IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Green Nanoparticle Synthesis: Towards Sustainable Nanotechnology

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Abstract: Green synthesis of nanoparticles is a promising and sustainable approach to nanoparticle production, addressing the growing need for environmentally friendly methods in nanotechnology. This review paper analyses current state-of-the-art techniques, including plant extracts, microorganisms, and bio-waste materials, and highlights their advantages over conventional synthesis approaches. Green synthesis offers numerous benefits, including reduced energy consumption, avoidance of hazardous chemicals, and minimal toxic byproducts. It also opens up new possibilities for applications in biomedicine, catalysis, environmental remediation, agriculture, and electronics. Characterization techniques are used to assess the size, shape, and structure of green-synthesized nanoparticles, and real-world case studies highlight their potential impact on various industries and environmental sustainability. However, challenges related to reproducibility and scalability remain, but interdisciplinary efforts and innovative strategies offer promising prospects for addressing these limitations. In conclusion, green nanoparticle synthesis is viable for sustainable nanoparticle production with diverse applications.

Index Terms: **Nanoparticle, green synthesis, sustainable, characterization technique, environment**

1. INTRODUCTION

The use of nanoscale materials and structures with dimensions ranging from 1 to 100 nanometers (nm) is a new field in nanoscience and nanotechnology. Nanomaterials have the potential to solve technical and environmental difficulties in solar energy conversion, catalysis, medicine, and water treatment (Dahl, J. A. et al, 2007). Nanotechnology is a novel and developing technology with several uses. It entails the production and utilization of materials with dimensions ranging from 1 to 100 nm. Nowadays, a wide range of physicochemical techniques is employed to synthesize nanoparticles (NPs). However, the biogenic reduction of metal precursors to create matching NPs is more environmentally friendly, less costly, and free of chemical impurities for medical and biological applications where NP purity is critical (Hussain et al, 1993). Recently, research in the production of nanoparticles utilizing microorganisms and plant extracts has gained prominence due to its eco-friendliness, flexibility, and essential feature of the avoidance of hazardous chemicals (Mann, S, 1993)).

Green synthesis of nanoparticles is a promising and sustainable approach to nanoparticle production, addressing the growing need for environmentally friendly methods in nanotechnology. Green synthesis offers numerous benefits, including reduced energy consumption, avoidance of hazardous chemicals, and minimal generation of toxic byproducts. The biocompatibility of green-synthesized nanoparticles opens up new possibilities for applications in biomedicine, catalysis, environmental remediation, agriculture, and electronics (Varma, R. S, 2014). The characterization techniques employed to assess the size, shape, and structure of green-synthesized nanoparticles are essential for understanding their properties and ensuring suitability for specific applications. Real-world case studies highlight the potential impact of green-synthesized nanoparticles on various industries and environmental sustainability. However, the field faces challenges related to reproducibility and scalability (Shafey, A. M. E,2020).

2. METHODS OF GREEN SYNTHESIS:

Green synthesis methods involve using environmentally friendly approaches to produce nanoparticles without the use of toxic chemicals or high-energy processes. These methods utilize natural sources or renewable materials, making them more sustainable and eco-friendlier. Standard green synthesis methods include plant extracts, microorganisms, bio-waste materials, green solvents, microwave and ultrasonic-aided synthesis, photochemical synthesis, green nanoreactors, and enzyme-mediated synthesis. These methods have gained significant attention due to their reduced environmental impact and potential for large-scale, cost-effective nanoparticle production. (Bolade, O. P., et al 2020).

2.1 Types Of Components

2.1.1 Plant extracts -contain bioactive compounds like polyphenols, flavonoids, and terpenoids, which act as reducing and stabilizing agents during nanoparticle synthesis. These compounds interact with metal ions, facilitating their reduction and nucleation, and provide a biocompatible surface coating (Tamuly, C., et al, 2013).

2.1.2 Microorganism-mediated green synthesis- is a sustainable method that utilizes renewable resources and offers precise control over nanoparticle size and shape. (Zhu, X., Pathakoti, K., & Hwang, H. M. (2019).

