Green Nanomedicine & Drug Delivery: Emerging Role of Nanoparticles in Targeted Therapy

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Abstract

In contemporary drug delivery methods, green nanomedicine has become a viable and biocompatible strategy. By integrating concepts of green chemistry with nanotechnology, eco-friendly nanoparticles are manufactured using biological sources such as plants, microbes, and biopolymers. These green-synthesized nanoparticles exhibit higher therapeutic efficacy, lower toxicity, and improved targeting ability compared to traditional nanocarriers. This study covers the concept of green nanomedicine, types of nanoparticles employed in drug delivery, their involvement in targeted therapy, analytical characterisation techniques, therapeutic uses, associated obstacles, and future possibilities in clinical translation

Keywords

Green nanomedicine; drug delivery; nanoparticles; targeted therapy; sustainable nanotechnology

1. Introduction

By enhancing medication solubility, stability, and site-specific targeting, nanomedicine has transformed drug delivery.In 2025, Saxena et al. However, hazardous chemicals are frequently used in traditional synthesis techniques, which raises issues with safety and the environment (Kumari et al., 2025). Green nanotechnology, which uses biological resources to create nanoparticles in moderate settings, has become a viable substitute. Green nanomedicine plays a critical role in targeted therapy by lowering systemic toxicity and enhancing therapeutic precision, as the prevalence of chronic and life-threatening diseases rises (Izadi et al., 2024).

Nanomedicine has evolved as a disruptive discipline that merges nanotechnology with medical and pharmaceutical sciences to better illness diagnosis, treatment, and prevention. The employment of nanoscale materials in medicine has considerably boosted medication solubility, bioavailability, targeted delivery, and therapeutic efficacy. Concerns about sustainability, safety, and long-term toxicity are raised by conventional nanomedicine approaches, which frequently rely on chemical and physical synthesis techniques that may involve hazardous solvents, high energy consumption, and environmentally hazardous by-products (Jahangirian et al., 2017).

Green nanomedicine has drawn more attention as a sustainable solution to these problems. In order to create nanoparticles with better biocompatibility and less of an impact on the environment, green nanomedicine highlights the use of environmentally friendly synthesis methods that make use of biological resources like plant extracts, microbes, and biopolymers. Because they contain bioactive surface functional groups, these biologically produced nanoparticles not only reduce harmful residues but also provide improved therapeutic effectiveness (Iravani, 2011). As a result, green nanomedicine is widely acknowledged as a viable technique for the development of safer and more effective drug delivery systems and targeted therapies.

2. Green Nanomedicine: An Overview

Green nanomedicine is built on the concepts of green chemistry, stressing non-toxic reagents, renewable resources, and energy efficiency(Damodar et al., 2026). Plant-mediated nanoparticle production is widely researched due to its simplicity, scalability, and high phytochemical content that works as reducing and stabilizing agents (Kumar et al., 2025; Rabiee, 2025). Although it necessitates strict growing conditions, microbial synthesis allows regulated nanoparticle production. Chitosan and alginate are two examples of biopolymer-based nanoparticles that offer superior biodegradability and biocompatibility (Ashutosh, 2025; Germain et al., 2020). Green nanoparticles are more biomedically applicable and less harmful than chemically produced nanoparticles.

Green-synthesized nanoparticles have special physicochemical characteristics, such as regulated size, surface charge, and improved stability, that make them appropriate for biomedical applications. These characteristics enable better biological system interaction, which results in increased cellular uptake, extended circulation time, and effective targeting of sick tissues (Fan et al., 2023). Furthermore, inherent therapeutic benefits like antioxidant, anti-inflammatory, and antibacterial properties can be imparted by the presence of endogenous biomolecules on the surfaces of nanoparticles.

Green nanomedicine has potential in targeted therapy, imaging, diagnostics, and drug administration. Green nanoparticles have been successfully investigated for the treatment of inflammatory ailments, cardiovascular diseases, neurological disorders, cancer, and antimicrobial therapy. Their capacity to support regulated and stimuli-responsive drug release further enhances therapeutic accuracy and decreases systemic adverse effects (Islam et al., 2025). Despite these advantages, issues relating to scalability, standardization, and regulatory approval remain and require focused research efforts to facilitate clinical translation.

