Resaecrch Article

Int J Pharma. Bio. Sci, Vol: 17, Issue: 1, 2026; 74-80

International Journal of Pharma and Biosciences

Content Available at www.lapinjournals.com ISSN: 0975-6299

A COMPREHENSIVE REVIEW ON THE APPROACHES AND APPLICATIONS OF NANOPARTICLES

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Article History: Received: 14.01.2026 Revised: 19.02.2026 Accepted: 26.Mar.2026

Abstract

Nanoparticles have emerged as a cornerstone of modern science and technology, offering unique physicochemical properties that differ significantly from their bulk counterparts. Their nanoscale dimensions confer high surface area, tunable morphology, and enhanced reactivity, enabling diverse applications across medicine, energy, and environmental sectors. This review comprehensively discusses the major approaches employed in nanoparticle synthesis, including top-down and bottom-up techniques such as mechanical milling, sol-gel processing, chemical reduction, and biological synthesis. Functionalization strategies-through surface modification, ligand attachment, and polymer coating-are highlighted for their role in improving stability, biocompatibility, and targeted delivery. Characterization methods like dynamic light scattering (DLS), transmission electron microscopy (TEM), and zeta potential analysis are examined to elucidate particle size, shape, and surface charge, which critically influence performance. The review further explores applications ranging from drug delivery and diagnostics to catalysis, imaging, and environmental remediation. In biomedical contexts, nanoparticles enable controlled release, site-specific targeting, and enhanced therapeutic efficacy, while in energy systems they contribute to improved solar cells, batteries, and sensors. Environmental uses include pollutant removal and water purification. Overall, the integration of advanced synthesis and characterization techniques continues to expand the functional versatility of nanoparticles, positioning them as indispensable tools in sustainable technological innovation.

Keywords: *Nanotechnology; Drug delivery; Therapeutic applications; Environmental remediation; Energy systems; Biomedical engineering; Surface modification; Sustainable innovation.*

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DOI: https://doi.org/10.22376/ijpbs.v17i1.142

INTRODUCTION

Nanotechnology has revolutionized modern science by enabling the manipulation of matter at dimensions below 100 nanometers [1]. At this scale, materials exhibit unique physicochemical properties-such as enhanced reactivity, quantum effects, and increased surface area-that distinguish them from their bulk counterparts [2]. Nanoparticles (NPs), the most widely studied nanostructures, are central to this field due to their versatility in biomedical, environmental, and industrial applications [3]. Their ability to be engineered with precise size, shape, and surface chemistry makes them indispensable in drug delivery, diagnostics, catalysis, energy storage, and environmental remediation [4]. This review provides a comprehensive overview of the approaches to nanoparticle synthesis, their classification, advantages, limitations, and diverse applications.

ADVANTAGES

Enhanced Bioavailability

One of the most significant advantages of nanoparticles in pharmaceutical science is their ability to improve the bioavailability of poorly soluble drugs. Many therapeutic agents, particularly plant-derived compounds and hydrophobic drugs, suffer from low solubility in aqueous environments, which limits their absorption in the gastrointestinal tract. Nanoparticles, due to their high surface area-to-volume ratio, enhance dissolution rates and facilitate better interaction with biological membranes. For example, curcumin and silybin, which traditionally exhibit poor oral absorption, show markedly improved uptake when formulated as nanoparticle complexes. This property not only increases therapeutic efficacy but also reduces the required dosage, thereby minimizing side effects [5].

TARGETED DELIVERY

Functionalization of nanoparticles with ligands, antibodies, or peptides enables site-specific drug release. This targeted approach ensures that therapeutic agents accumulate preferentially at diseased tissues, such as tumors, while sparing healthy cells. Such precision reduces systemic toxicity and enhances treatment outcomes. For instance, gold nanoparticles conjugated with folic acid can selectively bind to cancer cells overexpressing folate receptors. Similarly, polymeric nanoparticles coated with transferrin ligands can cross the blood–brain barrier, delivering drugs directly to the central nervous system. Targeted delivery is particularly valuable in oncology, where conventional chemotherapeutics often damage healthy tissues [6].

