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Design and characterization of phenytoin-loaded nanosponges: A novel platform for controlled and sustained delivery

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Abstract
Phenytoin, a widely used anticonvulsant with a narrow therapeutic index, exhibits poor aqueous solubility, variable bioavailability, and dose-dependent adverse effects, limiting its clinical efficacy. This study aimed to develop and characterize phenytoin-loaded nanosponges to enhance solubility, stability, and provide controlled drug release. Nanosponges were prepared using the solvent-emulsion diffusion method with ethyl cellulose as the polymer and polyvinyl alcohol (PVA) as the stabilizer. Preformulation studies confirmed the physicochemical suitability of phenytoin, with solubility being higher in ethanol, methanol, phosphate buffer pH 7.4, and PEG 400, and a partition coefficient of 2.47. UV Spectrophotometric analysis determined λ max at 205 nm, with a linear calibration curve obeying Beer's law (R^2 = 0.9996). Drug-excipient compatibility studies via FT-IR revealed no chemical interactions. Nine nanosponge formulations were evaluated for drug content, entrapment efficiency, and *in vitro* release. Formulation F5, with a 1:4 drug-to-polymer ratio and 1.0% PVA, exhibited the highest drug content (96.05 ± 0.44%) and entrapment efficiency (87.60 ± 0.35%), along with a sustained release profile of 65.11% over 420 min, demonstrating reduced initial burst release. SEM and optical microscopy revealed spherical, porous nanosponges, while DLS and zeta potential analysis indicated a mean particle size of 332 nm and -32.38 mV, confirming colloidal stability. The study concludes that nanosponge encapsulation effectively enhances phenytoin solubility, stability, and controlled release, offering a promising approach to minimize dose-dependent toxicity, improve therapeutic consistency, and extend potential for alternative delivery routes, including topical or localized administration and thereby improving patient compliance and overall clinical outcomes.

Keywords: Phenytoin, nanosponges, Sustained release, Encapsulation

1. Introduction
Phenytoin (5, 5-diphenylhydantoin), a hydantoin derivative, is extensively employed not only in epilepsy but also for conditions such as trigeminal neuralgia, wound repair and neuroprotection. As a BCS Class II drug, it has high membrane permeability yet suffers from very low aqueous solubility and a slow dissolution rate—factors that compromise its bioavailability and cause variable pharmacokinetics. Moreover, its narrow therapeutic index and high plasma-protein binding heighten the risk of toxicity when drug release or absorption is inadequately controlled.

In this context, nanosponge carriers—three-dimensional, nanoporous systems formed from cross-linked polymeric or cyclodextrin matrices—offer a promising strategy. These carriers can encapsulate hydrophilic and lipophilic drugs, enhance solubility, enable controlled or sustained release, protect labile drugs, mask undesirable taste or odor, and potentially reduce dosing frequency [1]. By adjusting key parameters such as cross-linking density, pore size and surface modifications, one can finely tune drug release and achieve targeted delivery. Given phenytoin's solubility constraints, absorption variability and narrow safety margin, its formulation into a nanosponge delivery system may markedly improve dissolution, stabilize plasma drug levels, limit dose-related toxicity and broaden its therapeutic versatility—including via alternative routes (topical, buccal or localized) that reduce systemic exposure. Developing and evaluating phenytoin-loaded nanosponges thus represents a rational

Fuel wood refers to the woody material collected from trees, approach to overcoming its longstanding biopharmaceutical challenges and optimizing clinical outcomes [2, 3].

1.1 Nanosponge drug delivery system

Nanosponges are three-dimensional, nanoporous polymeric carriers—typically based on cyclodextrin or synthetic polymers—that form hyper-cross linked networks with internal cavities capable of entrapping both hydrophilic and lipophilic molecules. Their structural parameters, including pore size, crosslinking density, and surface functionality, allow precise control over drug loading, release kinetics, and stability. They can be prepared using techniques such as emulsion solvent diffusion, melt fusion, and ultrasound-assisted synthesis, often employing crosslinkers like diphenyl or dimethyl carbonate to form the porous matrix [4, 5].

