and they are highly valued for their nutritional and medicinal properties. They are commonly used in health-conscious diets and in traditional medical procedures like Ayurveda and TCM. Flavonoids, alkaloids, polysaccharides, proteins, and vital minerals are among the many bioactive chemicals that make up their composition. These substances work together to offer antioxidant, anti-inflammatory, neuroprotective, and general health-supporting benefits.

Phytochemical Richness of *Nelumbinis semen*

A Comprehensive Overview of Flavonoids

Table no. 1: Flavonoid Constituents Identified in *Nelumbinis semen* (Lotus Seed)

Sr. No.	Compound	Reference
1	Rutin	Chen et al., 2012a
2	Hyperoside	Chen et al., 2012a
3	Isoquercitrin	Chen et al., 2012a
4	Kaempferol-3-O-robinobioside	Chen et al., 2012a
5	Isorhamnetin-3-O-rutinoside	Chen et al., 2012a
6	Isorhamnetin-3-O-neohesperidoside	Li et al., 2014
7	Diosmetin-7-rutinose	Li et al., 2014
8	Quercetin-3-O-neohesperidoside	Li et al., 2014
9	Luteolin-7-O-rutinose	Li et al., 2014
10	Myricetin-3-O-glucoside	Chen et al., 2012a

11	Myricetin-3-O-glucuronide	Chen et al., 2012a
12	Quercetin-3-O-glucuronide	Chen et al., 2012a
13	Astragalin	Chen et al., 2012a
14	Syringetin-3-O-glucoside	Chen et al., 2012a
15	Isorhamnetin-3-O-glucoside	Chen et al., 2012a
16	Kaempferol-3-O-glucuronide	Chen et al., 2012a
17	Quercetin	Kredy et al., 2010
18	Orientin	Li et al., 2014
19	Isoorientin	Li et al., 2014
20	Vitexin	Li et al., 2014
21	Isovitexin	Li et al., 2014
22	Apigenin-6,8-di-C-glucoside	Li et al., 2014
23	Luteolin-6-C-glucose-8-C-pentose	Li et al., 2014
24	Luteolin-6-C-pentose-8-C-glucose	Li et al., 2014
25	Apigenin-6-C-glucose-8-C-xylose	Li et al., 2014
26	Apigenin-6-C-xylose-8-C-glucose	Li et al., 2014
27	Schaftoside	Li et al., 2014
28	Isoschaftoside	Li et al., 2014
29	Apigenin-6-C-glucose-8-C-rhamnose	Li et al., 2014
30	Apigenin-6-C-rhamnose-8-C-glucose	Li et al., 2014

A Comprehensive Overview of Alkaloids

Table no. 2: Alkaloids Constituents Identified in *Nelumbinis semen* (Lotus Seed)

Sr. No.	Compound	Reference
1	Liensinine	Wu et al., 2004
2	Neferine	Wu et al., 2004
3	Isoliensinine	Wu et al., 2004

4	Nelumboferine	Itoh et al., 2011
5	Nelumborine A	Itoh et al., 2011
6	Nelumborine B	Itoh et al., 2011
7	Higenamine 4′-O-β-D-glucoside	Kato et al., 2015
8	Norisoliensinine	Lin et al., 2013
9	6-Hydroxy-Norisoliensinine	Lin et al., 2013

Therapeutic Importance of *Nelumbinis semen* in Modern Healthcare

1. Cardioprotective and Anti-Ischemic Potential

Nelumbinis semen, or lotus seed, has been shown in numerous studies to prevent ischemia harm to the heart. *Nelumbinis semen* successfully maintains perfusion pressure, aortic output, coronary flow, and cardiac performance during ischemia events, according to research utilizing isolated rat hearts (Kang et al., 2006; Kim et al., 2006). Furthermore, *Nelumbinis semen* facilitates the recovery of cardiac functions following reperfusion (Kang et al., 2006) and may protect the heart by regulating calcium activity (Kim et al., 2006) (1,2,4).

