



Research Paper**Comparative Procedures for Rapid, Efficient, and Environmentally Friendly Green
Synthesis of Nanoparticles Using Plant Extracts: Sustainable Approaches for
Environmental Applications****Chetan S. Sontakke**Chetas1432@gmail.com**Abstract**

A viable substitute for traditional physical and chemical production methods, green synthesis of nanoparticles (NPs) using plant extracts provides a quicker, less expensive, non-toxic, and ecologically safe option to create functional nanomaterials. The physical, chemical, and plant-extract-mediated biological synthesis methods for metal and metal-oxide nanoparticles are compared in this study, with a focus on process parameters and reaction processes. The effects of pH, temperature, extract concentration, precursor concentration, and reaction time on nanoparticle size, shape, and yield are examined, as well as the functions of phytochemicals flavonoids, polyphenols, terpenoids, alkaloids, and proteins as reducing and capping agents. Along with important characterisation methods (UV-Vis, FTIR, XRD, electron microscopy, DLS), synthesis approaches for silver, zinc oxide, copper/copper oxide, iron oxide, gold, and titanium dioxide nanoparticles are analyzed. Water disinfection, heavy-metal adsorption, photocatalytic dye degradation, and agricultural pest control are among the environmental applications that are reviewed. In its conclusion, the analysis identifies issues that hinder industrial adoption, such as batch variability, inadequate mechanistic knowledge, and scale-up concerns. It also suggests ways to standardize the manufacturing of green nanoparticles.

Keywords: *green synthesis; nanoparticles; plant extract; phytochemicals; comparative synthesis; environmental remediation.*

1. Introduction

One of the most revolutionary scientific fields of the twenty-first century is nanotechnology, which makes it possible to create materials with characteristics that are significantly different from those of their bulk equivalents because of their nanoscale dimensions, which are usually between 1 and 100 nm (Iravani, 2011). According to Ahmed, Annu, Ikram, and Yudha (2016), nanoparticles (NPs) are useful in the fields of medicine, agriculture, electronics, and environmental engineering due to their increased surface-area-to-volume ratio, improved reactivity, and adjustable optical, electrical, and catalytic capabilities.

Physical and chemical techniques are the two main categories of conventional approaches to nanoparticle manufacturing. Physical methods like ball milling, laser ablation, and vapor deposition can create very pure nanoparticles with a narrow size distribution, but they usually ask for costly machinery, a lot of energy, and high pressures or temperatures (Mittal, Chisti, & Banerjee, 2013). Chemical processes, such as chemical reduction, sol-gel processing, and co-precipitation, enable quick mass production and exact control of size and shape, but they frequently depend on organic solvents, stabilizers, and hazardous reducing agents that produce toxic byproducts and raise questions about biological safety and environmental contamination (Ahmed et al., 2016; Raveendran, Fu, & Wallen, 2003).

These restrictions have sparked interest in "green" or "biological" synthesis, which makes use of natural supplies of reducing and capping agents found in plants, bacteria, fungus, and algae (Makarov et al., 2014). Because plants are readily available, affordable, safe to handle, and abundant in a variety of phytochemicals like flavonoids, polyphenols, alkaloids, terpenoids, and proteins that can simultaneously reduce metal ions and stabilize the resulting nanoparticles in a single step, plant-extract-mediated synthesis is particularly appealing among biological routes (Shah, Fawcett, Sharma, Tripathy, & Poinern, 2015; Mohamad, Arham, Jai, & Hadi, 2014). Plant-mediated methods are often quicker, more scalable, and do not require the culture-maintenance associated with bacteria and fungus, in contrast to microbial synthesis (Iravani, 2011).

This review compares the principal procedures used for the green synthesis of nanoparticles using plant extracts, discusses how synthesis parameters govern process speed, yield, and product quality, and evaluates the growing body of evidence on the use of such nanoparticles for environmental applications, including wastewater treatment, dye degradation, and heavy-metal remediation.