Nanosponges offer several pharmaceutical advantages: they enhance solubility and dissolution of poorly water-soluble drugs, protect labile molecules from degradation, mask undesirable taste or odor, and enable controlled or sustained release, thereby improving bioavailability and patient compliance. They exhibit good stability across wide pH and temperature ranges, and their small pore sizes can prevent microbial contamination. However, challenges include limited loading capacity for larger molecules, risk of burst release if the matrix degrades prematurely, and potential toxicity from residual solvents or crosslinkers. Additionally, certain fabrication methods remain complex and may present scalability or reproducibility issues [6].

1.2 Solvent Emulsion Diffusion Method

In the emulsion solvent diffusion method, phenytoin and the selected polymer are co-dissolved in a water-miscible (or partially water-miscible) organic solvent to form the dispersed phase, while a stabilizer such as polyvinyl alcohol is dissolved in the aqueous phase. The organic phase is then added gradually to the aqueous phase under vigorous stirring (approximately 1000 rpm), resulting in the formation of an oil-in-water emulsion.

As the solvent diffuses from the organic droplets into the aqueous phase, the polymer becomes less soluble, precipitates around the drug, and forms porous nanosponge particles that encapsulate phenytoin.

Following complete diffusion and precipitation, the remaining solvent is removed through evaporation and filtration, and the nanosponges are dried under mild conditions (40-50 °C, vacuum desiccation) to eliminate residual traces [7]. Among the available nanosponge fabrication techniques—such as melt fusion, crosslinking, ultrasound-assisted synthesis, and solvent evaporation—the emulsion solvent diffusion method offers an optimal balance of efficiency, reproducibility, and product quality. It enables the use of biocompatible solvents, provides consistent yields with controlled particle size and porosity, and maintains drug stability under mild processing conditions. Given phenytoin's poor solubility and sensitivity to heat, this method ensures high entrapment efficiency, prevents polymorphic changes, and supports scalable, energy-efficient production with predictable, sustained-release characteristics [8, 9].

1.3 Rationale of formulating phenytoin as nanosponges

Phenytoin is a widely used anticonvulsant, yet its clinical utility is often constrained by its poor aqueous solubility, limited bioavailability, and a tendency toward dose dependent side effects. Conventional dosage forms may lead to fluctuations in plasma levels, which increase the risk of toxicity (e.g. gingival hyperplasia, nystagmus) or therapeutic failure. By converting phenytoin into a nanosponge-based delivery system, one can harness the porous, sponge-like architecture to host the drug molecules within a three-dimensional network. Such encapsulation can transform the crystalline drug into a more amorphous or molecularly dispersed form, improving apparent solubility and dissolution rate. In addition, the nanosponge's ability to entrap both lipophilic and hydrophilic moieties allows for versatile formulation design, thus helping overcome phenytoin's biopharmaceutical limitations [10, 11].

Beyond mere solubility enhancement, phenytoin-loaded nanosponges can offer sustained and controlled release, thereby smoothing out the drug plasma profile and reducing peak-driven toxicity. The porous cavities of the nanosponge framework act as "micro-reservoirs," from which phenytoin can be released in a regulated fashion over time. This mitigates the burst effect commonly seen in other nanoparticulate systems and allows dose reduction while maintaining therapeutic levels. Furthermore, encapsulation may also enhance chemical and physical stability of phenytoin by protecting it from degradation, and permit targeted delivery or localized application (e.g. topical, transdermal) with minimized systemic exposure. Collectively, these attributes make the nanosponge strategy a rational and promising approach to refine phenytoin therapy — achieving better efficacy, safety, and patient compliance [12, 13].

2. Materials and Methods

2.1 Preformulation Studies

Preformulation studies were conducted to evaluate the physicochemical properties of Phenytoin for its suitability in nanosponge-based drug delivery systems. Parameters assessed included solubility, melting point, pKa, partition coefficient, polymorphism, thermal behavior, and stability, as well as excipient compatibility [14,15].

Organoleptic Evaluation

Phenytoin was visually inspected under natural light for color, odor, and appearance.

Solubility Studies

Excess Phenytoin was added to various solvents (distilled water, ethanol, and buffer solutions of varying pH) and shaken at 37 °C for 24 hours. Samples were filtered or centrifuged, and the supernatant was analyzed by UV spectrophotometry or HPLC.

