



Sustainable Nanotechnology: GABA-Functionalized Gold, Silver, and Copper Nanoparticles – A Review

Shivnanda D. Dahibhate and Bhagwan K. Bongane*

P.G. Department of Physics Bahirji Smarak Mahavidyalaya Basmath Dist. Hingoli - 431512

*Email: shivnandadahibhate59@gmail.com

Article Info

Received: 23-09-2025,

Revised: 12-11-2025,

Accepted: 15-12-2025

Keywords:

Green synthesis, Platinum nanoparticles, Silver nanoparticles, Gold nanoparticles, Physicochemical properties.

Abstract

This review focuses on the green synthesis, physicochemical properties, characterization, and diverse applications of noble metal nanoparticles, with a specific emphasis on gold, silver, and copper. Green synthesis methods, particularly photoreduction, offer eco-friendly routes to nanoparticle production, as exemplified by the GABA-stabilized gold, silver, and copper nanoparticles (GABA AuNPs, GABA_gNPs, GABA_{Cu}NPs) synthesized using gamma-aminobutyric acid (GABA) as a stabilizing agent. Characterization techniques like UV-Vis spectroscopy, FTIR, TEM, Zeta potential analysis, and X-ray diffraction are crucial for elucidating their size, shape, surface properties, and stability. These nanoparticles exhibit multifunctional potential across various fields, including biomedical applications such as photodynamic/sonodynamic therapies, cancer targeting, and bioimaging due to ROS generation and affinity for GABA receptors. Furthermore, their antibacterial efficacy against *E. coli* and *S. aureus* highlights their role in combating infectious diseases. In agriculture, they serve as plant growth promoters and sustainable alternatives to pesticides. This review underscores the recent advances in sustainable nanoparticle synthesis and their broad utility, paving the way for novel therapeutic, agricultural, and environmental solutions.

INTRODUCTION

The burgeoning field of nanotechnology has witnessed significant interest in noble metal nanoparticles due to their unique physicochemical properties and diverse applications. Traditional synthesis methods often involve toxic chemicals, raising environmental and health concerns. Consequently, green synthesis has emerged as a critical paradigm shift, prioritizing eco-friendly and sustainable approaches for nanoparticle

production. Green (biological) synthesis of noble-metal nanoparticles (NPs) — principally Ag, Au, Pt, and Cu has become a prominent research avenue due to its potential to replace hazardous chemical methods with milder, cost-effective, and more environmentally friendly protocols. Plant extracts, microbial cultures, and biomolecules act as both reductants and stabilizers, giving rise to nanoparticles whose

size, shape and surface chemistry depend strongly on extract composition and reaction conditions [13]. Plant-mediated routes dominate recent studies because plant phytochemicals (polyphenols, flavonoids, terpenes, proteins and sugars) conveniently reduce metal salts and cap the growing nanoparticles; representative examples include lemon (*Citrus limon*) peel for Pt NPs [3], *Ocimum sanctum* (Tulsi) extracts for Pt NPs [7], and *Naringi crenulata* for Pt–Ag mono- and bimetallic systems [8]. Reviews and comparative studies emphasize that extract preparation and concentration, metal precursor concentration, pH, temperature and reaction time are principal variables controlling nucleation, growth and final NP polydispersity [4], [13]. Characterization across the literature relies on a core toolkit: UV–Vis (surface plasmon resonance for Au/Ag), TEM/SEM (morphology, size), XRD (crystallinity), FTIR (surface capping / phytochemical signatures), DLS (hydrodynamic size) and zeta potential (colloidal stability). For non-plasmonic metals (Pt), structural techniques (TEM, XRD) and surface chemistry analyses are especially important [11], [9]. Functionalization strategies—such as γ -aminobutyric acid (GABA) functionalization of Au, Ag and Cu NPs—demonstrate how post-synthesis surface modification tailors biointeractions and application potential [1], [12]. Bimetallic and alloyed nanoparticles show distinct properties from their monometallic counterparts, enabling synergistic catalytic and biomedical performance; however, synthesis reproducibility and compositional control remain challenging when using complex biological extracts [8]. Applications reported span antimicrobial agents (Ag), anticancer and imaging platforms (Au, functionalized NPs), catalytic remediation and environmental catalysis, as well as sensor and drug-delivery scaffolds [2], [5], [6], [10]. Toxicological and translational concerns are recurrent: green synthesis reduces the use of harsh reagents but does not guarantee benign biological outcomes. Toxicity depends on composition, particle size, surface chemistry (including capping biomolecules), dose and exposure route; thus