CONTROLLED RELEASE

Nanoparticles can be engineered to provide sustained and controlled drug release over extended periods. This is achieved through encapsulation within polymeric matrices or lipid-based carriers that degrade gradually, releasing the drug in a predictable manner. Controlled release reduces the frequency of dosing, improves patient compliance, and maintains therapeutic drug levels within the optimal range. For chronic conditions such as diabetes or cardiovascular diseases, nanoparticle-based formulations ensure long-term stability and consistent pharmacological action. Liposomes and dendrimers are widely studied for their ability to provide such controlled release profiles [7].

MULTIFUNCTIONALITY (THERANOSTICS)

Nanoparticles are uniquely capable of combining diagnostic and therapeutic functions within a single platform, a concept known as theranostics. For example, magnetic nanoparticles can simultaneously act as contrast agents in magnetic resonance imaging (MRI) and deliver chemotherapeutic drugs to tumors. Quantum dots can be used for imaging while also carrying therapeutic payloads. This multifunctionality allows real-time monitoring of drug distribution, treatment response, and disease progression. The integration of therapy and diagnostics into one system represents a paradigm shift in personalized medicine, enabling clinicians to tailor treatments more effectively [8].

ENVIRONMENTAL BENEFITS

Beyond biomedical applications, nanoparticles play a crucial role in environmental sustainability. Their high reactivity and tunable surface chemistry make them effective in pollutant removal, water purification, and air quality improvement. Metal oxide nanoparticles such as titanium dioxide and zinc oxide are used in photocatalytic degradation of organic pollutants, while iron oxide nanoparticles are applied in heavy metal removal from wastewater. Carbon-based nanomaterials, including graphene and carbon nanotubes, are employed in filtration systems to enhance adsorption capacity. These applications contribute to cleaner ecosystems and support global efforts toward sustainable development [9].

LIMITATIONS AND CHALLENGES

Despite their promise, nanoparticles face several challenges:

Toxicity and Biocompatibility

One of the foremost concerns in nanoparticle research is their potential toxicity and limited biocompatibility. While nanoparticles offer remarkable therapeutic and diagnostic benefits, their small size and high reactivity can lead to unintended biological interactions. Certain metallic nanoparticles, such as silver or cadmium-based quantum dots, may generate reactive oxygen species (ROS), causing oxidative stress, DNA damage, and inflammation. Long-term accumulation in organs such as the liver, spleen, or kidneys raises concerns about chronic toxicity. Moreover, the ability of nanoparticles to cross biological barriers, including the blood–brain barrier, poses both opportunities and risks. Ensuring biocompatibility requires careful surface modification, controlled dosing, and rigorous in vivo testing. Without standardized toxicity assessments, clinical translation remains slow and uncertain [10].

Scalability

Nanoparticle synthesis methods often demonstrate success at the laboratory scale but face significant challenges when scaled up for industrial production. Techniques such as sol-gel processing, microemulsion, or biological synthesis may yield consistent results in small batches but struggle with reproducibility, cost efficiency, and uniformity at larger volumes. Industrial-scale production demands strict control over particle size, morphology, and surface chemistry, which is difficult to achieve consistently. Additionally, specialized equipment, high energy requirements, and complex purification steps increase production costs. This scalability issue limits the widespread commercialization of nanoparticle-based products, particularly in pharmaceuticals and environmental applications [11].

Stability

Nanoparticles are prone to agglomeration, sedimentation, and chemical degradation, which compromise their effectiveness. High surface energy often drives particles to cluster together, reducing their functional surface area and altering their intended properties. For drug delivery systems, instability can lead to premature release of therapeutic agents, reduced bioavailability, and unpredictable pharmacokinetics. Environmental factors such as pH, ionic strength, and temperature further influence nanoparticle stability. Surface coatings, polymer encapsulation, and functionalization strategies are employed to enhance stability, but these add complexity and cost to the formulation. Long-term storage and shelf-life remain critical challenges, especially for clinical and commercial applications [12].