2. Anti-Inflammatory Properties

Studies on animals have shown that lotus seeds have significant anti-inflammatory properties; in rats, its extract effectively decreased paw edema (Chakravarthi & Gopakumar, 2010; Hafiz et al., 2021). Additionally, *Nelumbinis semen* extract's capacity to reduce inflammation is improved when combined with hyaluronic acid gel, showing promise for topical or localized treatment systems (India et al., 2024) (1–4).

3. Liver-Protective Benefits

Because of their wide variety of bioactive compounds, *Nelumbo nucifera* seeds have shown hepatoprotective properties (Arooj et al., 2021). These substances promote different metabolic processes and help reduce the incidence of chronic liver illnesses (Arooj et al., 2021; Rai et al., 2005).

4. Potential Role in Anti-Fibrotic Therapy

The potent anti-inflammatory properties of lotus seeds (Arooj et al., 2021; Chakravarthi & Gopakumar, 2010; Yang et al., 2024) indicate potential use in the treatment of fibrotic illnesses, since inflammation is a key factor in the development of fibrosis. Furthermore, the existence of bioactive chemicals with immunomodulatory, antioxidant, and anti-tumour characteristics (Arooj et al., 2021; Rai et al., 2005; Zhang et al., 2015).

5. Diuretic Activity Through Controlled Release Systems

Research indicates that *Nelumbinis Semen* markedly increases urine output when compared with standard formulations, highlighting its potential as a natural remedy for edema and hypertension. Its inherent diuretic compounds assist in maintaining fluid balance and offer sustained support in managing these conditions, ultimately enhancing therapeutic effectiveness.

6. Antioxidant Capacity

Lotus seed extract has demonstrated improved antioxidant activity, making it highly beneficial in conditions driven by oxidative stress such as inflammation, cardiovascular disorders, neurodegenerative diseases, and metabolic imbalances. The antioxidant phytochemicals help maintain prolonged free radical-scavenging effects, thereby supporting long-term protection against oxidative damage.

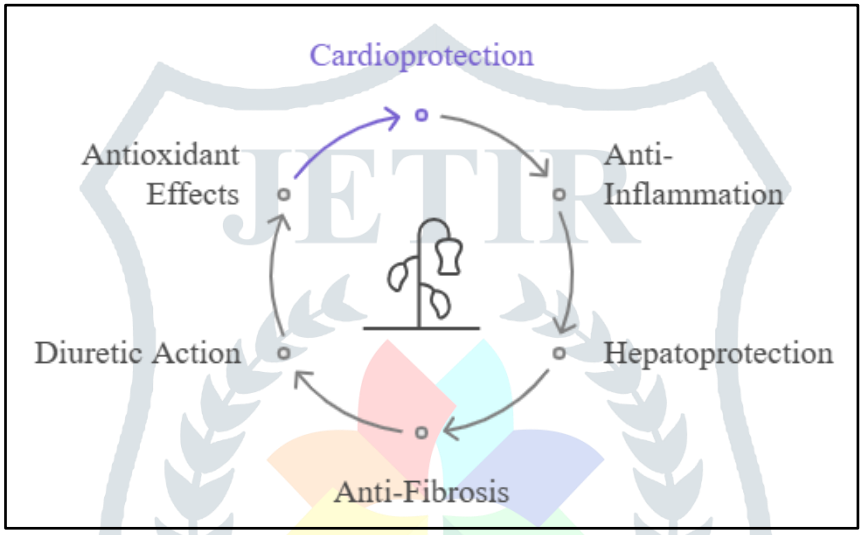

Fig. no. 2: Classification of *Nelumbinis semen* Therapeutic Activities

Introduction to microsphere

Microspheres are tiny spherical particles consisting of synthetic or natural polymers that typically have a diameter of 1 to 1000 micrometers. They are extremely valuable in pharmaceutical and biological applications due to their small size and adaptable composition. These particles are primarily utilized as medication or bioactive agent carriers, allowing for targeted delivery, controlled and prolonged release, and enhanced stability of delicate substances. Microspheres structure makes it possible to encapsulate both fat-soluble and water-soluble materials, improving their bioavailability and shielding them from deterioration. Microspheres are used not just for drug delivery but also for precise delivery and controlled release in the food, cosmetics, and diagnostics industries. Furthermore, their size, composition, and surface properties can be customized, increasing their potential for a variety of industrial and medicinal uses..