Partition Coefficient

Equal volumes of n-octanol and water were equilibrated with Phenytoin, shaken, and allowed to separate. Drug concentrations in each phase were measured spectrophotometrically to calculate the partition coefficient.

$$P = \frac{\text{CONCENTRATION OF DRUG IN } n\text{-OCTANOL}}{\text{CONCENTRATION OF DRUG IN WATER}}$$

Melting Point

The melting point was determined using a capillary melting point apparatus.

pH Stability
Phenytoin solutions were prepared in buffers of pH 1.2, 4.5, 6.8, and 7.4, and incubated at 37°C. Samples were withdrawn at regular intervals and analyzed for drug degradation using UV or HPLC. Stability was greatest in mildly acidic to neutral conditions (pH 6.8-7.4).

2.2 UV Spectrophotometric Analysis
Determination of λ max
A 10 µg/mL solution of Phenytoin in ethanol was scanned between 200-400 nm using a Shimadzu UV-visible spectrophotometer. The λ max was determined at 205 nm.

Calibration curve
Standard solutions (2-10 µg/mL) were prepared in ethanol and analyzed at 205 nm. Absorbance values were used to construct a calibration curve.

2.3 Drug and excipient compatibility studies
To determine whether there is any interaction between drug and excipients, compatibility studies are carried out. This was done to look for any modifications for the drug's chemical composition following its combination with excipients. This technique will be used to examine the compatibility between drugs and polymers.

2.4 Formulation and Evaluation of phenytoin loaded nanosponges
Phenytoin-loaded nanosponges were fabricated via the solvent-emulsion diffusion technique, employing ethyl cellulose as the structural polymer, dichloromethane as the organic solvent, and polyvinyl alcohol (PVA) as the emulsifier/stabilizer. In brief, phenytoin (1 % w/v) and ethyl cellulose were dissolved in an appropriate volume of dichloromethane to form the organic (dispersed) phase, while the aqueous (continuous) phase was prepared by dissolving 0.75 % PVA in distilled water with gentle heating to ensure complete dissolution. Under continuous stirring, the organic solution was added dropwise into the aqueous phase, and the mixture was maintained under stirring for 30 minutes to allow nanoparticle formation and solvent diffusion. The resulting nanosponges were collected by filtration and subsequently dried in a hot air oven at 45 °C until a constant weight was achieved.

Table 1: Phenytoin loaded nanosponge hydrogel formulation

Formulation Code	Drug : Polymer	Drug (mg)	Ethyl Cellulose (g)	Dichloromethane	Poly Vinyl Alcohol
F1	1:3	500	1.5	20 ml	0.5%
F2	1:3	500	1.5	20 ml	1.0%
F3	1:3	500	1.5	20 ml	20.%
F4	1:3	500	2	20 ml	0.5%
F5	1:3	500	2	20 ml	1.0%
F6	1:3	500	2	20ml	2.0%
F7	1:3	500	2.5	20 ml	0.5%
F8	1:3	500	2.5	20 ml	1.0%
F9	1:3	500	2.5	20 ml	2.0%

2.5 Characterization of Phenytoin loaded nanosponges
Drug Content Determination
A known quantity of phenytoin-loaded nanosponges was accurately weighed and dispersed in methanol. After sonication and filtration, the filtrate was diluted with phosphate buffer (pH 7.4) and analyzed at 205 nm using a UV-Visible spectrophotometer. Drug content was calculated from a previously constructed calibration curve.

Entrapment Efficiency (EE %)
To determine EE%, a measured amount of nanosponge formulation was centrifuged at 10,000-15,000 rpm for 10-30 min at 4 °C. The supernatant was filtered, diluted, and analyzed for unentrapped phenytoin. EE% was calculated as:

EE% = (Amount of encapsulated drug / Total amount of drug added) x 100

***In vitro* drug release**
Drug release from the optimized nanosponge formulation was studied using a Franz diffusion cell at 37 °C under constant stirring (~100 rpm). The donor compartment contained the nanosponge dispersion, while the receptor compartment held phosphate buffer (pH 7.4). Samples were collected at predetermined intervals, filtered, and analyzed spectrophotometrically at 205 nm. The cumulative percentage release was plotted against time. Experiments were conducted in triplicate [16, 17].

Selection of Optimized Formulation
The formulation exhibiting the highest drug content and entrapment efficiency was selected for further evaluation.

