CITE PUBLICATIONS
Journal of Innovative Pharma and Drug Sciences
Volume: 1, Issue: 1, 2026 (January - June), Pages: 1-5
DOI: https://doi.org/10.37446/jipds/ra/1.1.2026.1-5
Research Article

Green Synthesis of Nanoparticles from *Musa paradisiaca:* Comprehensive Review

Aswini Jeeva Ramesh[2], Mercy Madhumitha Kings[1], Anbumalarmathi Jeyabaskaran[1*], Sathya Bama S[2]

[1]Department of Biotechnology, Stella Maris College (Autonomous), Chennai – 600086, India.
[2]Department of Botany, Stella Maris College (Autonomous), Chennai – 600086, India.

[*]**Correspondence**
Anbumalarmathi Jeyabaskaran
amalarmathi@gmail.com

Received: 3 January 2026 / Accepted: April 2026 / Published: 30 June 2026

Nanotechnology, an interdisciplinary and fast-advancing field, deals largely with particles whose dimensions fall between 1 and 100 nm, valued for the distinctive optical, physicochemical, and biological behavior that emerges at this scale. Green synthesis routes rely on plant- and fruit-derived reagents that are inexpensive, renewable, and lower in toxicity than conventional chemical precursors, and such biologically produced nanoparticles tend to be more stable and quicker to form. Because they are highly biocompatible, green-synthesized nanoparticles find use across a wide span of biomedical and pharmaceutical settings. Metal oxide nanoparticles, in particular, display strong catalytic behavior and are routinely applied to neutralize toxic or hazardous substances, especially where environmental safety is a concern. Gold, aluminium, zinc, copper, titanium, iron, and silver are among the metals most frequently exploited for nanoparticle fabrication, with several standing out for their broad relevance in biomedicine; zinc oxide nanoparticles (ZnONPs), for instance, are extensively incorporated into food-packaging materials and into paint and varnish formulations. The plant at the centre of this review, Musa paradisiaca (locally called virupakshi), serves as a key raw material for producing several nanoparticle types, including those of silver, gold, iron oxide, copper oxide, and zinc oxide. Traditionally, this plant has been employed to manage ailments such as diabetes, diarrhoea, hypertension, ulcers, and inflammation, a therapeutic profile attributed to bioactive constituents that impart antioxidant, antibacterial, wound-healing, and anti-diarrhoeal effects. In this review, ZnONPs synthesized from Musa paradisiaca peel extract are examined for their relevance to biology, biomedicine, environmental remediation, industry, agriculture, and food science.

Keywords: green-synthesized, *Musa paradisiaca,* antioxidant, antibacterial, nanotechnology, sustainable

Introduction

Owing to their distinctive optical, biological, and physicochemical characteristics, nanoparticles have found application across numerous domains. Their fabrication draws on physical, chemical, and biological routes (Bayada et al., 2019; Joudeh et al., 2022). Physical methods are constrained by heavy energy demands, difficulty in scaling up, and contamination risk, while chemical routes bring their own drawbacks, namely toxicity, hazardous by-products, particle clumping, and contamination issues. Biological synthesis, by contrast, typically harnesses microorganisms, fungi, algae, or plant material. Because green methods depend on reagents that are less toxic, cheaper, renewable, and environmentally benign (Singh et al., 2018), the resulting particles tend to be more stable, and plant-mediated synthesis generally proceeds faster than alternative approaches. A further advantage of nanoparticles over their bulk counterparts is the markedly larger surface-area-to-volume ratio, which lets them function more efficiently as active agents. Metal oxides commonly assemble into densely packed structures and are noted for antimicrobial, magnetic, and catalytic behaviour (Vijayakumar et al., 2018). Gold, aluminium, zinc, copper, titanium, iron, and silver are the metals most often chosen for such synthesis, and a subset of these carries particular weight in biomedical contexts owing to their broad applicability (Dikshit et al., 2021; Mabrouk et al., 2021; Kvenkat et al., 2015; Zorraquin et al., 2020). Several also absorb harmful UV radiation, a property that underlies their use in sunscreens and cosmetic products (Vijayakumar et al., 2016). The catalytic capacity of metal oxide nanoparticles is frequently exploited to break down toxic compounds, particularly for environmental-safety purposes (Santhosh et al., 2017), and in the specific case of ZnONPs this catalytic ability stems from their crystal structure, porosity, surface area, and band gap, features that make them effective agents for photocatalytic degradation (Ashwarya et al., 2018).