Advantages of Microspheres

- **Controlled Drug Release:** They release drugs slowly over time, maintaining effective levels in the body and reducing the need for frequent doses.
- **Targeted Delivery:** Drugs can be delivered directly to specific sites, improving treatment outcomes and minimizing effects on healthy tissues.

- **Improved Bioavailability:** Microspheres protect drugs from degradation, enhancing absorption and therapeutic effectiveness.
- **Minimized Side Effects:** Localized and controlled delivery reduces exposure to non-target tissues, lowering potential adverse effects.
- **Versatility:** Capable of carrying various substances, including water-soluble and fat-soluble drugs, proteins, and genetic materials.

Disadvantages of Microspheres

- **Complex Production:** Manufacturing involves sophisticated techniques like emulsification, spray drying, or coacervation, requiring careful control.
- **High Production Costs:** The process, materials, and equipment needed are often expensive.
- **Reproducibility Challenges:** Consistent particle size, drug loading, and batch uniformity can be difficult to achieve.
- **Stability Issues:** Some microspheres may be sensitive to temperature, moisture, or pH, affecting their shelf-life

Microsphere Classification

Microspheres are adaptable spherical carriers used in drug delivery systems that encapsulate natural substances or medicinal agents for targeted and controlled release. They are particularly helpful for increasing the stability of delicate molecules, boosting medicinal performance, and reducing side effects. They can be produced from a range of natural and synthetic polymers (Sahu et al., 2021; Khopade et al., 2021; Vishwakarma et al., 2024). Their use in peptide and protein medication administration, where they assist in resolving problems with instability and quick disintegration, further demonstrates their significance (Thunder Madathil, 2019).

Polymeric Microspheres

Biocompatible polymers like PLGA, chitosan, alginate, or gelatin are used to create these microspheres. They provide extended or regulated drug-release patterns and have outstanding encapsulation capacity.

Characteristics

- Made from biodegradable or synthetic polymer matrices
- Suitable for encapsulating different types of drugs
- Enable extended drug release
- Protecting the drug from environmental degradation

Glass Microspheres

Glass microspheres are non-biodegradable, inorganic carriers with a stable surface that can be customized. They are employed in specific medication delivery systems that call for exact release control.

Key Advantages

- Provide predictable and sustained release
- Offer excellent stability against chemical and thermal degradation

- Allow surface modification for targeted action

Drawbacks

- Expensive manufacturing processes
- Challenges in large-scale production
- Lack of biodegradability

Ceramic Microspheres

Inorganic elements such as calcium phosphate, silica, or alumina are used to create ceramic microspheres. They are appropriate for safeguarding delicate active ingredients due to their great mechanical strength and resilience to challenging conditions.

Features

- Strong, rigid structure
- High thermal and chemical stability
- Effective for sustained or controlled drug release
- Provide robust protection for the encapsulated material

Hollow Microspheres

An interior cavity in hollow microspheres, also known as microballoons, reduces their density and increases their surface area, increasing their drug-loading effectiveness. They are perfect for prolonged release formulations because of their capacity to float and distinct release behaviour.

Benefits

- Capable of carrying larger amounts of drug
- Useful in gastroretentive drug-delivery systems due to buoyancy
- Provide long-lasting and controlled drug release
- Enhance storage stability of active compounds
- Improve patient convenience by reducing dosing frequency

Types of Microspheres

Table no. 3: Types of Microspheres and Key Features

Type of Microsphere	Key Characteristics	Common Preparation Methods
Bioadhesive Microspheres	Adhere to mucosal surfaces; improve retention time	Solvent diffusion, Emulsion solvent evaporation, Spray drying
Floating Microspheres	Low-density; remain buoyant in GI fluids	Solvent evaporation, Emulsion–solvent diffusion, Spray drying