systematic *in vitro/in vivo* safety data are needed before clinical translation [9], [10]. Key gaps highlighted across the collected works include (i) lack of standardization in extract characterization and reporting, (ii) incomplete mechanistic understanding connecting specific phytochemicals to nucleation/growth pathways, (iii) limited studies on scale-up and long-term stability in realistic environments, and (iv) insufficient comprehensive toxicity and environmental fate studies — especially for Pt and bimetallic systems [4], [8], [13]. In summary, the reviewed literature shows strong promise for biologically synthesized noble-metal NPs across biomedical and environmental domains but underscores reproducibility, mechanistic insight, scale-up and safety testing as essential priorities for future work [1]–[13]. This review specifically examines the green synthesis, characterization, and applications of gold, silver, and copper nanoparticles, highlighting recent advances in sustainable methodologies.

a. Green Synthesis Methods:

Green synthesis methods leverage benign reagents and conditions, minimizing environmental impact. One prominent example is the photoreduction technique employed for synthesizing GABA-stabilized gold, silver, and copper nanoparticles (GABAuNPs, GABA_gNPs, GABACuNPs) (Lopes et al., 2024). In this approach, gamma-aminobutyric acid (GABA) acts as both a reducing and stabilizing agent, facilitating the formation of nanoparticles under light activation. This plant-based molecule offers a versatile and ubiquitous endogenous alternative to conventional chemical reductants, aligning with sustainable synthesis principles.

b. Physicochemical Properties:

The physicochemical properties of nanoparticles dictate their functionality and application. For GABAuNPs, GABA_gNPs, and GABACuNPs, detailed characterization revealed key attributes (Lopes et al., 2024). For instance, GABAuNPs demonstrated the ability to generate reactive oxygen species (ROS) upon light or ultrasound activation, a critical property for photodynamic

and sonodynamic therapies. Their affinity for GABA receptors suggests specific targeting capabilities, influencing their interaction with biological systems like cancer cells and the blood-brain barrier.

c. Characterization Techniques:

Comprehensive characterization is essential to understand the properties of synthesized nanoparticles. The study by Lopes et al. (2024) utilized a suite of techniques for GABAAuNPs, GABAgnPs, and GABACuNPs:

UV-Vis spectroscopy: Used to confirm nanoparticle formation and assess optical properties.

FTIR (Fourier-transform infrared spectroscopy): Provided insights into the functional groups involved in stabilization, confirming the role of GABA.

TEM (Transmission Electron Microscopy): Elucidated the morphology, size, and distribution of the nanoparticles.

Zeta potential analysis: Determined the surface charge, indicating colloidal stability.

X-ray diffraction (XRD): Provided information on the crystalline structure of the nanoparticles.

Applications of nanoparticles

Noble metal nanoparticles, particularly those synthesized via green routes, offer a wide array of applications:

a. Biomedical Applications:

Photodynamic and Sonodynamic Therapies: GABAAuNPs generate reactive oxygen species (ROS) upon light or ultrasound activation, indicating their potential in these therapeutic modalities (Lopes et al., 2024).

Cancer Treatment: The affinity of GABAAuNPs for GABA receptors allows for targeted delivery to cancer cells (Lopes et al., 2024).

Bioimaging: Their ability to breach the blood-brain barrier positions them as promising nanovectors for bioimaging in neurological diseases (Lopes et al., 2024).