2.6 Evaluation of optimized formulation
Morphological analysis
Surface morphology and particle distribution were assessed via optical microscopy and scanning electron microscopy (SEM). Samples were mounted on aluminium stubs and imaged using a gaseous secondary electron detector.

Fourier Transform Infrared spectroscopy
FTIR analysis was conducted to assess potential interactions between phenytoin and polymers in the optimized formulation.

Vesicle size and zeta potential
Dynamic light scattering (DLS) was used to measure average particle size, while zeta potential was determined via electrophoretic light scattering to evaluate surface charge and colloidal stability.

3. Result and Discussion
3.1 Preformulation studies
Description
The drug was crystalline, white coloured, odorless powder and compiled as per the manufacturer's Certificate of Analysis.

Determination of melting point
The melting point of Phenytoin was determined by using open capillary tube method in digital melting point apparatus was found to be 295-298 °C.

Solubility Studies
The solubility of phenytoin was determined in various solvents and it was observed that the solubility of the drug is better in ethanol, methanol, phosphate buffer pH 7.4, and polyethylene glycol (PEG 400) when compared to other solvents.

Partition coefficient

The Partition coefficient of Phenytoin was found to be as 2.47.

3.2 Spectroscopic studies of phenytoin

Determination of (maximum absorption) λ max for Phenytoin

The λ max of Phenytoin was determined by scanning the solution with the concentration 10µg/ml of drug in ethanol by UV- Spectrophotometer in the UV range of 200-400nm and thus the λ max of Phenytoin was found to be 205 nm.

Calibration curve of Phenytoin

Calibration Curve of Phenytoin was done in ethanol. The correlation coefficient was found to be 0.9996. Hence, Phenytoin obeys the Beer's law within the concentration range of 0-10µg/ml.

Table 2: Standard calibration curve of Phenytoin

Concentration (µg/ ml)	Absorbance at 205nm
0	0
2	0.181
4	0.283
6	0.391
8	0.489
10	0.602

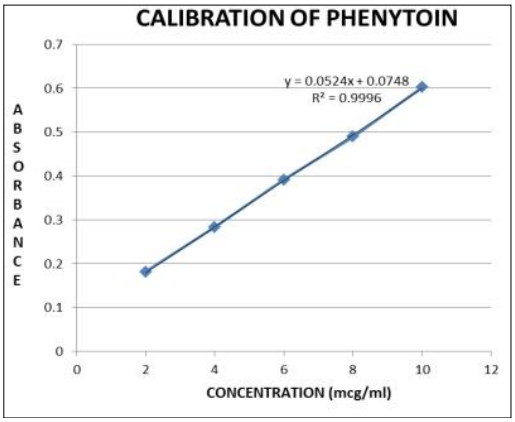

Fig 1: Calibration Curve of Phenytoin

3.3 Drug and excipient compatibility studies

The FT-IR study confirmed that all characteristic peaks of the drug and excipient remained unchanged in the physical mixture, indicating no chemical interaction between the drug and excipient.

3.4 Characterization of phenytoin loaded nanosponges

Drug content of phenytoin loaded nanosponges

Table 3: Drug content of phenytoin loaded nanosponges

Formulation code	Drug content (%) (±S.D)
F1	90.25 ± 0.42
F2	91.18 ± 0.38
F3	92.34 ± 0.47
F4	93.12 ± 0.51
F5	96.05 ± 0.44
F6	97.04 ± 0.49
F7	96.14 ± 0.36
F8	93.72 ± 0.41
F9	97.05 ± 0.39

Estimation of entrapment efficiency

Table 4: Entrapment efficiency of phenytoin loaded nanosponges

Formulation code	Entrapment efficiency (%)
F1	62.93 ± 0.13
F2	67.50 ± 0.20
F3	71.03 ± 0.20
F4	80.91 ± 0.15
F5	87.60 ± 0.35
F6	84.16 ± 0.08
F7	83.77 ± 0.07
F8	85.07 ± 0.23
F9	82.06 ± 0.20

Inference for Entrapment Efficiency

Entrapment efficiency increased with higher drug-to-polymer ratios, reaching a peak at formulation F5 (87.60 ± 0.35%) with a 1:4 drug: polymer ratio and 1.0% PVA concentration. Initially, increasing polymer concentration from 1:3 to 1:4 improved drug encapsulation due to enhanced matrix formation and reduced drug diffusion during preparation. However, further increase to 1:5 (F7-F9) showed a slight decline or plateau in EE%, possibly due to polymer saturation or increased viscosity hindering effective entrapment. Similarly, varying PVA concentration influenced EE%, with optimal stabilization at 1.0% PVA, while higher concentrations (2.0%) may have altered emulsification efficiency. Thus, F5 was identified as the optimized formulation based on maximum EE%.