Radioactive Microspheres	Contain radioactive isotopes for targeted therapy	Solvent evaporation, Emulsion polymerization, Nanoprecipitation
Magnetic Microspheres	Respond to external magnetic field; enable targeted delivery	Coacervation, Solvent evaporation, Emulsion polymerization
Polymeric Microspheres	Prepared using natural or synthetic polymers; controlled release	Solvent evaporation, Spray drying, Nanoprecipitation
Biodegradable Microspheres	Use biodegradable polymers; safe degradation	Emulsion–solvent evaporation, Nanoprecipitation, Spray drying
Synthetic Polymeric Microspheres	Made from synthetic polymers; tunable properties	Spray drying, Solvent evaporation, Emulsion polymerization

a) Bioadhesive Microspheres

The ability of bioadhesive microspheres to adhere to mucosal surfaces prolongs their retention period and improves drug absorption. Components like polysaccharides, flavonoids, or alkaloids can improve their adhesive qualities. Depending on the intended particle size, drug loading, and release properties, common preparation methods include solvent diffusion, emulsion solvent evaporation, and spray drying.

b) Floating Microspheres

Extended gastric retention and prolonged medication release are made possible by floating microspheres, which are low-density systems that stay buoyant in gastric fluids. Usually, spray drying, emulsion-solvent diffusion, or solvent evaporation are used to prepare them. Particle size, buoyancy, stability, and medication release rate are all impacted by the chosen technique. To achieve optimal performance, variables like polymer type, formulation ratios, and processing conditions are crucial.

c) Radioactive Microspheres

To create radioactive microspheres for specific uses, therapeutic radioisotopes are encapsulated in a polymer matrix. Methods such as emulsion polymerization, solvent evaporation, and nanoprecipitation aid in achieving effective isotope loading and uniform particle size. To guarantee precise localization of the therapeutic substance and regulated release, the radioisotope is selected based on the target site.

d) Magnetic Microspheres

An external magnetic field can be used to steer or concentrate magnetic microspheres at a particular location since they contain magnetic materials. They can be made by emulsion polymerization, solvent evaporation, or coacervation. Each method has benefits in terms of drug-loading capacity, magnetic responsiveness, and particle size management. The physicochemical and medicinal characteristics of the microsphere are directly influenced by the preparation technique.

e) Polymeric Microspheres

To encapsulate medications and give regulated release, polymeric microspheres are created using appropriate polymers, either natural or manufactured. Biodegradable polymers are frequently utilized, including PLGA and chitosan. Drug release behaviour, particle shape, and encapsulation efficiency can all be fine-tuned using techniques like solvent evaporation, spray drying, and nanoprecipitation.

• Biodegradable Microspheres

Polymers used in biodegradable microspheres safely decompose over time within the body. They can be made using methods such emulsion solvent evaporation, spray drying, and nanoprecipitation. The breakdown rate and release profile can be tailored for therapeutic requirements by varying formulation variables such as polymer content, drug loading, and particle size.

• Synthetic Polymeric Microspheres

Synthetic polymeric microspheres are produced using man-made polymers, offering better control over mechanical strength, particle size, and drug release patterns. They are fabricated using methods such as spray drying, solvent evaporation, or emulsion polymerization. The selected technique strongly influences release kinetics, drug-loading efficiency, and overall system performance in drug delivery.

Applications of Microspheres

- **Pharmaceuticals:** Used in oral, injectable, and inhalable forms for controlled and site-specific drug delivery.
- **Cosmetics:** Encapsulate active ingredients in skincare and personal care products for gradual release and improved effectiveness.
- **Food Industry:** Control the release of flavors, nutrients, or probiotics, enhancing taste, nutrition, and stability.
- **Diagnostics and Imaging:** Act as carriers for contrast agents or targeted imaging to assist in precise disease detection.
- **Other Uses:** Employed in enzyme immobilization, biodegradable implants, and tissue engineering scaffolds due to their biocompatibility and structural adaptability.