REGULATORY BARRIERS

The absence of standardized safety protocols and regulatory frameworks poses another major limitation. Nanoparticles occupy a gray area between conventional chemicals and advanced medical devices, making it difficult for regulatory agencies to classify and evaluate them. Current guidelines often fail to account for nanoscale-specific properties such as quantum effects, enhanced reactivity, and unique biodistribution. As a result, approval processes for nanoparticle-based drugs, diagnostics, or consumer products are slow and inconsistent across regions. Ethical concerns regarding environmental release, occupational exposure, and long-term health effects further complicate regulation. Establishing globally harmonized standards for nanoparticle characterization, toxicity testing, and risk assessment is essential to accelerate clinical translation and commercialization [13].

APPROACHES TO NANOPARTICLE SYNTHESIS

Nanoparticles are synthesized using two primary approaches and shown in figure 1:

1. Top-Down Methods:

Top-down approaches involve reducing bulk materials into nanoscale dimensions by physical or mechanical means. Techniques such as mechanical milling, lithography, and laser ablation are commonly employed. Mechanical milling grinds bulk powders into nanoparticles, while lithography uses patterned etching to create nanoscale structures. Laser ablation vaporizes material from a solid surface, producing nanoparticles in a controlled environment. These methods are advantageous for producing large quantities of nanoparticles and are relatively straightforward. However, they often suffer from poor size control, irregular morphology, and high energy consumption. Additionally, contamination from milling media or processing tools can compromise purity. Despite these drawbacks, top-down methods remain valuable for producing metallic nanoparticles and nanostructures used in electronics and coatings [14].

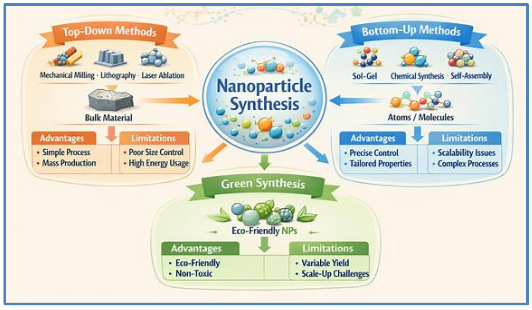

Figure 01: Various approachesfor Nanoparticles

2. Bottom-Up Methods

Bottom-up approaches assemble nanoparticles from atoms or molecules, offering superior control over particle size, shape, and composition. Techniques include chemical reduction, sol-gel processing, precipitation, and biological synthesis. In chemical reduction, metal ions are reduced to form nanoparticles, often stabilized by surfactants. Sol-gel processing involves hydrolysis and condensation reactions to produce oxide nanoparticles with uniform properties. Precipitation methods rely on controlled nucleation and growth, yielding nanoparticles with narrow size distributions. Biological synthesis, using plant extracts, fungi, or bacteria, represents a sustainable alternative. Bottom-up methods are particularly effective for producing nanoparticles with tailored functionalities, such as drug carriers or catalysts. Their precision makes them ideal for biomedical and energy applications, though challenges include reproducibility and scalability [15].

3. Green Synthesis

Recent advances emphasize green synthesis, which leverages biological systems to produce nanoparticles in an eco-friendly and cost-effective manner. Plant extracts rich in phytochemicals act as reducing and stabilizing agents, enabling the synthesis of metallic nanoparticles without toxic chemicals. Microorganisms such as bacteria and fungi can also biosynthesize nanoparticles through metabolic processes. Green synthesis offers several advantages: it reduces environmental impact, avoids hazardous reagents, and often yields biocompatible nanoparticles suitable for medical use. For example, silver nanoparticles synthesized using neem or aloe vera extracts demonstrate antimicrobial properties with minimal toxicity. However, green synthesis faces challenges in achieving consistent particle size, scaling up production, and standardizing protocols [16].

TYPES OF NANOPARTICLES

Nanoparticles can be broadly classified into following types and shown in the figure 2:

1. **Inorganic Nanoparticles:** Metals (gold, silver, iron oxide), metal oxides (zinc oxide, titanium dioxide), and quantum dots.
2. **Organic Nanoparticles**: Liposomes, dendrimers, polymeric nanoparticles.
3. **Carbon-Based Nanoparticles:** Fullerenes, carbon nanotubes, graphene.