Musa paradisiaca, known locally as virupakshi and belonging to the genus Musa within the Musaceae family, is native to Southeast Asia but is now grown worldwide. Beyond its role as a substrate for green nanoparticle synthesis, the plant has a long history in folk medicine for treating diabetes, diarrhoea, hypertension, ulcers, and inflammation, credited to antioxidant, antibacterial, wound-healing, and anti-diarrhoeal properties arising from bioactive molecules such as polyphenols, flavonoids, and dietary fibre. Virtually every part of the plant, fruit, peel, flowers, leaves, and roots, has traditional uses ranging from digestive remedies to treatment for snakebite, functioning variously as an astringent, demulcent, or general nutrient source. The peel specifically is rich in phenolic constituents (gallic acid, flavonoids, tannins, catechins), along with alkaloids, saponins, and terpenoids that contribute to its antioxidant and antimicrobial character, and it further supplies dietary fibre, carbohydrates, fatty acids, and minerals of nutraceutical and industrial value. More broadly, banana peel contains phenolics (flavonoids, tannins, catechins, gallic and ferulic acids), fibre, carbohydrates, proteins, lipids, minerals such as potassium and magnesium, and vitamins, together with saponins and other bioactives responsible for antioxidant, antimicrobial, and antifungal activity, benefits that extend to anti-ulcer, anti-diabetic, hypolipidemic, wound-healing, hepatoprotective, and anticancer effects. Zinc oxide nanoparticles generate elevated intracellular reactive oxygen species, including superoxide anion, hydrogen peroxide, and hydroxyl radicals, giving them broad antimicrobial activity against diverse pathogens. This review therefore focuses on ZnONPs synthesized from Musa paradisiaca peel and their documented roles in biology, biomedicine, environmental applications, industry, agriculture, and food science (Aswathi et al., 2022; Saffar et al., 2021; Hassan-Basari et al., 2020).

Synthesis, Characterization and Application

Banana peels were rinsed thoroughly under running water, cut into small pieces, and air-dried at ambient temperature overnight. The dried peel material was subsequently heated to 70 °C with magnetic stirring at 1000 rpm, after which the resulting liquid was passed through Whatman No. 1 filter paper (Jamdagni et al., 2018). The zinc oxide nanoparticles were produced by a co-precipitation route: peel extract was added dropwise to a zinc salt solution, and the mixture was heated on a magnetic stirrer at 100 °C until a white precipitate appeared. This precipitate was recovered by centrifugation at 10,000 rpm, washed with distilled water and ethanol, and then calcined in a muffle furnace at 200 °C for two hours (Malaikozhunhundan et al., 2017). Characterization involved UV-spectrophotometry (Elico) across 250-400 nm to assess optical behaviour, FTIR analysis in the same wavelength range to identify functional groups, and scanning electron microscopy (SEM) to determine particle shape and size. Elemental composition was verified through energy-dispersive X-ray spectroscopy (EDX) (Shanmugam et al., 2023), and particle size was calculated using the Debye-Scherrer equation.

Antibacterial Activity

Compared with unprocessed crude extracts, ZnO nanoparticles show markedly stronger antibacterial action, a consequence of their nanoscale dimensions, large surface area, and ability to release Zn2+ ions that damage bacterial membranes and enzymatic machinery. Mediavilla et al. (2025) reported that ZnO-ZnS composites made from banana peel strongly suppressed both E. coli and Staphylococcus aureus, while Rattanaburi et al. (2025) showed that cotton fabric treated with banana-peel-derived ZnONPs gained antibacterial properties suited to biomedical use. Likewise, Krishna et al. (2024) found that ZnO nanoparticles produced from medicinal leaf extracts outperformed the corresponding crude extracts in antibacterial potency, underscoring the benefit of nanoparticle-based formulations, and Lavanya et al. (2025) confirmed broad-spectrum activity for ZnO nanoparticles derived from Oxalis stricta and betel leaf that paralleled the results obtained here. The heightened antibacterial performance of banana-peel-derived ZnONPs can be traced to a combination of ion release and reactive-oxygen-species (ROS) generation, which together induce oxidative stress and structural damage within bacterial cells, mechanisms that jointly explain the consistent inhibition observed across the strains tested in this body of work. Taken together, the literature supports banana peel, an abundant agricultural by-product, as an eco-friendly precursor for nanoparticle fabrication, consistent with global efforts toward greener nanotechnology.