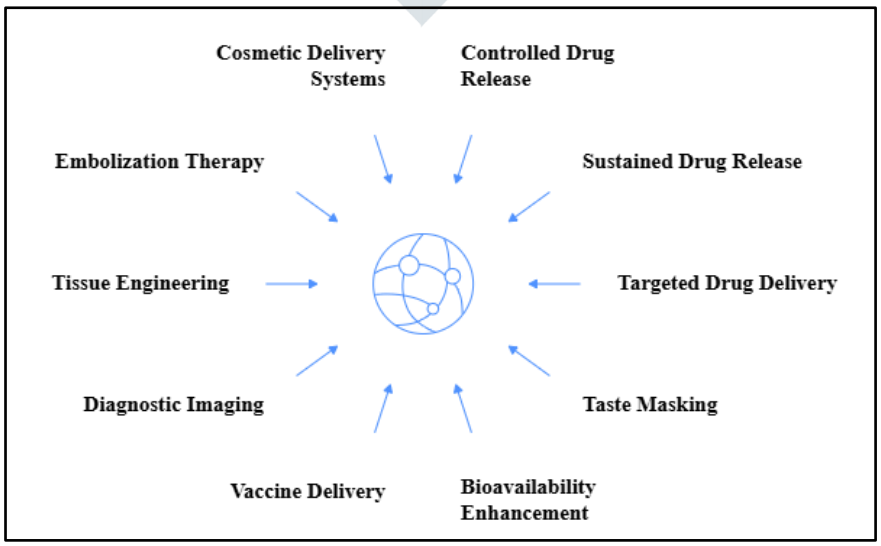

Fig. no. 3: Applications of microspheres in modern formulations

Formulation Methods for Microspheres

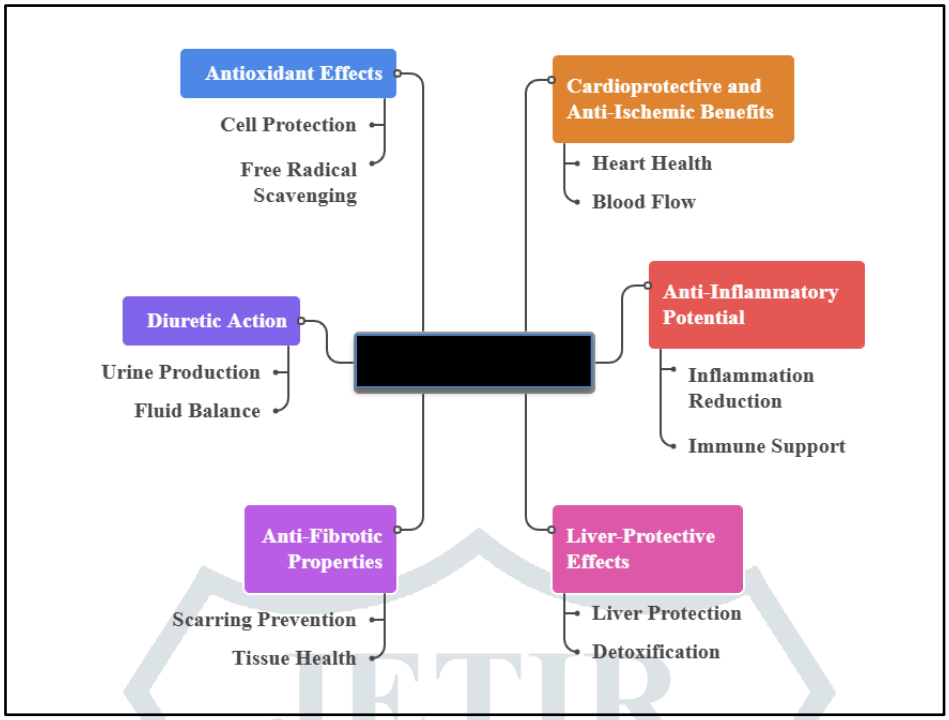

Fig. no. 4: Microsphere Formulation Techniques

1. Solvent Evaporation Technique: A Foundational Microencapsulation Process

A common technique for creating microspheres is the solvent evaporation method. This method creates an o/w emulsion by dissolving the medication and polymer in an organic solvent and emulsifying them into an aqueous phase. Dispersed droplets harden into solid microspheres or nanospheres because of continuous mixing, which permits the volatile solvent to escape. This technique is valued for its excellent encapsulation efficiency and capacity to generate particles of controlled size (9) .