Each type offers distinct properties-metallic nanoparticles excel in catalysis and imaging, polymeric nanoparticles in drug delivery, and carbon-based structures in energy and electronics [17].

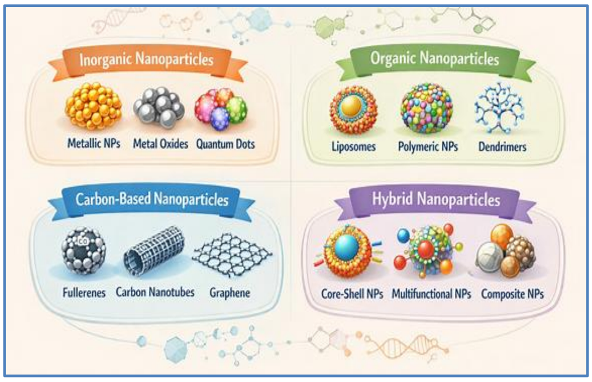

Figure 2: Types of Nanoparticles

CHARACTERIZATION METHODS

Accurate characterization is essential to ensure reproducibility and functionality. Characterization (shown in figure 3) is a crucial step in nanoparticle research, as it provides detailed information about the physical, chemical, and structural properties that determine their performance in various applications. The behavior of nanoparticles-such as stability, reactivity, and biological interaction-depends strongly on parameters like size, shape, surface charge, and composition. Therefore, accurate characterization ensures reproducibility, quality control, and functional optimization [18].

1. Dynamic Light Scattering (DLS): Dynamic Light Scattering is one of the most widely used techniques for determining particle size distribution in colloidal suspensions. It measures fluctuations in light intensity caused by Brownian motion of particles, allowing calculation of the hydrodynamic diameter. DLS is rapid, non-destructive, and ideal for monitoring aggregation or stability in solution. However, it assumes spherical particle geometry and may be less accurate for polydisperse or irregular samples [19].

2. Transmission Electron Microscopy (TEM): TEM provides direct visualization of nanoparticles at atomic or nanometer resolution. It reveals morphology, size, and internal structure, enabling precise measurement of particle dimensions. High-resolution TEM can also identify crystallinity and lattice defects. Despite its accuracy, TEM requires complex sample preparation and operates under vacuum, which may alter soft or hydrated samples.

3. Zeta Potential Analysis: Zeta potential measurement evaluates the surface charge of nanoparticles, which influences their colloidal stability and interaction with biological systems. A high absolute zeta potential value (positive or negative) indicates strong electrostatic repulsion, preventing aggregation. This technique is essential for predicting dispersion behaviour and optimizing formulations for drug delivery or environmental applications [20].

4. Spectroscopic Techniques: Spectroscopic methods such as UV–Visible (UV-Vis), Fourier Transform Infrared (FTIR), and X-Ray Diffraction (XRD) provide complementary insights into nanoparticle composition and structure [21-23].

UV-Vis spectroscopy detects optical properties and confirms nanoparticle formation through characteristic absorption peaks [23].

FTIR spectroscopy identifies functional groups and surface modifications, revealing chemical bonding and interactions with stabilizers or ligands [23].

XRD analysis determines crystalline phase, particle size, and lattice parameters, offering information on structural integrity and purity [18].

5. Additional Techniques: Other advanced methods include Atomic Force Microscopy (AFM) for surface topography, Scanning Electron Microscopy (SEM) for morphology and elemental mapping, and Thermogravimetric Analysis (TGA) for thermal stability. Combining multiple techniques provides a comprehensive understanding of nanoparticle characteristics [17-18].