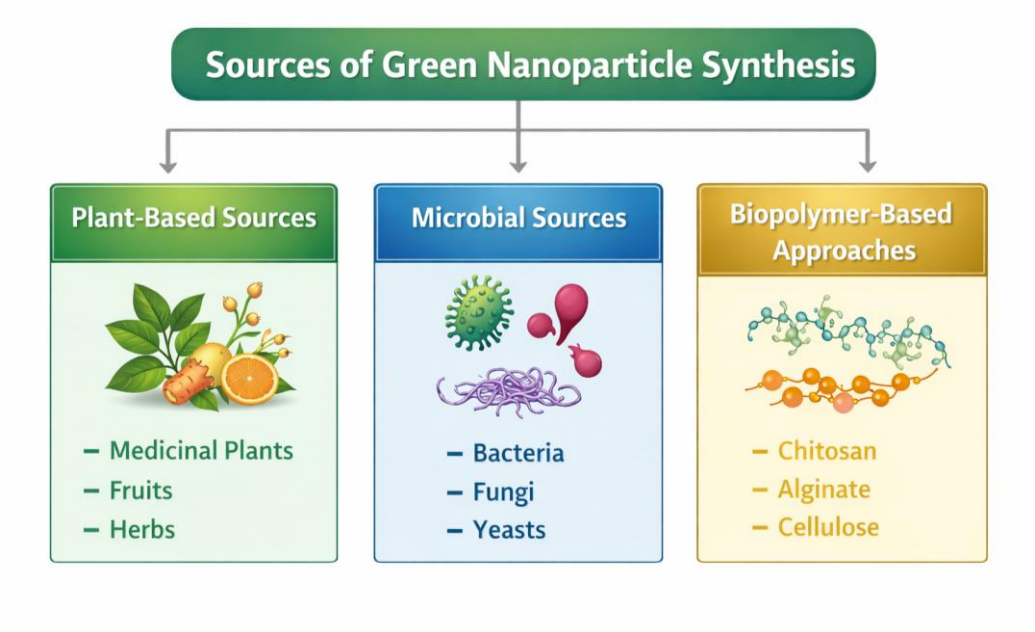

Figure 1: Sources of green Nanoparticle synthesis

3. Nanoparticles in Drug Delivery Systems

Drug delivery nanoparticles fall into four categories: metallic, polymeric, lipid-based, and hybrid systems. Gold and silver are examples of metallic nanoparticles that have special physicochemical and antibacterial qualities that make them useful for treating infectious diseases and cancer. Polymeric nanoparticles enable variable drug loading and controlled release, while lipid-based nanoparticles demonstrate higher biocompatibility and encapsulation efficiency (Fan et al., 2023). Nanoparticle size, surface charge, and shape greatly influence cellular uptake, biodistribution, and therapeutic efficacy. Diffusion, degradation, and stimuli-responsive release brought on by pH, temperature, or enzymes are examples of drug release processes (Lawal et al., 2025).
As drug transporters, nanoparticles shield therapeutic compounds from enzymatic deterioration and early elimination. This is particularly crucial for delicate compounds such as proteins, peptides, and nucleic acids. Surface modification of nanoparticles extends circulation time and improves interaction with biological membranes, leading to sustained and regulated drug release and lower dosage frequency (Singh et al., 2024).

A major advantage of nanoparticles in medication delivery systems is their capacity to accomplish tailored drug distribution. The increased permeability and retention (EPR) effect, which enables nanoparticles to preferentially accumulate in sick tissues like tumors, is how passive targeting works. By functionalizing the surfaces of nanoparticles with ligands, antibodies, or peptides that bind precisely to receptors overexpressed on target cells, active targeting is accomplished, increasing therapeutic efficacy and reducing systemic toxicity (Fan et al., 2023).

Nanoparticles also enable stimuli-responsive drug release, where drug release is initiated by specific environmental parameters such as pH, temperature, enzymes, or redox potential at the target site. This site-specific release lessens side effects and enhances therapy results. Various nanoparticle systems, including polymeric, lipid-based, metallic, and hybrid nanoparticles, have been successfully created for enhanced drug delivery applications (Islam et al., 2025; Jahangirian et al., 2017).