2. Single-Emulsion Technique: A Basic Entrapment Method

An aqueous polymer solution is dispersed into an organic, water-immiscible phase, such as oil or chloroform, using stirring or sonication in the single-emulsion (usually water-in-oil) technique. Heat-induced or chemically induced cross-linking produces microspheres. Following centrifugation, the produced particles are completely cleaned, dried, and segregated. This approach is especially useful for active ingredients that dissolve in water (9).

3. Double-Emulsion Technique: Effective for Hydrophilic Molecules

For hydrophilic medications, the double-emulsion method (w/o/w) was created especially. To make a primary emulsion, an aqueous drug–polymer solution is first emulsified in an organic medium. This is then emulsified once more in an external aqueous PVA solution to create a multiple emulsion. Uniform microspheres with enhanced drug loading and controlled-release behavior are produced by removing the organic solvent, washing, and drying (9).

4. Spray Drying Method: Rapid, Clean, and Industrially Feasible

A quick, ongoing, and scalable technique is spray drying. First, a polymer solution comprising volatile solvents such as dichloromethane or acetone is used to disseminate the medication. The mixture is homogenized and then atomized into a

hot air stream. After the dried microparticles are collected by a cyclone separator, any remaining solvent is removed by vacuum drying. Aseptic and large-scale production are supported by this method (9).

5. Phase Separation (Coacervation): Tailored Polymer Layer Formation

The foundation of coacervation is the separation of a liquid phase rich in polymers from its solution, which can be achieved by modifying environmental factors like pH or temperature or by adding a coacervating agent. This stage creates drug-loaded polymer droplets that solidify after being cleaned and dried. The procedure is perfect for encasing heat-sensitive substances and provides exact control over polymer deposition (9).

6. Quasi-Emulsion Solvent Diffusion: A Versatile Method for Porous Formulations

This process involves introducing an exterior PVA-containing aqueous phase into an interior mixture including the medication, polymer, and ethanol (kept at about 60 °C). Constant stirring encourages the diffusion of solvents, resulting in the formation of porous microspheres or microsponges. Following around two hours of mixing, the particles are washed, filtered, and dried at 40 °C. Using this technique to create porous carriers with extended drug release is especially beneficial (9).

7. Ionotropic Gelation Technique: A Mild, Solvent-Free Gelation Method

Sodium alginate and other natural polymers are used in ionotropic gelation. The medicine is evenly integrated once the polymer has been dissolved in warm distilled water. After that, the mixture is submerged in a calcium chloride solution, where ionic cross-linking takes place right away, creating spherical microspheres. The particles are collected and cleaned after a brief gelation phase. Because it does not use heat or organic solvents, this environmentally safe method is perfect for creating delicate bioactive molecules (9).

Physicomechanical and Functional Evaluation of Lotus Seed Microspheres

Flow Dynamics Assessment

Powder packing and flow behavior were assessed through bulk density, tapped density, Hausner ratio, Carr's compressibility index, and angle of repose, all of which provide insight into interparticle friction and flowability.

Angle of Repose (θ)

$$\boldsymbol{\theta = \tan^{-1}\left(\frac{h}{r}\right)}$$

where *h* is the height of the microsphere heap and *r* is the base radius.