2. Overview of Nanoparticle Synthesis Approaches

2.1 Physical Methods

Physical techniques produce nanoparticles by either vapor-phase condensation or top-down fragmentation of bulk material. Arc discharge, thermal evaporation, sputtering, ball milling, and laser ablation are common methods. Although these techniques can produce nanoparticles free of chemical contamination and achieve precise control over particle size distribution, they are energy intensive, require complex equipment, and are typically not appropriate for large-scale, low-cost production (Mittal et al., 2013; Ahmed et al., 2016).

2.2 Chemical Methods

Chemical reduction, sol-gel synthesis, hydrothermal and solvothermal procedures, micro emulsion methods, and electrochemical deposition are all part of chemical synthesis, which is still the most popular bottom-up process. These methods usually combine stabilizers like polyvinylpyrrolidone or sodium citrate with reducing agents like sodium borohydride or hydrazine. Chemical techniques provide quick, high-yield manufacture with a fair degree of morphological control; nevertheless, the chemicals used are often hazardous, combustible, or non-biodegradable, and disposing of them has a substantial negative impact on the environment (Raveendran et al., 2003; Gnanasangeetha & Sarala Thambavani, 2013).

2.3 Biological (Green) Methods

Microorganisms, algae, or plant extracts are used as bioreduction agents in biological synthesis. Despite being environmentally benign, microbial synthesis is frequently sluggish due to its reliance on cell multiplication, enzyme activity, and carefully regulated culture conditions. It may also require extra purification procedures to extract nanoparticles from biomass (Hulkoti & Taranath, 2014). Plant-extract-mediated synthesis produces nanoparticles that are naturally capped with biomolecules that enhance colloidal stability and, in some cases, confer additional bioactivity. It also proceeds quickly at ambient or slightly elevated temperatures and eliminates the need for aseptic culture maintenance (Das & Chatterjee, 2019; Pal, Rai, & Pandey, 2019).

2.4 Comparative Summary of Synthesis Approaches

Table 1 summarizes the relative characteristics of physical, chemical, and plant-mediated green synthesis routes based on process attributes reported across the literature reviewed above.

Attribute	Physical Methods	Chemical Methods	Plant-Extract Green Synthesis
Typical reaction time	Minutes to hours; requires specialized equipment run-time	Minutes to a few hours	Minutes to a few hours; comparable or faster than chemical routes for many metals
Capital/operating cost	High (vacuum systems, lasers, mills)	Moderate (reagents, solvents)	Low (aqueous extract, ambient conditions)
Energy requirement	Very high (high temperature/pressure, vacuum)	Moderate	Low (often ambient to ~80 °C)
Toxic byproducts	Minimal, but energy footprint is high	Significant (reducing agents, solvents, capping chemicals)	Minimal; extract residues are largely biodegradable
Size/shape control	High precision	High precision	Moderate; depends on phytochemical profile and reaction parameters
Scalability	Limited by equipment cost	Good, but generates hazardous waste at scale	Good; limited mainly by extract standardization
Biocompatibility of product	Variable	Often requires post-synthesis purification	Generally high due to natural capping agents

Sources: Iravani (2011); Mittal et al. (2013); Ahmed et al. (2016); Makarov et al. (2014); Shah et al. (2015).

3. Mechanism of Plant-Extract-Mediated Green Synthesis

Three main phases are involved in the formation of nanoparticles in plant extracts: an activation phase where metal ions are reduced and nucleation centers form, a growth phase where neighboring nuclei combine to form larger particles, and a termination phase where phytochemicals adsorb onto the particle surface and stop further growth, establishing the final shape and size (Makarov et al., 2014).

Flavonoids, polyphenols, terpenoids, alkaloids, and proteins are frequently linked to bio-reduction, albeit the specific phytochemicals involved depend on the kind of plant and the extraction technique. These molecules' hydroxyl and carbonyl groups donate electrons that reduce metal ions (such as Ag^+ to Ag^0 or Cu^{2+} to Cu^0). The same or additional functional groups then attach to the surface of the nanoparticle and act as capping agents, preventing agglomeration and providing colloidal stability (Ahmed et al., 2016; Shah et al., 2015). Studies of plant-derived nanoparticles using Fourier-transform infrared spectroscopy regularly show changes in the hydroxyl, carbonyl, and amide absorption bands following synthesis, indicating that these functional groups are involved in both reduction and capping (Ghosh, 2015; Ramesh, Devi, Battu, & Basavaiah, 2018). The efficiency, particle size, and morphology of green-synthesized nanoparticles exhibit significant variation between studies due to the phytochemical composition of an extract depending on plant species, plant part, extraction solvent, and preparation method. This factor continues to complicate direct comparison across the literature (Mohamad et al., 2014).