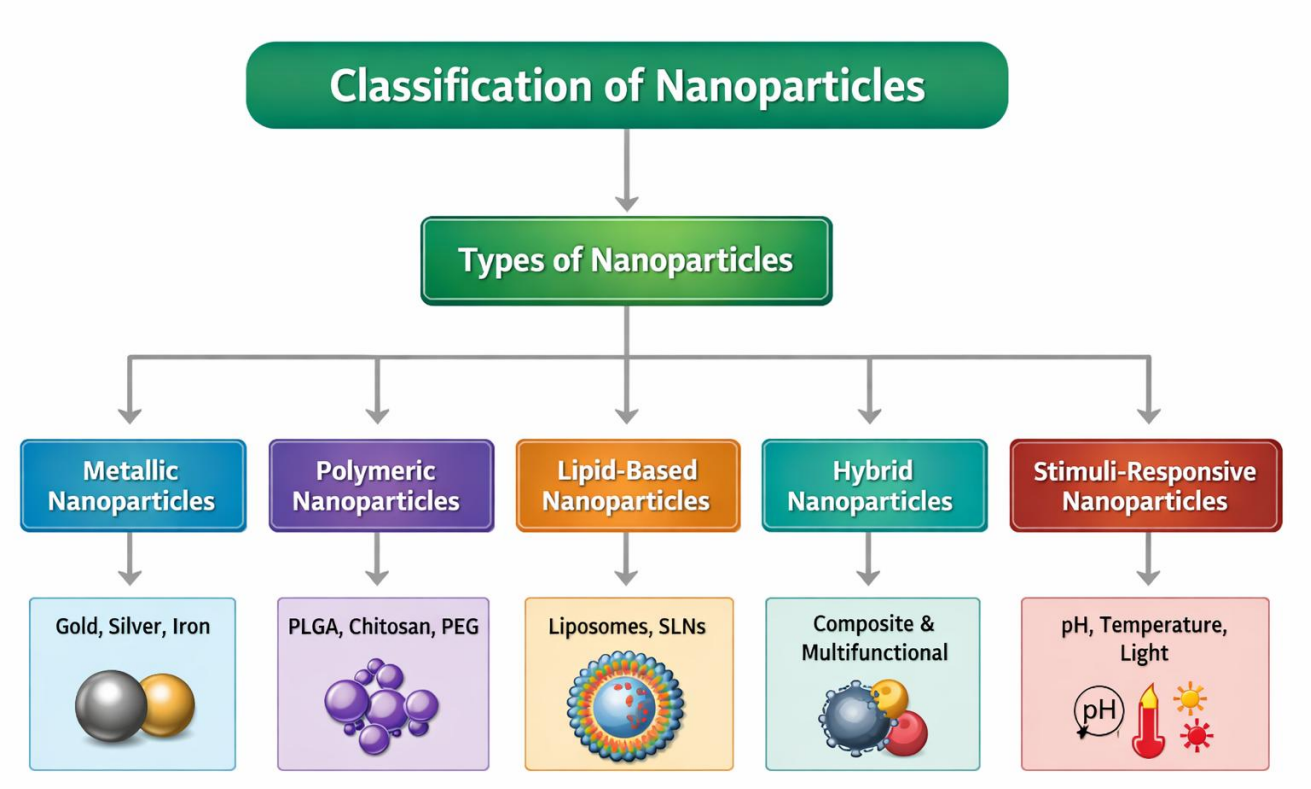

Figure 2: Classification of Nanoparticles

4. Role of Green-Synthesized Nanoparticles in Targeted Therapy

Both passive and active targeting techniques are made possible by green nanoparticles (Aringazina&Hoseinzadeh, 2024). While active targeting uses ligand-receptor interactions for precise medication delivery, passive targeting takes advantage of disease characteristics like increased vascular permeability in tumors. Green nanoparticles with surface functionalization improve biodistribution profiles and increase cellular absorption via receptor-mediated endocytosis. Their ecologically friendly production contributes to better safety and therapeutic selectivity.

The goal of targeted therapy is to minimize systemic toxicity and off-target effects while delivering therapeutic medicines to sick tissues in a targeted manner. Green-synthesized nanoparticles have emerged as highly promising platforms for targeted therapy due to their biocompatibility, surface functionality, and sustainable production methods. Green synthesis uses biological compounds generated from microorganisms, plants, or biopolymers that function as natural stabilizing and capping agents, enabling improved interaction with particular cellular receptors and biological targets (Iravani, 2011).