***In vitro* drug release studies**

Table 5: *In vitro* drug release of phenytoin loaded nanosponges

Time (min)	F1	F2	F3	F4	F5	F6	F7	F8	F9
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	14.25	12.60	11.80	10.30	6.12	8.50	9.10	8.70	9.00
60	28.40	25.70	23.90	19.60	11.40	16.80	17.20	16.50	16.80
120	47.10	43.50	40.40	34.90	21.85	29.20	30.10	29.30	29.90
180	66.75	62.30	58.10	50.50	33.62	42.60	44.30	43.00	43.70
240	81.95	77.60	73.00	65.20	44.10	55.30	57.20	55.80	56.90
300	91.20	87.30	84.00	78.80	52.23	65.10	67.50	66.20	67.00
360	96.50	93.40	90.80	88.60	59.10	73.40	75.90	74.80	75.60
420	99.10	97.60	95.20	94.10	65.11	79.90	82.00	80.90	81.50

Inference for *in vitro* drug release

The *in-vitro* release and entrapment data demonstrate that increasing the polymer (ethyl cellulose) load and optimising PVA stabiliser concentration significantly influence both entrapment efficiency and release kinetics. Formulation F5 achieved the highest entrapment efficiency and the lowest initial burst, followed by a gradual cumulative release (~65.11 % at 420 min). In contrast, formulations with lower polymer load or lower PVA (e.g., F1-F4) released over ~90 % within the same time and exhibited higher initial burst. The superior performance of F5 can be attributed to increased matrix tortuosity and controlled porosity, which retard diffusion and reduce surface associated drug loss — key strategies in sustained release systems. Literature consistently shows that minimising the initial burst is essential for achieving predictable, prolonged delivery of the active agent. Accordingly, F5 is selected as the optimal formulation for sustained, controlled release with minimal early release.

Selection and evaluation of optimised formulation

Among the prepared nine nanosponge formulations, F5 was selected as the best formulation based on its high encapsulation efficiency (87.60 ± 0.35%), drug content (94.05 ± 0.44%).

Morphological Analysis

The SEM and optical microscopy of formulation F5 revealed spherical nanosponges with a porous surface, indicating consistent matrix formation. A 1:4 drug-to-polymer ratio (phenytoin: ethyl cellulose) created an optimal network for drug incorporation and uniform particle morphology.

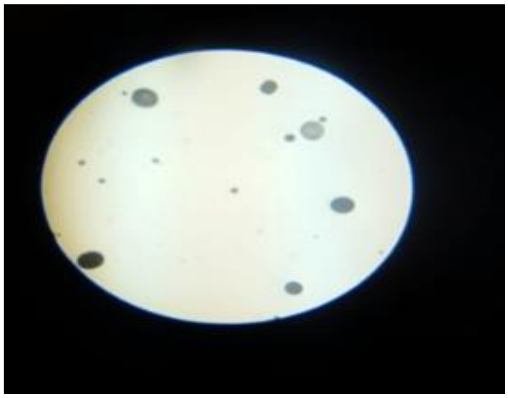

Fig 2: Optimal microscopy image of F5 formulation

Fig 3: SEM image of F5 formulation

Particle size and zeta potential

Table 6: Particle size and zeta potential

Formulation code	Particle size	Zeta potential
F5	332 nm	-32.38 mV

FT-IR Study

The results obtained from FT-IR study of best formulation. The peaks obtained in the pure phenytoin were also found in final formulation, which indicates that there is no interaction between the drug and excipients.