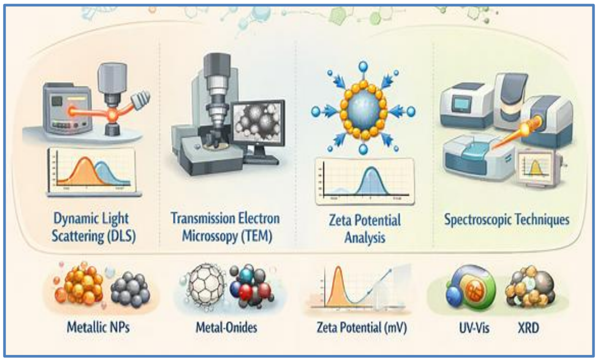

Figure 3: Characterization methods of nanoparticles

APPLICATIONS OF NANOPARTICLES

Biomedical Applications

Nanoparticles have transformed biomedical science by enabling precise, efficient, and multifunctional approaches (Table 1) to diagnosis and therapy. Their tunable size, surface chemistry, and ability to interact with biological systems at the molecular level make them ideal candidates for targeted drug delivery, advanced diagnostics, and therapeutic interventions [24-25].

Drug Delivery: Nanocarriers such as liposomes, polymeric nanoparticles, and solid lipid nanoparticles enhance the therapeutic index of drugs by improving solubility, stability, and bioavailability. They can be engineered to release drugs in a controlled manner and to target specific tissues or cells, thereby minimizing systemic toxicity. For instance, ligand-functionalized nanoparticles can recognize tumor markers, ensuring site-specific delivery of anticancer agents. This targeted approach reduces side effects and improves treatment efficacy compared to conventional formulations [21-22].

Diagnostics: Nanoparticles have revolutionized diagnostic imaging and biosensing. Quantum dots, gold nanoparticles, and magnetic nanoparticles serve as contrast agents in imaging modalities such as MRI, CT, and fluorescence microscopy. Their high sensitivity and signal amplification enable early detection of diseases at the molecular level. Additionally, nanoparticle-based biosensors can detect biomarkers with remarkable precision, facilitating rapid and non-invasive diagnostics [21].

Therapy: Nanoparticles are increasingly used in therapeutic applications such as photothermal therapy, gene delivery, and cancer treatment. Gold and magnetic nanoparticles can convert light or magnetic energy into localized heat, selectively destroying cancer cells. Similarly, polymeric and lipid nanoparticles act as carriers for genetic material, enabling gene therapy and regenerative medicine [22-24].

Energy Applications

Nanoparticles play a pivotal role in advancing energy technologies by enhancing efficiency, stability, and sustainability. In solar cells, quantum dots and metal oxide nanoparticles improve light absorption and charge transport, leading to higher conversion efficiencies. In fuel cells, platinum and carbon-based nanoparticles act as superior catalysts, reducing activation energy and improving reaction kinetics. In batteries, nanostructured electrodes such as lithium iron phosphate nanoparticles increase surface area, accelerate ion diffusion, and extend cycle life. Collectively, these innovations contribute to cleaner energy production, improved storage capacity, and reduced environmental impact, positioning nanoparticles as key enablers of next-generation energy systems [26].

ENVIRONMENTAL APPLICATIONS

Nanoparticles are increasingly employed in environmental science due to their high reactivity, tunable surface chemistry, and large surface area. In wastewater treatment, metal oxide nanoparticles such as titanium dioxide and iron oxide act as photocatalysts and adsorbents, effectively removing heavy metals, dyes, and organic pollutants. For pollutant degradation, nanoparticles accelerate chemical reactions that break down hazardous compounds, including pesticides and industrial effluents, into less harmful byproducts. In air purification, carbon-based nanomaterials like graphene and carbon nanotubes enhance filtration systems by trapping fine particulates and toxic gases. Collectively, these applications contribute to cleaner ecosystems and support sustainable environmental management [26].

INDUSTRIAL APPLICATIONS

Nanoparticles are widely utilized in industrial sectors due to their unique physicochemical properties. In catalysis, metallic nanoparticles such as platinum, palladium, and gold provide high surface area and enhanced reactivity, making them efficient catalysts for chemical reactions, fuel processing, and pollution control. In food preservation, nanoparticles like zinc oxide and silver are incorporated into packaging materials to extend shelf life by preventing microbial growth and oxidation. For antimicrobial coatings, silver and copper nanoparticles are applied to textiles, medical devices, and surfaces to inhibit bacterial colonization and reduce infection risks. Collectively, these applications improve efficiency, safety, and sustainability in industry [26].