2.1.3 Bio-waste materials- like fruit peels, tea waste, eggshells, or sawdust, contain natural compounds with reducing potential, making them eco-friendly and cost-effective. Green solvents, like water or plant-based solvents, provide an environment conducive to the reduction of metal ions and nanoparticle formation, making the synthesis process safer, more sustainable, and easily accessible. Senthil, C., & Lee, C. W. (2021).

2.1.4 Microwave and ultrasonic-aided synthesis, photochemical synthesis, green nanoreactors, and enzyme-mediated synthesis are three methods for reducing and stabilizing metal ions during nanoparticle formation. These methods offer reduced reaction times, energy consumption, and improved efficiency. (Dumur, F., et al 2011).

2.1.5 Photochemical synthesis uses natural light sources and allows precise control over the reaction. Green nanoreactors provide confined spaces for nanoparticle growth, enabling more uniform and monodisperse nanoparticles. (Dahl, J. A. et al, 2007).

2.1.6 Enzyme-mediated synthesis uses enzymes as biocatalysts, promoting precise nanoparticle formation and biocompatibility for biomedical applications. By adopting green synthesis, researchers can contribute to sustainable nanotechnology and reduce the environmental impact of nanoparticle production. (Dumur, F., et al 2011).

TABLE.1.: Example of some nanoparticles synthesized using different green synthesis methods.

S.No.	**Type Of Green Method Synthesis**	**Example Of Nanoparticle (Metal/Nonmetal)**	**Methods (Organisms /Material)**	**Role In Activity**	**Activity**	**References**
1.	Plant Extract	Silver nanoparticles (AgNPs)	using leaf extracts from plant	stabilizing agents	reduction of silver ions	(Tamuly, C., et al, 2013).
2.	Microorganism	Gold nanoparticles (AuNPs)	using bacterial strains	stabilizing agents	reduce gold ions	(Zhu, X., Pathakoti, K., & Hwang, H. M. (2019).
3.	Bio-Waste Material	Iron oxide nanoparticles (Fe_3O_4 NPs)	using banana peel extracts	Reducing agent	reduce iron ions	Senthil, C., & Lee, C. W. (2021).
4.	Green Solvent	Copper oxide nanoparticles (CuO NPs)	Using Water	reaction medium	reduction of copper ions	Senthil, C., & Lee, C. W. (2021).
5.	Microwave and Ultrasonic-Assisted Synthesis	Zinc oxide nanoparticles (ZnO NPs)	using microwave irradiation	Providing energy	reduction of zinc ions	(Dumur, F., et al 2011).
6.	Photochemical Synthesis	Titanium dioxide nanoparticles (TiO_2 NPs)	using solar irradiation	Providing energy	reduction of titanium ions	(Dahl, J. A. et al, 2007).
7.	Green Nanoreactors	Silver-gold bimetallic	using micelles	nanoreactors	reduction of silver and gold ions	(Dumur, F., et al 2011).
8.	Enzyme-Mediated Synthesis	Platinum nanoparticles (PtNPs)	using enzymes like horseradish peroxidase (HRP).	biocatalyst	promotes the reduction of platinum ions	(Dumur, F., et al 2011).

3. ADVANTAGES OF GREEN SYNTHESIS

3.1. Green synthesis of nanoparticles offers numerous environmental benefits, including-

3.1.1. Reduced energy consumption
3.1.2. Elimination of hazardous chemicals
3.1.3. Waste reduction, biodegradable
3.1.4. Biocompatible nanoparticles
3.1.5. Sustainable resource utilization and
3.1.6. Encouragement of green technologies.

These methods use natural sources, renewable materials, or biocompatible compounds to reduce and stabilize nanoparticles, minimizing the risk of chemical pollution and ecosystem harm. The green synthesis also produces less waste, promoting a circular economy and reducing the use of bio-waste materials. Additionally, green synthesis methods rely on renewable resources, promoting sustainable practices and reducing dependence on non-renewable resources. By adopting green synthesis approaches, researchers and industries can drive innovation, influence policy changes, and create a positive impact on the environment and society. (Devatha, C. P., & Thalla, A. K. 2018).