The capacity of green nanoparticles to take advantage of both passive and active targeting mechanisms is one of its main advantages in targeted therapy. Passive targeting is done by the enhanced permeability and retention (EPR) effect, particularly in tumor tissues with leaky vasculature. The nanoscale size and surface charge of green nanoparticles enable preferential accumulation at sick areas, thereby enhancing therapeutic concentration and decreasing harm to healthy tissues (Fan et al., 2023). By functionalizing the surfaces of nanoparticles with ligands, antibodies, or peptides that bind specifically to overexpressed receptors on target cells, active targeting can be further improved.

Green-synthesized nanoparticles also demonstrate significant potential in stimuli-responsive targeted therapy. Localized therapeutic activity can be ensured by controlling drug release from green nanocarriers in response to changes in pH, redox environment, enzyme levels, or temperature at sick locations. Because microenvironmental variations are well-characterized in cancer and inflammatory illnesses, such responsive behavior is especially beneficial (Islam et al., 2025). Moreover, the presence of phytochemicals and biomolecules on nanoparticle surfaces often promotes synergistic therapeutic benefits, improving efficacy through combined pharmacological actions.

Significantly, green nanoparticles are less toxic and immunogenic, which makes them appropriate for long-term or frequent use in chronic illnesses. According to studies, green-synthesised nanocarriers outperform conventionally synthesised nanoparticles in terms of cellular absorption, circulation time, and therapeutic index (Jahangirian et al., 2017). All of these qualities contribute to their expanding use in precision medicine.

5. Therapeutic Applications

Green nanomedicine has proven great potential in cancer therapy by promoting tumor formation and lowering chemotherapy-induced toxicity(Barathi et al., 2024; Geetha et al., 2024). Strong antibacterial and antiviral properties are demonstrated by green-synthesised nanoparticles, especially against infections that are resistant to many drugs. They facilitate the tailored administration of anti-inflammatory and antithrombotic medications in cardiovascular conditions (Phan et al., 2021).

Neurological applications include enhanced medication transport across the blood–brain barrier for treating neurodegenerative disorders(Geszke-Moritz & Moritz, 2024). Additionally, because of their immunomodulatory qualities, green nanoparticles offer potential in the treatment of inflammatory and autoimmune diseases.

Green nanoparticles have emerged as attractive instruments in modern therapies due to their better biocompatibility, lower toxicity, and eco-friendly manufacturing techniques. Green nanotechnology provides multifunctional nanocarriers with enhanced safety profiles and focused therapeutic potential for a variety of ailments by utilizing biologically generated reducing and capping agents.

Cancer Therapy

One of the uses of green nanoparticles that has been studied the most is cancer treatment. Through processes like the production of reactive oxygen species (ROS), mitochondrial malfunction, and apoptosis induction, green-

synthesized metallic nanoparticles—specifically, silver, gold, and iron oxide nanoparticles—display intrinsic anticancer activity. Furthermore, by improving tumor targeting through the increased permeability and retention (EPR) effect, green nanoparticles function as effective drug delivery systems, increasing therapeutic efficacy while reducing systemic toxicity (Fan et al., 2023). Capping compounds produced from plants also enhance cellular absorption and have synergistic anticancer effects (Iravani, 2011).

Antimicrobial and Antiviral Applications

Green nanoparticles demonstrate broad-spectrum antibacterial action against bacteria, fungi, and viruses. Silver nanoparticles produced utilizing plant extracts or microbial sources demonstrate significant antibacterial effect by membrane rupture, protein denaturation, and DNA damage. These characteristics enable them to effectively combat bacteria that are resistant to many drugs, hence tackling the worldwide issue of antimicrobial resistance (Patra et al., 2024). According to recent research, green nanoparticles have the ability to prevent viral entrance, replication, and assembly. This suggests that they could be used to treat viral infections, including as respiratory and emerging viral disorders (Mukherjee et al., 2024).

Cardiovascular Disorders

Green nanoparticles are being investigated in cardiovascular medicine for tissue repair, imaging, and targeted drug delivery. Green nanoparticles based on polymers and lipids increase the bioavailability of poorly soluble cardiovascular medications and allow for regulated drug release, which lowers adverse effects and dosage frequency. Because of their good safety profiles and magnetic properties, iron oxide nanoparticles produced using green technologies have demonstrated potential in targeted therapy for atherosclerosis and thrombosis as well as diagnostic imaging (Singh et al., 2024). Their therapeutic value in cardiovascular illnesses is further enhanced by their capacity to regulate inflammation and oxidative stress.