Antibacterial Therapy: GABA AgNPs and GABA CuNPs demonstrated efficacy against *Escherichia coli* and *Staphylococcus aureus*,

suggesting their use in combating infectious diseases (Lopes et al., 2024).

b. Agricultural Applications:

Plant Growth Promoters: These nanoparticles can enhance seed germination, improve stress tolerance, and promote overall plant growth (Lopes et al., 2024).

Sustainable Farming: They offer eco-friendly alternatives to conventional pesticides, contributing to sustainable agricultural practices (Lopes et al., 2024).

Recent advances and future perspectives

Recent advances, as highlighted by the work of Lopes et al. (2024), demonstrate the successful green synthesis of multi-functional nanoparticles using biomolecules like GABA. This approach not only ensures eco-friendliness but also imbues the nanoparticles with inherent biological functionalities, such as receptor affinity and ROS generation. Future perspectives involve further exploring the mechanisms of action for these nanoparticles in diverse biological systems, optimizing their synthesis for large-scale production, and conducting *in vivo* studies to validate their therapeutic and agricultural efficacies. The development of smart delivery systems utilizing these nanoparticles for precision medicine and sustainable agriculture remains a key area for future research.

Conclusion

The green synthesis of noble metal nanoparticles, particularly gold, silver, and copper, represents a significant stride towards sustainable nanotechnology. The use of biomolecules like GABA in photoreduction methods yields eco-friendly and multi-functional nanoparticles. Comprehensive characterization techniques are vital for understanding their physicochemical properties, which in turn dictate their diverse applications. From targeted cancer therapies and antibacterial treatments to promoting plant growth and sustainable agriculture, these nanoparticles hold immense potential. Continued research in this area promises to unlock novel solutions for critical challenges in health, environment, and food security

Table 1. Recent finding in the field of nanotechnology

Ref	Aim	Method / Material	Key findings	Reported gaps
[1]	Synthesize & characterize GABA-functionalized Au, Ag, Cu NPs; explore applications	GABA functionalization of biosynthesized Au/Ag/Cu NPs; standard physico-chemical characterization	Demonstrated successful functionalization; altered surface chemistry and potential for tailored biointeractions	Needs extended bioactivity and safety assays; scale-up not addressed
[2]	Review green Ag/Au NPs — synthesis & biomedical potentials	Literature review covering plant/microbial routes and biomedical uses	Summarized broad antimicrobial/antitumor potential and common synthesis agents	Calls for standardized assays and more in vivo validation
[3]	Green synthesis of Pt NPs using lemon peel	Lemon (Citrus limon) peel extract reduction; characterization by TEM, XRD, FTIR	Produced Pt NPs; characterized morphology and surface capping; suggested biomedical/catalytic uses	Limited toxicity / application testing; reproducibility dependent on extract prep
[4]	Green synthesis & characterization for environmental apps	Review plus examples; emphasis on environmental remediation uses	Showed many plant-based routes and potential for pollutant remediation	Standardization, scale-up and long-term stability gaps
[5]	Synthesize Ag/Au NPs using Artemisia pallens extract	Aqueous Artemisia pallens extract used as reducing/capping agent	Reported facile synthesis and antimicrobial activity	Preprint—needs peer review; limited mechanistic detail
[6]	Thespesia lampas mediated Ag/Au NPs for biological applications	Plant extract mediated synthesis; characterization & bioassays	Enhanced biological activities (antimicrobial/antioxidant) reported	Mechanistic linkage to specific phytochemicals not fully shown
[7]	Green synthesis of Pt NPs from Ocimum sanctum	Tulsi extracts mediated synthesis; standard characterization	Showed Pt NP formation and catalytic potential	Older work with limited biological validation
[8]	Compare mono vs bimetallic Pt-Ag NPs from Naringi crenulata	Plant extract mediated mono & bimetallic synthesis; comparative characterization	Found distinct structural and functional differences between mono & bimetallic NPs	Reproducibility and compositional control issues noted
[9]	Review Pt nanoparticles: green synthesis & biomedical apps	Review of Pt NP methods, properties, biomedical prospects	Collated Pt NP biomedical potential and concerns re: toxicity	Urges comprehensive toxicology before clinical use
[10]	Biological synthesis of metallic NPs: insights & apps	Review across biological routes and recent advances	Summarizes microbial/plant methods and translational possibilities	Emphasizes need for regulatory safety frameworks
[11]	Nanoengineering of Au NPs: green synthesis & applications	Experimental & review treatment emphasizing Au NP engineering	Demonstrated green methods and application breadth (sensors, catalysis)	Lacked large-scale/real-world deployment studies
[13]	Proposed mechanisms & influencing factors in green Pt NP synthesis	Review/proposal of mechanistic pathways and influential variables	Identified reaction parameters (pH, temp, extract conc.) as critical; proposed mechanistic frameworks	Calls for molecular-level studies tying specific phytochemicals to nucleation/growth