4. Factors Influencing the Efficiency of Green Synthesis

4.1 Extract and Precursor Concentration

Although an excessive extract concentration can also encourage aggregation by reducing free capping sites in relation to the number of nucleating particles, a higher concentration of plant extract typically supplies more reducing biomolecules, accelerating nucleation and increasing nanoparticle yield (Makarov et al., 2014). Particle size is also influenced by precursor salt concentration: because nucleation and growth fight for a small pool of reducing phytochemicals, greater metal-ion concentrations often result in bigger or more polydisperse particles.

4.2 Reaction Temperature

In general, raising the reaction temperature speeds up the rate of bio-reduction and reduces the time needed for synthesis. However, too high of a temperature can break down thermolabile phytochemicals like polyphenols, decreasing their capping effectiveness and encouraging Ostwald

ripening, a process where larger particles grow at the expense of smaller ones (Mohamad et al., 2014).

4.3 Solution pH

The pH of the solution affects the surface charge of forming nanoparticles as well as the ionization state of phytochemical functional groups. While acidic circumstances can widen the particle size distribution, alkaline conditions have often been linked to the creation of smaller, more evenly distributed nanoparticles (Mohamad et al., 2014).

4.4 Reaction Time and Light

Up to a saturation threshold, longer reaction periods often accelerate the conversion of metal ions to nanoparticles; beyond that, prolonged incubation may encourage agglomeration. Certain plant-mediated syntheses are also light-sensitive: photon flux has been shown to activate biomolecular functional groups, and once the first nanoparticles develop, they can catalyze further ion reduction under light, speeding up the process as a whole (Makarov et al., 2014).

Table 2 summarizes typical ranges of these parameters reported for representative plant-mediated nanoparticle syntheses.

Parameter	Typical Range Reported	General Effect on Product
Plant extract concentration	Low to moderate dilution (e.g., 10–50% v/v)	Higher concentration → faster nucleation, smaller particles up to an optimum, then aggregation
Metal precursor concentration	1–5 mM (common for Ag, Cu, Au salts)	Higher concentration → larger/more polydisperse particles
Temperature	Ambient to ~80 °C	Higher temperature → faster reaction; excess heat degrades reducing phytochemicals
pH	Acidic to alkaline (commonly 5–9)	Alkaline conditions favor smaller, more uniform particles
Reaction time	Minutes to a few hours	Longer time → higher conversion until saturation; excess time promotes aggregation

5. Comparative Synthesis Procedures for Different Nanoparticle Types

This section compares representative plant-mediated synthesis procedures reported for six widely studied nanomaterials, highlighting how plant source, precursor, and reaction conditions influence particle characteristics and synthesis efficiency.

5.1 Silver Nanoparticles (AgNPs)

Due in large part to their strong antibacterial action and the simplicity with which plant phytochemicals may decrease Ag^+ ions, silver nanoparticles are the most investigated green-synthesised nanomaterial (Vanlalveni et al., 2021). According to reported methods, an aqueous leaf, fruit, or root extract is mixed with silver nitrate (AgNO_3) solution at concentrations of 1–5 mM. The completion of the reaction is typically indicated by a color shift to yellow-brown and verified by a surface plasmon resonance peak in UV-visible spectroscopy between 420 and 450 nm (Ahmed, Saifullah, Ahmad, Swami, & Ikram, 2016; Pirtarighat, Ghannadnia, & Baghshahi, 2019). Studies have reported a wide range of particle sizes, from about 3 nm for *Lysiloma acapulcensis* root extract (Garibo et al., 2020) to 20–60 nm for extracts like *Gymnema sylvestre* and *Vitex agnus-castus*. The morphology (spherical, rod-like, or irregular) and stability are highly dependent on the particular phytochemical profile of the plant used (Rajkumar et al., 2020; Ramesh et al., 2018).