3.2. . **Green-synthesized nanoparticles large-scale production, cost-effectiveness, the biocompatibility for biomedical applications-**

3.2.1. Green-synthesized nanoparticles exhibit inherent biocompatibility, making them suitable for various biomedical applications. These nanoparticles are non-toxic and biocompatible, ensuring reduced risks of adverse effects when used in medical or biological systems. They also offer controlled and tenable properties, enabling precise control over nanoparticle size, shape, and surface characteristics. Additionally, biocompatible nanoparticles synthesized through green methods have a lower chance of triggering immune responses, minimizing the risk of adverse reactions during medical treatments. These methods also offer cost-effective materials, reducing the overall cost of synthesis and waste management. (Nasrollahzadeh, M., et al 2019).

3.2.2. The integration of green-synthesized nanoparticles into clinical practice holds the promise of revolutionizing healthcare and contributing to a greener, healthier future. As research in green synthesis methods continues to advance, the integration of these eco-friendly nanoparticles into clinical practice holds the promise of revolutionizing healthcare and contributing to a greener, healthier future. (Waris, A., et al 2021).

4. NANOPARTICLE CHARACTERIZATION TECHNIQUE

Characterizing nanoparticles is critical for understanding their size, shape, structure, composition, and surface qualities, which all have a direct impact on their behavior and applications. Several analytical methods are routinely employed for nanoparticle characterization. Here are some of the most important techniques:

5. APPLICATIONS OF GREEN-SYNTHESIZED NANOPARTICLES

Green-synthesized nanoparticles have a wide range of applications due to their eco-friendly nature, biocompatibility, and controlled properties. They are used in medicine, biomedicine, environmental remediation, solar cells, batteries, catalysis, agriculture, crop enhancement, textiles and clothing, electronics and optoelectronics, nanophotonics, food and packaging, and more. (Nasrollahzadeh, M., et al 2019).