Neurological and Neurodegenerative Diseases

The blood–brain barrier's (BBB) restrictive nature makes treating neurological illnesses difficult. By enabling medication transport across the blood-brain barrier by surface functionalization and nanoscale size optimization, green nanoparticles provide novel possibilities. By providing antioxidants, neuroprotective medicines, and anti-inflammatory medications directly to the brain, studies show their potential in treating neurodegenerative disorders like Alzheimer's and Parkinson's disease (Islam et al., 2025). The lower neurotoxicity associated with green synthesis processes boosts their appropriateness for long-term neurological uses.

Inflammatory and Autoimmune Disorders

Green nanoparticles are extensively researched for treating inflammatory and autoimmune disorders due to their capacity to alter immune responses and deliver anti-inflammatory medicines selectively to inflamed tissues. Polymeric and biopolymer-based nanoparticles made utilizing green techniques provide regulated medication release and targeted distribution, lowering systemic immunosuppression. Their antioxidant qualities help attenuate chronic inflammation, making them useful for illnesses such as rheumatoid arthritis, inflammatory bowel disease, and autoimmune skin disorders (Jahangirian et al., 2017).

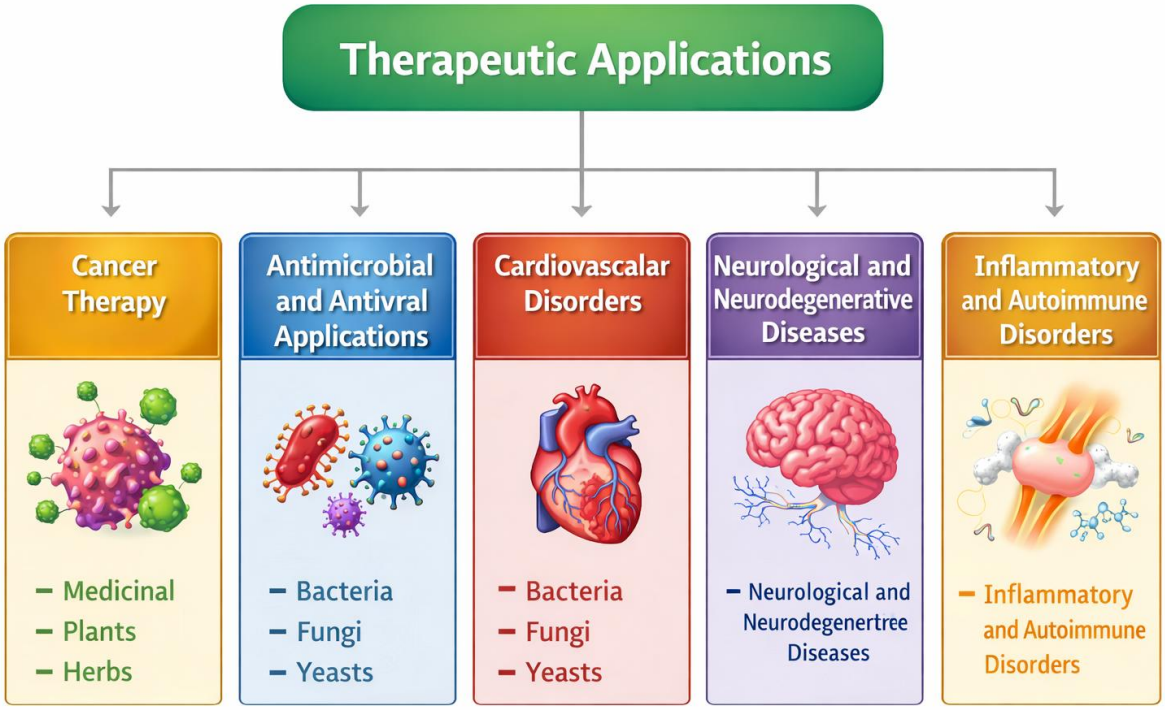

Figure 3: Therapeutic Applications of Nanoparticles

6. Analytical Evaluation of Green Nanoparticles

To guarantee the quality and safety of nanoparticles, thorough characterization is necessary. Spectroscopic techniques are utilized to establish chemical composition, whereas microscopic techniques provide insights into morphology and size distribution(Chattopadhyay et al., 2025). Particle size and surface charge studies are crucial for evaluating stability and biological interactions (Yu et al., 2025). While in vivo research analyze pharmacokinetics, biodistribution, therapeutic efficacy, and toxicity, in vitro investigations investigate cytotoxicity, cellular uptake, and drug release kinetics.