Antioxidant Activity (ABTS & DPPH)

DPPH assays consistently confirm antioxidant activity in these nanoparticles, an enhancement attributed to increased surface area, more efficient electron transfer, and the stabilizing influence of banana-peel phytochemicals acting as capping agents. Bhole et al. (2025) observed that ZnO nanoparticles made from banana peel waste scavenged DPPH radicals more effectively than the crude extract alone, and Jovanović et al. (2024) similarly noted that plant-derived ZnO nanostructures generally outperform crude extracts because of nanoscale effects combined with surface-bound bioactive compounds. Studies on agro-waste-derived ZnO nanoparticles likewise report lower IC50 values relative to the parent extracts, reinforcing the idea that green synthesis both repurposes waste material and yields nanomaterials with improved antioxidant capacity. These results collectively point to banana-peel-mediated ZnO nanoparticles as promising candidates for antioxidant applications in biomedical and food-related sectors. For ABTS scavenging, Al-Khaial et al. (2024) reported greater activity for banana-peel-derived ZnO nanoparticles than for the crude extract, with an IC50 near 30 µg/mL; Islam et al. (2025) found IC50 values of 25-32 µg/mL for banana-peel pectin-ZnO nanoparticles, again exceeding the extract's performance; and Balasubramaniyam et al. (2025) reported over 80% inhibition at 100 µg/mL for Musa paradisiaca leaf-ZnO nanoparticles, with an IC50 close to 27 µg/mL. Collectively, these figures confirm that ZnO nanoparticles synthesized from agro-waste display stronger antioxidant capacity than the corresponding crude extracts.

Antidiabetic Activity

The nanoscale size and enlarged surface area of ZnO nanoparticles improve their attachment to target enzymes, strengthening inhibitory interactions, while phytochemicals from banana peel act as capping agents that further boost this activity. Al-Khaial et al. (2024) found that banana-peel-derived ZnO nanoparticles inhibited α-amylase considerably more than the crude extract, with IC50 values near 40 µg/mL; Rehana et al. (2017) reported strong α-amylase inhibition (38-45 µg/mL) for ZnO nanoparticles synthesized from Azadirachta and Hibiscus extracts; and Khan et al. (2025) recorded an IC50 near 41 µg/mL for Cydonia graveolens leaf-ZnO nanoparticles, again surpassing the crude extract's effectiveness.

Anti-Inflammatory Activity

Across the albumin denaturation assay, these nanoparticles exhibit anti-inflammatory effects that scale with concentration, indicating that nanoparticle formation amplifies the intrinsic bioactivity of banana-peel phytochemicals, likely through increased surface area, greater structural stability, and stronger interaction with target proteins, plant-derived ZnO nanoparticles generally show superior anti-inflammatory outcomes relative to crude extracts. For example, ZnO nanoparticles synthesized from Musa paradisiaca produced more effective protein-denaturation inhibition than those derived from leaves or peels of other sources, whereas ZnO nanoparticles from Fe'i and Cavendish banana varieties showed improved anti-inflammatory outcomes in zebrafish models. Broader evaluation of green-synthesized ZnO nanoparticles indicates that phytochemical-capped nanostructures consistently outperform crude plant extracts in anti-inflammatory efficacy, typically yielding IC50 values in the 65-75 µg/mL range.

Seed Germination

Germination studies involving banana-peel-extract-mediated ZnO nanoparticles reveal a clear dose-dependency in green gram development: extract-derived ZnO nanoparticles promote stronger seedling vigour in cereals and legumes at optimal concentrations, but higher doses suppress growth owing to excess zinc-ion release and nanoparticle aggregation. Work carried out between 2023 and 2024 similarly highlights banana peel extract as a sustainable capping agent, rich in phytochemicals and minerals, that stabilizes nanoparticles and improves their biocompatibility. Studies involving Vigna species and millet further show that, applied at appropriate concentrations, these nanoparticles enhance both germination rate and shoot length.

Conclusion

This review underscores the potential of green synthesis, particularly of zinc oxide nanoparticles (ZnONPs), derived from Musa paradisiaca (banana peel) as a sustainable and eco-friendly alternative to conventional physical and chemical fabrication routes. Banana peel, an abundant agricultural waste stream, is rich in phytochemicals that act as natural reducing and stabilizing agents, supporting efficient nanoparticle formation while limiting toxicity and environmental impact. ZnONPs produced from banana peel display a range of biological activities, spanning antibacterial, antioxidant, antidiabetic, and anti-inflammatory effects, alongside promising uses in seed germination and agriculture. Their small size, expansive surface area, and phytochemical stabilization elevate their bioactivity relative to unprocessed extracts, positioning them for use in biomedical, pharmaceutical, environmental, and industrial contexts. Overall, banana-peel-mediated ZnONPs exemplify how waste valorization can be paired with nanotechnology in support of global sustainability goals. Future work should prioritize refining synthesis protocols, improve reproducibility, and exploring clinical and industrial applications so that the full potential of green-synthesized nanoparticles can be realized.

Acknowledgment

The authors sincerely thank the Principal and the Management of Stella Maris College (Autonomous), Chennai, for their continuous support and for providing the necessary research facilities.