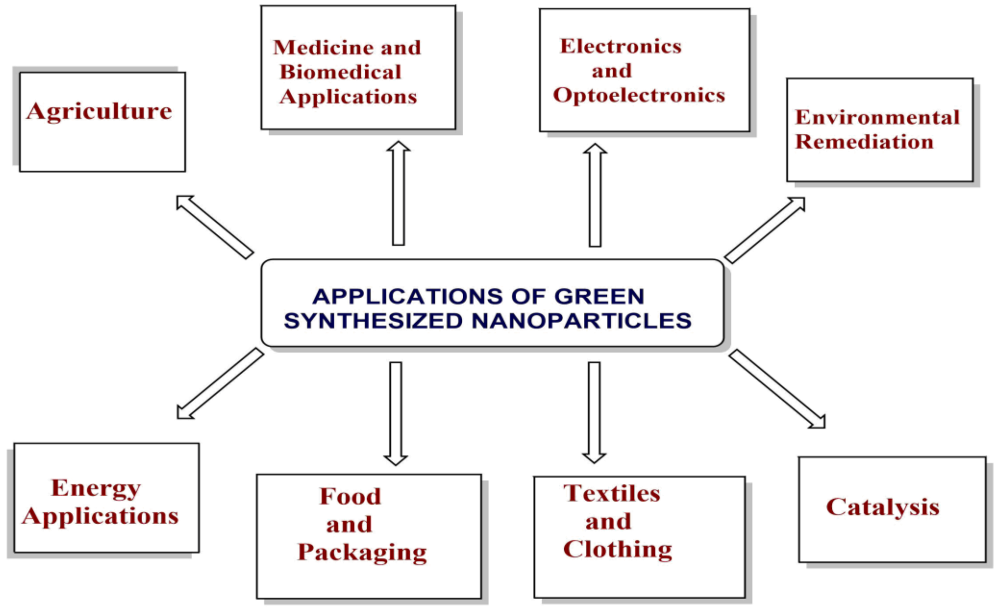

Fig.1- APPLICATION OF GREEN-SYNTHESIZEDNANOPARTICLES

6. CHALLENGES AND FUTURE PERSPECTIVES

S.NO.	TECHNIQUE	DATA RETRIEVE	REFERENCE
1.	Transmission Electron Microscope (TEM)	provides information about particle size, shape, and distribution	(Rice, S. B., et al 2013).
2.	Scanning Electron Microscopy (SEM)	provides surface information, particle size, and shape, but has a lower resolution compared to TEM	(Akhtar, K., et al 2018).
3.	Dynamic Light Scattering (DLS)	provides the hydrodynamic size distribution of nanoparticles in solution	(Hackley, V. A., & Clogston, J. D. (2011).
4.	X-ray Diffraction (XRD)	helps identify the crystalline phases and the average crystallite size of nanoparticles	(Sharma, R., et al 2012).
5.	Fourier Transform Infrared Spectroscopy (FTIR)	provides information about the chemical composition and surface functionalization of nanoparticles	(Dutta, A. (2017).
6.	UV-Visible Spectroscopy	Provides electronic and optical properties of nanoparticles	(Sarkar, R., et al 2010).
7.	Zeta Potential and Electrophoretic Mobility	helps understand nanoparticle stability and the likelihood of aggregation.	(Keller, A. A., et al 2010).
8.	Thermogravimetric Analysis (TGA)	presence of residual solvents or organic materials on the nanoparticle surface	(Prakash, A., et al 2009).

Green synthesis techniques face several challenges and limitations, including reproducibility, standardization, scalability, stability, and long-term storage. These challenges can be addressed through standardized protocols, continuous flow, and optimization of reaction parameters. Stability and long-term storage are also crucial, as green-synthesized nanoparticles may exhibit lower stability over time due to agglomeration or oxidation. Surface modifications or coatings can enhance the stability and dispersibility of green-synthesized nanoparticles, while research on new stabilizing agents or encapsulation techniques can improve their long-term storage properties. (Park, S., et al 2020).

Characterization and quality control are essential for understanding the properties and ensuring consistent quality. Advanced analytical techniques and in-situ characterization methods can provide real-time monitoring and better-quality control. A thorough evaluation of long-term biocompatibility and potential side effects in vivo is necessary for biomedical applications. Exploration of new green sources and materials, such as untapped plant species, microorganisms, or bio-waste materials, can lead to the discovery of novel green sources for nanoparticle synthesis. (Clijsters, S., et al 2014).

Multi-functional nanoparticles, such as imaging, drug delivery, and therapeutic capabilities, remain a complex task. Advances in nanotechnology and materials science can facilitate the engineering of multi-functional nanoparticles with precise control over their properties, opening new possibilities for personalized medicine and targeted therapies. (Van Vlerken, L. E., & Amiji, M. M.,2006).

Life cycle assessment is crucial for ensuring overall sustainability. Conducting life cycle assessments (LCAs) of green synthesis techniques can help identify potential environmental hotspots and guide the optimization of green nanoparticle production from a holistic perspective. Future research should focus on addressing these challenges and limitations, developing robust and scalable synthesis methods, advancing characterization techniques, exploring new green sources, and enhancing the application-specific properties of green-synthesized nanoparticles. Collaborative efforts among researchers, industry partners, and policymakers will drive innovation and realize the full potential of green synthesis techniques for sustainable nanotechnology applications. (Kralisch, D., Ott, D., & Gericke, D.,2015).

7. CONCLUSION

The review paper on green synthesis of nanoparticles highlights the importance of adopting environmentally friendly methods in nanoparticle production. Green synthesis offers significant environmental benefits, such as reduced energy consumption, elimination of hazardous chemicals, and waste reduction. This eco-friendly approach minimizes the environmental impact of conventional synthesis techniques and is suitable for various biomedical applications, such as drug delivery and bioimaging. Green-synthesized nanoparticles have potential applications in medicine, energy, and agriculture, enabling more effective therapies, improved solar cell efficiency, advanced batteries, and water purification. Furthermore, green synthesis contributes to a circular economy by recycling bio-waste materials and promoting sustainable resource utilization. In conclusion, green synthesis is a transformative and sustainable approach that addresses conventional methods and contributes to a greener, more environmentally conscious future.

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