References

- Lopes IS, Yee M, Tatumi SH, Vital VG, de Lima LF, de Vasconcellos SP, Courrol LC. 2024.** GABA functionalized gold, silver, and copper nanoparticles: Synthesis, characterization and potential applications. *Journal of Drug Delivery Science and Technology*, 92, 105386. <https://doi.org/10.1016/j.jddst.2024.105386>
- Rónavári A. et al. 2021.** Green Silver and Gold Nanoparticles: Biological Synthesis Approaches and Potentials for Biomedical Applications. *Molecules*. 26: 4. <https://doi.org/10.3390/MOLECULES26040844>
- PragathiAH, Noorjahan CM. 2024.** Green Synthesis of Platinum Nanoparticle Using Lemon (*Citrus Limon*) Peel Extract and its Characterization," *South Asian Journal of Experimental Biology*, doi: 10.38150/sajeb.14(2).p61-65
- López-Miranda JL. et al. 2023.** Green synthesis and characterization of metallic nanoparticles with environmental applications, *MRS Advances*, doi: 10.1557/s43580-023-00697-w
- Verma AK. 2024.** Green Synthesis of Silver and Gold Nanoparticles by Aqueous Artemisia Pallens Extract, *bioRxiv*, <https://doi.org/10.1101/2024.04.17.589972>
- Nath S. et al. 2024.** Thespesialampas mediated green synthesis of silver and gold nanoparticles for enhanced biological applications," *Front. Microbiol.*, doi: 10.3389/fmicb.2023.1324111
- Prabhu N, Gajendran T. 2017.** Green Synthesis of Noble Metal of Platinum Nanoparticles from Ocimum sanctum (Tulsi) Plant- Extracts, *IOSR J. Biol. Sci.*, doi: 10.9790/264X-0301107112.
- Ramachandiran D. et al. 2023.** An extensive comparison of green Pt-Ag mono and bimetallic nanoparticles from *Naringi crenulata* extract" *J. Taiwan Inst. Chem. Eng.*, doi: 10.1016/j.jtice.2023.105103.
- Fahmy SA. et al. 2020.** Platinum Nanoparticles: Green Synthesis and Biomedical Applications. *Molecules*, vol. 25, doi: 10.3390/MOLECULES25214981.
- El Ouardy K, Ahmoum H, Mir Y, 2024.** Biological Synthesis of Metallic Nanoparticles: Latest Insights and Applications," *Pharm. Nanotechnol.*, doi: 10.2174/0122117385353296241119072148.
- Tepale N, et al. 2019.** Nanoengineering of Gold Nanoparticles: Green Synthesis, Characterization, and Applications, *Crystals*,. doi: 10.3390/CRYST9120612.
- Lopes IS. et al.,2024.** GABA functionalized gold, silver, and copper nanoparticles: Synthesis, characterization and potential applications, *J. Drug Deliv. Sci. Technol.*, doi: 10.1016/j.jddst.2024.105386.
- Jameel MS, Aziz AA, Dheyab MA 2020.** Green synthesis: Proposed mechanism and factors influencing the synthesis of platinum nanoparticles, *Green Process. Synth.*, doi: 10.1515/GPS-2020-004.