The analytical evaluation of green-synthesized nanoparticles is a vital step in ensuring their quality, safety, and therapeutic efficacy for biomedical applications. Prior to clinical translation, thorough characterisation and biological evaluation are necessary to comprehend their physicochemical characteristics, biological interactions, and toxicological profile. To guarantee the stability and repeatability of green nanoparticles, sophisticated analytical techniques are being used more and more (Patra et al., 2024).

1. Characterization Techniques

Determining the size, shape, composition, surface chemistry, and stability of nanoparticles—all of which have a substantial impact on biological performance—requires physicochemical characterization.

To verify the creation of nanoparticles by surface plasmon resonance in metallic nanoparticles, spectroscopic methods including ultraviolet–visible (UV–Vis) spectroscopy are frequently employed. To determine functional groups and verify the existence of biomolecules from plant extracts or microbial sources functioning as reducing and capping agents, Fourier transform infrared spectroscopy (FTIR) is utilized (Iravani, 2011).

The size, shape, and surface morphology of nanoparticles can be thoroughly determined using microscopic methods such as transmission electron microscopy (TEM) and scanning electron microscopy (SEM). Nanoscale surface topology study is further made possible by atomic force microscopy (AFM). X-ray diffraction (XRD) is used to examine crystallinity and phase composition, confirming the structure and purity of nanoparticles (Kamyab et al., 2025).

Particle size and surface charge analysis are commonly accomplished using dynamic light scattering (DLS) and zeta potential measurements. According to Jahangirian et al. (2017), these factors are essential for forecasting the stability, aggregation behavior, and interaction of nanoparticles with biological membranes.

2. In Vitro Evaluation

Preliminary information about the biological performance of green nanoparticles, such as cytotoxicity, cellular uptake, and drug release behavior, is provided by in vitro investigations. MTT, XTT, and LDH assays are examples of cytotoxicity tests that are frequently used to evaluate cell viability and establish safe dose ranges. These tests aid in comparing green nanoparticles' toxicity to that of their chemically produced equivalents. Endocytosis and other modes of nanoparticle internalization are revealed by cellular uptake investigations employing flow cytometry and fluorescence imaging (Fan et al., 2023).

In order to assess regulated and stimuli-responsive release patterns, drug release experiments are often carried out in physiologically mimicked environments. Assays for oxidative stress and in vitro hemocompatibility evaluate interactions with blood components and cellular redox balance, which are crucial for intravenous applications (Islam et al., 2025).
However, disparities between in vitro and in vivo results continue to be a significant barrier to the advancement of nanomedicine (Rizvi & Saleh, 2023).

3. In Vivo Assessment

In vivo evaluation is necessary to confirm the therapeutic efficacy and safety of green nanoparticles under physiological conditions. Animal models are used to study pharmacokinetics, biodistribution, and bioavailability. Imaging tools such as fluorescence imaging, magnetic resonance imaging (MRI), and positron emission tomography (PET) assist track nanoparticle distribution and accumulation in target tissues (Singh et al., 2024). illness-specific results, such as tumor regression in cancer models or decreased inflammation in inflammatory illness models, are evaluated in therapeutic efficacy studies. Major organ histopathology investigation also sheds light on tissue-level interactions and possible side effects after nanoparticle delivery.

4. Toxicological Studies

To guarantee the long-term safety of green nanoparticles, toxicological evaluation is essential. Repeated-dose studies investigate systemic toxicity and bioaccumulation, whereas acute and chronic toxicity studies evaluate dose-dependent effects. Particular focus is devoted to metal-based green nanoparticles, which may persist in tissues and produce organ-specific toxicity over prolonged exposure (Jahangirian et al., 2017).

Immunotoxicity and genotoxicity studies assess potential immunological activation, inflammatory reactions, and DNA damage. In order to comprehend underlying damage mechanisms, oxidative stress indicators and inflammatory cytokines are frequently tracked. Because biological synthesis techniques vary, thorough toxicological profiling is still necessary even if green synthesis is typically associated with lower toxicity (Kumari et al., 2010). According to recent research, the main mechanisms behind nanoparticle-induced toxicity are oxidative stress and immunological regulation (Mukherjee et al., 2024).