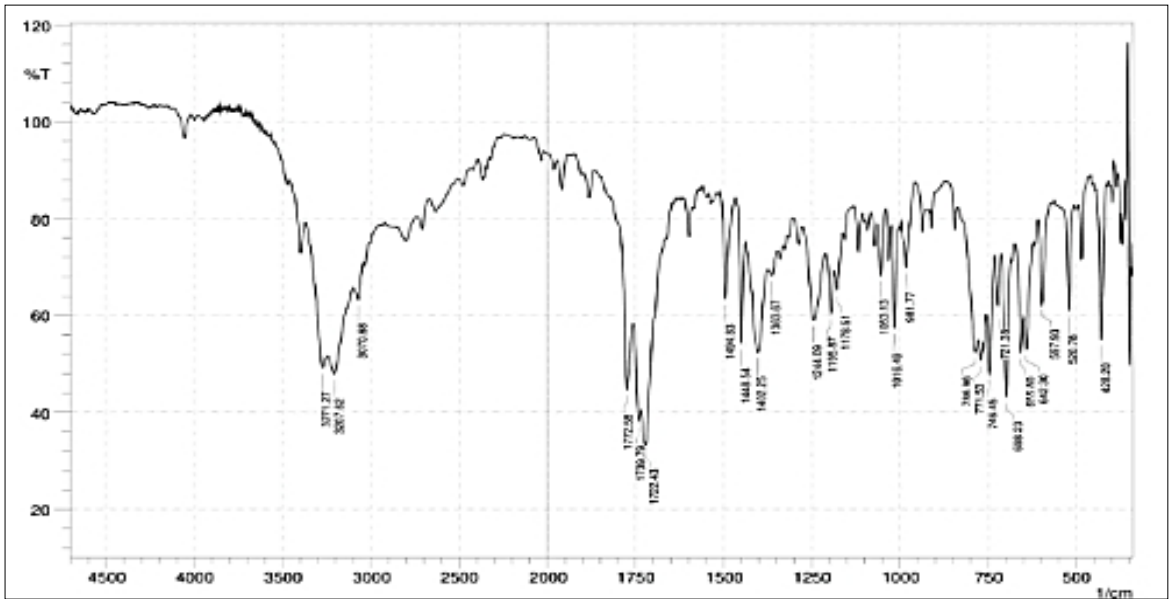

Fig 4: FT-IR spectrum of F5 formulation

4. Conclusion

The present study successfully developed and characterized phenytoin-loaded nanosponges using the solvent emulsion diffusion method with ethyl cellulose as the polymeric matrix and PVA as the stabilizer. Comprehensive preformulation and compatibility analyses confirmed the physicochemical suitability of phenytoin and its compatibility with selected excipients. Among the nine formulations prepared, formulation F5 demonstrated superior performance, exhibiting the highest drug content (96.05 ± 0.44%) and entrapment efficiency (87.60 ± 0.35%), along with an optimized and sustained drug release profile (65.11% at 420 min). The Scanning electron microscopy (SEM) results revealed a uniformly spherical and porous morphology, while dynamic light scattering (DLS) analysis indicated a mean particle size of 332 nm and a zeta potential of -32.38 mV, confirming good colloidal stability. FTIR spectra confirmed the absence of chemical interactions between phenytoin and formulation excipients, ensuring structural and chemical integrity of the drug within the nanosponge network.

Overall, the findings demonstrate that nanosponge-based encapsulation significantly enhances the solubility, stability, and controlled release behavior of phenytoin compared to its conventional formulations. The optimized nanosponge system (F5) effectively minimizes initial burst release and provides a sustained release pattern, which could reduce dosing frequency, improve therapeutic consistency, and mitigate dose-dependent adverse effects associated with phenytoin. Therefore, the nanosponge-based delivery approach offers a promising and rational strategy to overcome the biopharmaceutical limitations of phenytoin, potentially extending its application to alternative routes of administration—such as topical or localized delivery—thereby broadening its therapeutic utility and improving patient compliance.