Table 1: Applications of nanoparticles

Domain	Key Applications	Examples of Nanoparticles Used	Benefits
Biomedical	Drug delivery, diagnostics, therapy (photothermal, gene delivery, cancer treatment)	Liposomes, polymeric NPs, gold NPs, quantum dots, magnetic NPs	Enhanced bioavailabilit, targeted release, reduced side effects, theranostics
Energy	Solar cells, fuel cells, batteries	Quantum dots, TiO_2, ZnO, Pt NPs, carbon-based nanomaterials	Improved efficiency, faster charge transport, extended cycle life
Environmental	Wastewater treatment, pollutant degradation, air purification	TiO_2, Fe_3O_4, graphene, carbon nanotubes	Pollutant removal, photocatalysis, adsorption of heavy metals, cleaner air
Industrial	Catalysis, food preservation, antimicrobial coatings	Pt, Pd, Au NPs, ZnO, Ag, Cu NPs	High reactivity, extended shelf life, microbial inhibition, sustainability
Hybrid/Multifunctional	Theranostics, composite materials, smart coatings	Core–shell NPs, multifunctional composites	Combined diagnostic and therapeutic roles, multifunctionality, adaptability

CONCLUSION

Nanoparticle synthesis relies on three major approaches: top-down, bottom-up, and green synthesis. Top-down methods reduce bulk materials to nanoscale but face challenges in precision and energy use. Bottom-up strategies assemble nanoparticles from atoms or molecules, offering superior control over size and morphology, though scalability remains an issue. Green synthesis, using plants or microorganisms, emphasizes sustainability and biocompatibility, aligning with eco-friendly innovation. Collectively, these approaches provide complementary pathways to engineer nanoparticles for biomedical, energy, environmental, and industrial applications. Addressing limitations in scalability, stability, and regulation will be crucial for translating laboratory advances into real-world impact.