7. Challenges and Limitations

Despite promising achievements, green nanomedicine has issues related to reproducibility, scalability, and long-term stability(S. Singh et al., 2024). Variations in biological manufacturing processes can affect nanoparticle uniformity. Clinical translation is hampered by the ongoing development of green nanomedicine-specific regulatory frameworks

(Billah et al., 2025). Assessments of long-term toxicity and environmental effects are still necessary for broad implementation.

Safety and Scalability Issues

One of the key challenges of green nanomedicine is the difficulty in scaling up green synthesis techniques for commercial and clinical applications. Green synthesis relies on biological sources such as plant extracts, microorganisms, and biopolymers, which often display batch-to-batch variability due to differences in biological composition, growth conditions, and seasonal factors (Iravani, 2011; Jahangirian et al., 2017). The size, shape, and surface chemistry of nanoparticles can all be greatly impacted by this diversity, which can lead to uneven therapeutic outcomes.

Furthermore, it is still difficult to maintain consistency and reproducibility in large-scale production. Green synthesis techniques necessitate rigorous optimization to maintain biological functioning while guaranteeing nanoparticle stability, in contrast to traditional chemical synthesis techniques that permit fine control over reaction parameters (Singh et al., 2024).

Regulatory and Ethical Concerns

Clinical approval is severely hampered by the regulatory environment for green nanomedicine, which is still developing. Regulatory agencies require extensive data on nanoparticle characterization, pharmacokinetics, biodistribution, and long-term safety; however, the complex and heterogeneous surface chemistry of green-synthesized nanoparticles complicates regulatory assessment and standardization (Jahangirian et al., 2017).
Large-scale biological resource utilization also raises ethical questions, especially when it comes to overharvesting therapeutic plants and using genetically modified microbes to create nanoparticles. Furthermore, the absence of globally defined regulatory criteria for green nanomedicine leads to uncertainties in risk assessment, quality control, and post-market surveillance (Kumari et al., 2010).

Safety, Toxicity, and Biocompatibility Issues

Biogenic nanoparticles are not completely free from toxicity concerns, despite the fact that green nanomedicine is typically thought to be safer than conventional nanomedicine. The biological molecules serving as reducing and capping agents may produce unexpected immunogenic or inflammatory responses depending on nanoparticle dose, size, surface charge, and route of delivery (Fan et al., 2023).
Metal-based green-synthesized nanoparticles, in particular, pose issues regarding long-term toxicity, bioaccumulation, and organ-specific distribution. Research has demonstrated that physicochemical characteristics such particle size and surface chemistry have a significant impact on nanoparticle–cell interactions and toxicity profiles (Kamyab et al., 2025). Moreover, the lack of defined in vitro and in vivo toxicity evaluation models precludes valid comparison between green and conventional nanomedicine systems (Islam et al., 2025).

Translational Barriers

A limited understanding of nano–bio interactions and insufficient clinical evidence represent major translational hurdles for green nanomedicine. Most investigations remain confined to preclinical models, and well-designed human trials are scarce. Regulatory approval and broad clinical acceptance continue to be difficult in the absence of long-term safety and effectiveness data (Singh et al., 2024).

8. Discussion

Comparative studies reveal that green-synthesized nanoparticles offer greater biocompatibility and lower toxicity compared to conventional nanocarriers(Jahangirian et al., 2017; Saxena et al., 2025). However, lack of uniformity and poor clinical data impede large-scale application. Addressing these gaps through interdisciplinary research and regulatory harmonization is crucial for improving green nanomedicine(Khan et al., 2025; K. Singh et al., 2024). A

sustainable and biocompatible substitute for traditional medication delivery methods based on nanotechnology is provided by green nanomedicine. Green nanomedicine uses biological resources that function as natural reducing and stabilizing agents, in contrast to traditional nanomedicine, which frequently uses hazardous reagents and energy-intensive procedures. This leads in nanoparticles with better surface biofunctionality, improved cellular interactions, and lower cytotoxicity. Additionally, green-synthesised nanoparticles exhibit intrinsic medicinal qualities like antibacterial and antioxidant activity that can work in concert to improve medication efficacy.

By utilizing environmentally safe synthesis techniques with biological materials like plants, microbes, and biopolymers, green nanomedicine has become a viable substitute for traditional nanomedicine. Compared to traditional chemical and physical procedures, these green synthesis techniques greatly reduce environmental toxicity and the generation of hazardous byproducts by using natural phytochemicals, proteins, and enzymes as reducing and stabilizing agents (Jahangirian et al., 2017).