References

1. Tamkhane V, Sharma PH. Nanosponge-a novel drug delivery system. J Curr Pharm Res. 2014 Apr 1;4(3):1186-1190.
2. Selvamuthukumar S, Anandam S. Nanosponges: A novel class of drug delivery system-review. J Pharm Pharm Sci. 2012 Jan 17;15(1):103-111.
3. Thakre AR, Gholse YN, Kasliwal RH. Nanosponges: a novel approach of drug delivery system. J Med Pharm Allied Sci. 2016 Jun 12;78(92):78-82.
4. Ghourab N, Gad S, Moustafa Y. Nanosponge as a drug delivery system. Rec Pharm Biomed Sci. 2020 Mar 1;4(1):17-31.
5. Shivani S, Poladi KK. Nanosponges-novel emerging drug delivery system: A review. Int J Pharm Sci Res. 2015 Feb 1;6(2):529-533.
6. Pandey P, Purohit D, Dureja H. Nanosponges-A promising novel drug delivery system. Recent Pat Nanotechnol. 2018 Dec 1;12(3):180-191.
7. Lee JS, Oh H, Kim S, Lee JH, Shin YC, Choi WI. A novel chitosan nanosponge as a vehicle for transepidermal drug delivery. Pharmaceutics. 2021 Aug 25;13(9):1329-1334.
8. Penjuri SC, Ravouru N, Damineni S, Bns S, Poreddy SR. Formulation and evaluation of lansoprazole loaded Nanosponges. Turk J Pharm Sci. 2016 Sep 1;13(3):304-310.
9. Seema G, Kumar SA, Manoj B. Development and evaluation of curcumin loaded nanosponges for colon drug delivery. World J Pharm Res. 2015 Feb 28;4(5):1650-1666.
10. Shringirishi M, Mahor A, Gupta R, Prajapati SK, Bansal K, Kesharwani P. Fabrication and characterization of nifedipine loaded β-cyclodextrin nanosponges: An *in vitro* and *in vivo* evaluation. J Drug Deliv Sci Technol. 2017 Oct 1;41:344-350.
11. Sengupta P, Das A, Khanam J, Biswas A, Mathew J, Mondal PK, *et al*. Evaluating the potential of ethyl cellulose/eudragit-based griseofulvin loaded nanosponge matrix for topical antifungal drug delivery in a sustained release pattern. Int J Biol Macromol. 2024 Sep 1;276:133953-133962.
12. Ahmed MM, Fatima F, Alali A, Kalam MA, Alhazzani K, Bhatia S, *et al*. Ribociclib-loaded ethylcellulose-based nanosponges: Formulation, physicochemical characterization, and cytotoxic potential against breast cancer. Adsorption Sci Technol. 2022 Mar 14;2022:1922263-1922270.
13. Abbas N, Irfan M, Hussain A, Arshad MS, Hussain SZ, Latif S, Bukhari NI. Development and evaluation of scaffold-based nanosponge formulation for controlled drug delivery of naproxen and ibuprofen. Trop J Pharm Res. 2018 Oct 5;17(8):1465-1474.
14. Francis DJ, Yusuf FS. Development and evaluation of nanosponges loaded extended release tablets of lansoprazole. Univ J Pharm Res. 2019 Mar 12;1:48-55.
15. Manyam N, Budideti KK, Mogili S. Formulation and in-vitro evaluation of nanosponge loaded extended release tablets of trimethoprim. UPI J Pharm Med Health Sci. 2018;78-86.
16. Yadav JR, Jagdale SC, Chabukswar AR. Formulation and Evaluation of Ethyl Cellulose Based Fluconazole Nanosponges. J Pharm Res Int. 2021;33(38B):135-145.
17. Ratnaparkhi MP, Kshirsagar SD. Formulation and Evaluation of Propolis Loaded Nanosponges Based Topical Anti-Inflammatory Gel. Indian J Pharm Educ Res. 2025 Oct 1;59(4):1312-1322.
18. Pawar AY, Jadhav KR, Rathod SP, Sanap AS, Umekar MJ. Formulation and evaluation of nanosponges loaded hydrogel of Metformin hydrochloride. Indian J Pharm Educ Res. 2023 Jan 1;57(1):53-61.
19. Satpathy TK, Chaubey N, Brahma CK, Maheshwari M. Formulation and evaluation of lamotrigine loaded nanosponges. Res J Pharm Technol. 2022;15(1):229-235.
20. Swathi YA, Aparna GU, Alugubelly NI, Naresh KO, Ali SH. Formulation and Evaluation of Epirubicin loaded Nanosponges. J Innov Dev Pharm Technol Sci. 2024 Oct;7(10):250-260.