REFERENCES

1. Sapavatu SN, Chinthala R, Jadi RK. An overview on pharmacokinetics of polymeric nanoparticles intended for oral delivery. Journal of Young Pharmacists. 2020;12(3):187-9.
2. Pranay R, Tatikayala RK, Damera S, Pathakala N, Jadi RK. Insights of nose to brain delivery in treating Parkinson's disease: A systematic review. Journal of Applied Pharmaceutical Research. 2024;12(6):57-72.
3. Avula PR, Chettupalli AK, Chauhan V, Jadi RK. Design, formulation, in-vitro and in-vivo pharmacokinetic evaluation of Nicardipine-nanostructured lipid carrier for transdermal drug delivery system. Materials today: Proceedings. 2023.
4. Chettupalli AK, Ajmera S, Amarachinta PR, Manda RM, Jadi RK. Quality by Design approach for preparation, characterization, and statistical optimization of naproxen sodium-loaded ethosomes via transdermal route. Current bioactive compounds. 2023;19(10):79-98.
5. Prasad RR, Kumar JR, Vasudha BA, Kumar CA. Formulation development and evaluation of allopurinol solid dispersions by solvent evaporation technique. Int J Appl Pharm. 2018;10(4):168-71.
6. Sapavatu SN, Jadi RK. Development of floating drug delivery system for loratadine: in vitro and in vivo evaluation. International journal of pharmaceutical sciences and research. 2020;11:3021-2.
7. Sharaff CS, Renukuntla P, Peddapalli H, Kuchukuntla M, Bakshi V, Jadi RK. Formulation, development, and characterization of loratadine emulgel. Journal of applied pharmaceutical research. 2024;12(2):42-50.
8. Sapavatu SN, Jadi RK. Formulation development and characterization of gastroretentive drug delivery systems of loratadine. Int. J. Appl. Pharm. 2019;11(6):91-9.
9. Madduluri SK, Chigurupati VS, Dronavalli SA, Godavarthi LS, Jadi RK, Kuchukuntla M. Advances in novel drug delivery systems for neuropsychiatric disorders: a comprehensive review. Indian Drugs. 2025;62(12):7-20.
10. Togaru V, Venisetty RK, Bakshi V, Jadi RK. Formulation Development and In Vitro Evaluation of Propranolol Hydrochloride Extended Release Matrix Tablets. Emergent Life Sciences Research. 2017;3(1):38-47.
11. Vemula SK, Kadiri SK, Kumar MV, Narala N, Jadi RK, Kuchukuntla M, Narala S, Repka MA. Methodologies Adopted in Drug Repurposing. InDrug Repurposing: Innovative Approaches to Drug Discovery and Development 2024 (pp. 13-27). Singapore: Springer Nature Singapore.
12. Konatham MO, Gorle MT, Pathakala NA, Bakshi VA, Mamidisetti YD, Chinthakindi PR, Jadi RK. In situ gel polymers: A review. Int J Appl Pharm. 2021;7:86-90.
13. Komati S, Dasi V, Jadi RK, Padala NR. Formulation Development and Characterization of Atazanavir Sulphate Controlled Release Non-Effervescent Floating Matrix Tablets. Journal of Drug Delivery and Therapeutics. 2019;9 (4A):p601.
14. Jadi RK, Tatikonda A, Reedy PR, Venisetty RK. Design and characterization of pregabalin swellable core osmotic pumps. International journal of pharmaceutical research and allied sciences. 2016;5(3):8-15.
15. Pandala S, Bakshi V, Jadi RK. Formulation development and in vitro characterization of zolmitriptan controlled release drug delivery systems. INNOSC Theranostics Pharmacol. Sci. 2019;2(1):6-11.
16. Geetha A, Rajendra K, Krishna MC, Satish V, Raju P. A review on floating drug delivery systems. Int J Pharm Res Biomed Anal. 2012;1:1-3.
17. Chettupalli AK, Kakkerla A, Jadi RK, Uppu P, Ghazwani M, Hani U, Amarachinta PR, Sarvani P, Haque MA. Design, development, and preclinical evaluation of pirfenidone-loaded nanostructured lipid carriers for pulmonary delivery. Scientific Reports. 2025;15(1):11390.
18. Chettupalli AK, Unnisa A, Peddapalli H, Jadi RK, Anusha K, Amarachinta PR. Development and evaluation of empagliflozin-loaded solid lipid nanoparticles: Pharmacokinetics and pharmacodynamics for oral delivery. Intelligent pharmacy. 2025;3(3):193-206.
19. Akula G, Sapavatu SN, Jadi RK, Battineni JK, Boggula N. Analytical method development and validation for the estimation of tramadol in bulk and its formulations by UV-spectroscopy. Journal of Advanced Scientific Research. 2021;12(02):77-83.
20. Jadi RK, Bomma R, Sellappan V. Development of a new single unit dosage form of propranolol HCl extended release non-effervescent floating matrix tablets: In vitro and in vivo evaluation. Journal of applied pharmaceutical science. 2016;6(5):112-8.
21. Eslavath RN, Bakshi V, Jadi RK. Formulation Development and In Vitro Release Studies of Tenofovir-containing Microsponges. INNOSC Theranostics and pharmacological sciences. 2019;2(2):16-24.
22. Jadi RK, Bomma R. Gastroretentive Drug Delivery System of Propranolol HCl for the Effective treatment of Hypertension: Development, In vitro and In vivo Evaluation. Novel Aspects on Pharmaceutical Research Vol. 6. 2023;6:90-122.
23. Vinukonda A, Bolledla N, Jadi RK, Chinthala R, Devadasu VR. Synthesis of nanoparticles using

advanced techniques. Next Nanotechnology. 2025;8:100169.
24. Hosny S, Mohamed LZ, Ragab MS, Alomoush QK, Abdalla EM, Aly SA. Nanomaterials in biomedical applications: opportunities and challenges—a review. Chem Pap. 2025;79:2657–78.
25. Rezić I. Nanoparticles for biomedical application and their synthesis. Polymers (Basel). 2022;14(22):4961.
26. Kumar P, Kaur J. Role of nanotechnology in biomedical advances: a review of innovations and future directions. BiologicaNyssana. 2025 Jun 1;16(1).