In contrast, conventional nanomedicine generally rely on synthetic chemicals and energy-intensive methods, which enable great repeatability and exact control over nanoparticle size and morphology but raise issues regarding cytotoxicity and environmental effect (Iravani, 2011). The presence of residual hazardous chemicals in chemically produced nanoparticles generally needs further surface modifications to promote biocompatibility before biomedical application.

Green-synthesized nanoparticles are especially well suited for targeted drug administration and therapeutic applications because of their enhanced biocompatibility and decreased cytotoxicity as a result of biomolecules' natural surface functionalization (Jahangirian et al., 2017). However, problems associated to batch-to-batch variability, stability, and large-scale production hinder their quick clinical translation. Conventional nanomedicine, on the other hand, benefits from well-established production methods, regulatory approval, and several clinically authorized formulations, especially in cancer therapy and polymer-based drug delivery systems (Kumari et al., 2010).

Green nanomedicine, which offers safer, more sustainable, and biologically integrated nanotherapeutic platforms, has great promise for future uses, even if conventional nanomedicine now dominates clinical practice due to its standardization and scalability. Addressing difficulties related to reproducibility and regulatory frameworks will be critical for the effective clinical translation of green nanomedicine techniques (Iravani, 2011; Jahangirian et al., 2017).

However, despite its advantages, green nanomedicine confronts issues relating to reproducibility, stability, and large-scale manufacture due to variability in biological sources. Conventional nanomedicine, on the other hand, has established regulatory frameworks, better control over particle properties, and standardized synthesis procedures that facilitate quicker clinical translation. Therefore, if issues with standardization and scalability are resolved, green nanomedicine has great promise for future sustainable and customized therapeutic approaches, even though conventional nanomedicine now dominates clinical applications.

Table 1: Parameters of Green & Conventional Nanomedicine

Parameter	**Green Nanomedicine**	**Conventional Nanomedicine**
Synthesis Approach	Uses eco-friendly biological sources such as plant extracts, microorganisms, and biopolymers	Relies on chemical and physical methods involving toxic solvents and reducing agents
Reducing &Capping Agents	Natural phytochemicals, enzymes, proteins, and polysaccharides	Synthetic chemicals (e.g., sodium borohydride, hydrazine)
Environmental Impact	Environmentally sustainable with minimal hazardous waste	Generates toxic by-products and environmental pollution
Energy Requirement	Low energy, mild reaction conditions	High energy input (high temperature, pressure, radiation)
Biocompatibility	High biocompatibility due to biological surface	Often requires additional surface

Parameter	Green Nanomedicine	Conventional Nanomedicine
	functionalization	modification to improve compatibility
Toxicity Profile	Reduced cytotoxicity and improved safety	Higher risk of cytotoxicity and long-term accumulation
Stability	Moderately stable; depends on biological source variability	High stability and reproducibility
Reproducibility	May vary due to biological source variation	Highly reproducible and standardized
Scalability	Challenging but improving with process optimization	Well-established large-scale production
Cost Effectiveness	Cost-effective due to inexpensive raw materials	Expensive due to synthetic chemicals and equipment
Drug Loading Efficiency	Moderate to high due to natural functional groups	High and well-controlled
Targeting Ability	Enhanced natural targeting via biomolecules	Requires artificial ligands and surface modification
Regulatory Acceptance	Emerging; limited standardized guidelines	Established regulatory pathways
Clinical Translation	Mostly preclinical; limited clinical trials	Several clinically approved nanomedicines
Therapeutic Applications	Cancer, antimicrobial, inflammatory, neurological disorders	Cancer, vaccines, imaging, gene therapy

9. Future Prospects and Emerging Trends

Future research is focused on smart, stimuli-responsive, and individualized nanocarriers(Kamyab et al., 2026). Integration with artificial intelligence and precision medicine is expected to optimize nanoparticle design and therapeutic outcomes. Clinical translation will proceed more quickly with sustainable large-scale production and more precise regulations (Aringazina&Hoseinzadeh, 2024).

10. Conclusion

Green nanomedicine represents a sustainable and novel technique for targeted drug delivery. Green-synthesized nanoparticles promise greater biocompatibility, lower toxicity, and improved therapeutic efficacy. Green nanomedicine will become a crucial part of next-generation healthcare if research on scalability, regulation, and safety is continued.

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