

# Green Synthesis of Functional Nanomaterials for Biomedical Use

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**Keywords:** *Green nanotechnology, hazardous effect, non-toxic, environment*

## ABSTRACT

Green nanotechnology combines the principles of green chemistry and nanotechnology to bring about nanomaterials for various applications. By using eco-friendly and non-toxic approaches, the synthesise of nanomaterials has circumvented the effects of hazardous chemicals, unwieldy process and innocuous handling adhering to the sustainable developmental goals. Various sources such as plants, microbes, and animals are being used to synthesize nanoparticles, reducing the overall cost of production. Such nanoparticles have shown to report antimicrobial, anticancer, anti-diabetic, antioxidant and anti-inflammatory properties.

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## INTRODUCTION

Noble nanoparticles have a unique property like small size and large surface area. There are many methods for synthesizing the nanoparticle, the chemical reduction which are prevalently used and the physical method. These methods are extremely expensive and toxic in nature which cause potential environmental and biological risk (Forough and Farhadi, 2010). Green synthesis is a technique where the plant extracts are utilized to synthesize nanoparticles, as evidenced in a study using *Actaea racemosa* to produce commonly known as black cohosh silver nanoparticle (Okafor et al., 2013). Functionally, green-synthesized nanomaterials often exhibit the biocompatibility, reduced cytotoxicity and improved biological activity which is ecofriendly to the environment.

### Principles Of Green Nanotechnology

Existing nanotechnological innovations, despite enhanced advantages, face some major drawbacks and undesirable impacts on health and environment due to their nature, and synthesis approach, which yields toxicity, low yields, and generation of greenhouse gases (Dhingra et al., 2010; Hutchison, 2016). 'Green' principles focus on preventing any pollution due to chemical processes thereby eradicating environmental hazards (Soltys et al., 2021). It uses microbes, plants, viruses, proteins and lipids instead of expensive chemicals and high energy consumption (Zahra et al., 2024). Various types of nanoparticles are synthesized by green synthesis, based on the composition and functionality the types of functional nanomaterials are separated. Metal nanoparticles like silver, gold, copper nanoparticles are one of the most important nanomaterials used in biomedical therapies and widely synthesized by plant extract (Chandran et al., 2006; Samrot et al., 2019; Shende et al., 2015). Another common nanoparticle is carbon-based like carbon dots, graphene oxide, carbon nanotubes, these nanomaterials have unique property of optical and electricity property which enhance the bioimaging, biosensor development (Oliveira et al., 2018; Liu et al., 2017).

### The Mechanism Behind Green-Synthesized Functional Nanomaterials

The green synthesis mechanism involves the formation of nanoparticles using plant extract, bacteria, fungi, or algae instead of toxic chemical synthesis (Samrot et al., 2018; Zulfiqar et al., 2024; Ahmad et al., 2017; Bala et al., 2015; Rabiee, 2025). The crucial stages in the formation of nano sized particles are reduction, nucleation, and stabilization. Biomolecules like phenols, flavonoids, proteins and terpenoids present in the extract act as reducing agents, converting metal ions ( $Ag^+$ ,  $Au^{3+}$ ) into neutral metal atoms (Rabiee, 2025). Finally, the function of the biomolecules acts as stabilizing agents (Hashmat et al., 2025). Since all of these processes are inaudibly happening from the same substrate maintained at optimum conditions, this approach eliminates the use of heavy metals thereby reducing toxicity.

The crude gum of *A. heterophylla* have been used for the synthesis of nanoparticle and the nano-toxicity study was carried on earthworms and zebra fish (Samrot et al., 2019a). Samrot et al, (2018a) have examined the extracts of some edible fruit to synthesize silver nanoparticle. The nanoparticles are also synthesized by using micro-organisms, the metabolic activity of microbes that leads to the precipitation of nanoparticles (Sadowski et al., 2008; Singh et al., 2015).

### **Functional Properties Of Green-Synthesized Nanomaterials**

The research studies have been reported, that the green-synthesized nanomaterials from the biological extracts exhibit multifunctional properties. These nanomaterials have strong antimicrobial and anticancer activities (Samrot et al., 2018; Shrestha et al., 2025; Samrot et al., 2019), during synthesis these phytochemicals acts as a reducing and capping agents, which leads to increase the efficiency of the material. For example, plant-mediated silver (Ag) and zinc oxide (ZnO) nanoparticles, showed significant activities, such as antibacterial, antioxidant, and cytotoxic effects in various experimental models (Maind et al., 2025; Elmehalawy et al., 2025). Moreover, green synthesis methods are more effective compared to chemical synthesis methods because of their reduced toxicity and biocompatibility, which makes these nanomaterials more valuable for biomedical applications such as drug delivery and therapy (Ngangom et al., 2025; Lithi et al., 2025). Researches also highlights, the photocatalytic efficiency of green synthesized nanoparticles for environmental remediation, including dye reduction and pollutant removal, owing to their high surface area and active sites (Samrot et al., 2019; Lithi et al., 2025; Samrot et al 2018; RR et al., 2024; Shrestha et al., 2025). The functional properties like biological activity, biocompatibility, and catalytic performance, which exhibits the potential of green nanomaterials for sustainable biomedical and environmental technologies (Lithi et al., 2025; Shrestha et al., 2025). Recently, nanoparticles are widely studied as targeted drug delivery vehicles to improve efficacy and reduce side effects by enhancing cellular uptake and controlled release. Furthermore, their adjustable size and surface properties support advanced diagnostic imaging, biosensing, detection of disease precisely, and monitoring (Samuel et al., 2022; Samrot et al., 2018).

### **Advantages Of Green-Synthesized Nanomaterials In Biomedicine**

By synthesizing the nanoparticles using such green methods, their applications in biomedical fields increase. Green nanotechnology uses the eco-friendly, non-toxic, biocompatible and energy efficient principles of both green chemistry and engineering, which has given rise to the new domain 'green nanomedicine' (Naryal et al., 2024). Nanoparticles synthesized from green sources have showed antioxidant, anti-diabetic, and anti-inflammatory properties and are used in making antimicrobial agents, medical and electronic devices, as well as cancer therapy (Abuzeid et al., 2023).

## CONCLUSION

Green nanotechnology gives rise to advanced and enhanced nanomaterials made in an eco-friendly and non-toxic approach, which prevents any adverse and harmful effects to the environment. Such nanomaterials can be widely used in different kinds of biomedical applications such as drug delivery, medical and electronic devices, and medical imaging. This approach offers sustainability and biocompatibility rather than using conventionally fabricated nanoparticles.

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