Bulk Density (ρb)

$$\boldsymbol{\rho_b (\text{g cm}^{-3}) = \frac{\text{Mass of powder}}{\text{Bulk volume}}}$$

Tapped Density (ρt)

$$\boldsymbol{\rho_t\ (\text{g cm}^{-3}) = \frac{\text{Mass of powder}}{\text{Tapped volume}}}$$

Carr's Compressibility Index (CI)

$$\mathbf{CI}(\%) = \frac{\boldsymbol{\rho_t - \rho_b}}{\boldsymbol{\rho_t}} \times \mathbf{100}$$

Hausner Ratio (HR)

$$\mathbf{HR} = \frac{\boldsymbol{\rho_t}}{\boldsymbol{\rho_b}}$$

Production Efficiency (Percentage Yield)

Production efficiency was expressed in terms of percentage yield:

$$\%\mathbf{Yield} = \frac{\textbf{Weight of microspheres obtained}}{\textbf{Total weight of drug + polymer used}} \times \mathbf{100}$$

Drug Loading and Entrapment Efficiency

The drug content was calculated using the established calibration factor (CF) and dilution factor (DF):

$$\textbf{Drug Content} = \textbf{Abs} \times \textbf{CF} \times \textbf{DF}$$

Entrapment efficiency was computed as

$$\%\textbf{Entrapment Efficiency} = \frac{\textbf{Actual drug content}}{\textbf{Theoretical drug content}} \times \mathbf{100}$$

Hydrophilic Expansion (Swelling Index)

Swelling behavior was evaluated by measuring the increase in microsphere weight after immersion in the swelling medium for a specified time.

$$\textbf{Swelling Index}(\%) = \frac{\boldsymbol{W_t - W_0}}{\boldsymbol{W_0}} \times \mathbf{100}$$

where $W_0$is the initial weight and $W_t$is the weight after swelling.

Morphological and Dimensional Characterization

Particle Size: Determined using an optical microscope equipped with a calibrated eyepiece micrometer

Surface Morphology: Scanning Electron Microscopy (SEM) was employed to examine particle shape, surface texture, and size uniformity after gold sputter-coating the samples.

***In-vitro* Drug Release Profiling**

USP Dissolution Apparatus II (paddle method) was used to assess drug release behavior. 900 mL of phosphate buffer (pH 6.8) was kept at 37 ± 0.5 °C and swirled at 50 rpm. Sample aliquots were removed, filtered, and examined using a suitable analytical method for phytoconstituent quantification at prearranged intervals. To maintain sink conditions, fresh dissolving medium was added at the same time. To forecast diffusional channels, polymer relaxation behaviour, and overall release mechanisms for future formulation modification, the obtained release profiles may be further evaluated using sophisticated kinetic models and computational fitting techniques.

Future Perspectives

Lotus seed (*Nelumbinis Semen*) extract has significant potential as a therapeutic and functional agent due to its antioxidant, anti-inflammatory, neuroprotective, and cardioprotective properties. Future work should focus on advanced delivery systems like nanoparticles, microspheres, and hydrogels to improve stability, bioavailability, and targeted delivery. Standardization and stringent quality control are essential for clinical use, alongside well-designed human trials to confirm safety and efficacy. Its combination with other bioactive and inclusion in functional foods or nutraceuticals could further enhance its health benefits and commercial applications.

Conclusion

A promising approach to the creation of sophisticated herbal drug delivery systems is the formation of *Nelumbinis semen* microspheres, which offer a platform to enhance the stability, bioavailability, and therapeutic efficacy of naturally occurring bioactive chemicals. Sensitive phytoconstituents are shielded against deterioration by encapsulation into polymeric carriers, which also allows for controlled and prolonged release, circumventing the drawbacks of conventional herbal formulations. *Nelumbinis semen* wide range of pharmacological activities, which include cardioprotective, anti-inflammatory, hepatoprotective, anti-fibrotic, diuretic, and antioxidant effects, further bolster its potential for integration into cutting-edge delivery systems intended to produce focused and long-lasting therapeutic results.

By optimizing polymer selection, refining encapsulation methods, and employing detailed physicochemical and functional characterization, microspheres can be engineered to meet specific therapeutic requirements and release profiles. Continued investigations focusing on advanced polymer matrices, enhanced encapsulation efficiency, and rigorous *in vitro* and *in vivo* evaluations will be essential to translate these formulations into practical clinical applications. Overall, *Nelumbinis semen* microspheres present a versatile, effective, and patient-friendly approach in modern herbal therapeutics, with the potential to improve drug bioavailability, ensure sustained pharmacological effects, and contribute significantly to the evolution of natural product-based medicine.

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