Author contributions

Concept and study design: Mercy Madhumitha Kings, Anbumalarmathi Jeyabaskaran, Sathya Bama S

Data collection: Aswini Jeeva Ramesh

Funding

No funding.

Conflict of interest

The author declared no conflict of interest.

Ethics approval

NA

AI tool usage declaration

No AI tool was used in manuscript preparation.

References

Singh, Dutta, Kim, Rawat, Samddar, & Kumar, (2018). ‘Green’synthesis of metals and their oxide nanoparticles: applications for environmental remediation. *Journal of nanobiotechnology*, *16*(1), 84.

Santhoshkumar, Kumar, & Rajeshkumar, (2017). Synthesis of zinc oxide nanoparticles using plant leaf extract against urinary tract infection pathogen. *Resource-Efficient Technologies*, *3*(4), 459-465.

Dikshit, Kumar, Das, Sadhu, Sharma, Singh, & Kim, (2021). Green synthesis of metallic nanoparticles: applications and limitations. *Catalysts*, *11*(8), 902.

Mabrouk, Das, Salem, & Beherei, (2021). Nanomaterials for biomedical applications: production, characterisations, recent trends and difficulties. *Molecules*, *26*(4), 1077

Jamdagni, Khatri, & Rana, (2018). Green synthesis of zinc oxide nanoparticles using flower extract of Nyctanthes arbor-tristis and their antifungal activity. *Journal of King Saud University-Science*, *30*(2), 168-175.

Aswathi, Meera, Maria, & Nidhin, (2023). Green synthesis of nanoparticles from biodegradable waste extracts and their applications: a critical review. *Nanotechnology for Environmental Engineering*, *8*(2), 377-397.

Bayda, S., Adeel, M., Tuccinardi, T., Cordani, M., & Rizzolio, F. (2019). The history of nanoscience and nanotechnology: from chemical–physical applications to nanomedicine. *Molecules*, *25*(1), 112.

Malaikozhundan, Vaseeharan, Vijayakumar, Pandiselvi, Kalanjiam, Murugan, & Benelli, (2017). Biological therapeutics of Pongamia pinnata coated zinc oxide nanoparticles against clinically important pathogenic bacteria, fungi and MCF-7 breast cancer cells. *Microbial pathogenesis*, *104*, 268-277.

Shanmugam, Christiana, Kesavan, Anbumalarmathi, Balaji, Gopal, & Vijayakumar, (2025). Biosynthesis of Malus pumila extract mediated silver nanoparticles and study on its biomedical application. *Biomass Conversion and Biorefinery*, *15*(19), 26565-26578.

Mediavilla, Valencia, Quiroz-Vela, Zúñiga-Benítez, Villa, & Peñuela, (2025). Antimicrobial and Photocatalytic Potential of a Composite of ZnO-ZnS and Activated Carbon Obtained From Banana Peel. *Water, Air, & Soil Pollution*, *236*(9), 578.

Rattanaburi, Porrawatkul, Pimsen, Tongsom, Nuengmatcha, & Khongsai, (2025). Multifunctional Cotton Fabrics Coated with Banana Peel-Synthesized ZnO Nanoparticles. *Trends in Sciences*, *22*(6), 9852-9852.

Krishna, Raju, Lakshmi, Hanumanthu, & Begum, Green Synthesis of ZnO Nanoparticles Using Five Medicinal Leaf Extracts: A Comparative Review on Physicochemical and Biological Properties.

Lavanya, Aparna, Reddy, & Ramana, (2026). Green-Synthesized ZnO nanoparticles from plant extracts: Characterization, photo catalytic activity, and antibacterial activity. *Ionics*, *32*(1), 849-866.

Mutukwa, Taziwa, & Khotseng, (2024). A review of plant-mediated ZnO nanoparticles for photodegradation and antibacterial applications. *Nanomaterials*, *14*(14), 1182.

Jovanović, Bognár, Despotović, Finčur, Jakšić, Putnik, & Šojić Merkulov, D. (2024). Banana peel extract-derived ZnO nanopowder: Transforming solar water purification for safer agri-food production. *Foods*, *13*(16), 2643.

Al-Khaial, Chan, Abu-Zurayk, & Alnairat, (2024). Biosynthesis and characterization of zinc oxide nanoparticles (ZnO-NPs) utilizing banana peel extract. *Inorganics*, *12*(4), 121.

Islam, Mustak, Shishir, Karim, & Khan, (2025). Biosynthesis of ZnO nanoparticles using banana peel pectin for antibacterial and photocatalytic applications. *South African Journal of Chemical Engineering*, *52*(1), 127-140.