5.2 Zinc Oxide Nanoparticles (ZnO NPs)

Plant extract and a zinc salt precursor, such as zinc nitrate or zinc acetate, are frequently combined to create zinc oxide nanoparticles. The intermediate hydroxide is then calcined to produce crystalline ZnO. According to reports (Jamdagni, Khatri, & Rana, 2018; Akhter, Mahmood, Ahmad, & Mohammad, 2018), syntheses utilizing *Nyctanthes arbor-tristis* flower extract and *Swertia chirayita* leaf extract have generated nanoparticles in the 20–50 nm range with hexagonal wurtzite crystal structure verified by X-ray diffraction. Due to surface functionalization by leftover phytochemicals, plant-mediated ZnO synthesis has been shown to produce nanoparticles with a similar or lower band gap and increased photocatalytic activity when compared to chemical co-precipitation (Gnanasangeetha & Sarala Thambavani, 2013).

5.3 Copper and Copper Oxide Nanoparticles (Cu/CuO NPs)

Since Cu⁰ is prone to quick oxidation, it is more difficult to produce copper nanoparticles using green methods than silver or gold. As a result, certain techniques specifically target the more stable CuO phase. *Aerva javanica* leaf extract for CuO nanoparticles with verified antimicrobial and cytotoxic activity (Amin et al., 2021), *Moringa oleifera* hydroalcoholic extract for antimicrobial

copper nanoparticles (Das, Abu-Yousef, Majdalawieh, Narasimhan, & Poltronieri, 2020), and *Camellia sinensis* leaf extract combined with copper salts for dye-degradation applications (Ahmed, Usman, Liu, Shen, Yu, & Cong, 2019). In order to overcome slower reduction kinetics, reaction temperatures for copper systems are frequently higher than for silver (60–90 °C), and reaction durations are correspondingly longer (Heera, Shanmugam, & Ramachandran, 2015).

5.4 Iron Oxide Nanoparticles ($\text{Fe}_3\text{O}_4/\text{Fe}_2\text{O}_3$ NPs)

In order to create iron oxide nanoparticles, a combination of ferric and ferrous salts is reduced and capped by extract phytochemicals in an alkaline environment. This process is known as plant-extract-assisted co-precipitation. This method is especially useful for water-treatment applications because it produces magnetic nanoparticles that can be extracted from treated water using an external magnetic field (Getahun et al., 2022; Vishnu & Dhandapani, 2021). According to various studies, plant-mediated iron oxide nanoparticles typically have particle sizes between 10 and 30 nm, and they exhibit superparamagnetic behavior that makes them appropriate for recurrent recovery and reuse in adsorption cycles (Getahun et al., 2022).

5.5 Gold Nanoparticles (AuNPs)

One of the quickest green synthesis methods described is the reduction of chloroauric acid (HAuCl_4) by plant phytochemicals, which frequently occurs at room temperature and takes only a few minutes to produce gold nanoparticles (Ahmed, Annu, Ikram, & Yudha, 2016). According to Vinay, Udayabhanu, Shashank, Nagaraju, and Chandrasekhar (2021), seed extracts like *Elaeocarpus ganitrus* have produced spherical AuNPs with antibacterial, antioxidant, and cytotoxic activity. Reaction completion is indicated by a color change to ruby red and a distinctive surface plasmon resonance band near 520–550 nm.

5.6 Titanium Dioxide Nanoparticles (TiO_2 NPs)

The remarkable photocatalytic activity of titanium dioxide nanoparticles makes them particularly interesting for the environment. *Mentha arvensis* leaf extract is one example of a plant-mediated synthesis that usually entails combining the extract with a titanium precursor (such as titanium isopropoxide or titanyl sulfate) and then calcining the mixture to produce the photoactive anatase phase (Ahmad, Jaiswal, & Soni, 2020). While eliminating the hazardous organic solvents employed in traditional sol-gel processes, green-synthesised TiO_2 nanoparticles have demonstrated antibacterial activity equivalent to chemically manufactured counterparts.

Table 3 consolidates representative comparative data across these nanoparticle types.

Nanoparticle	Representative Plant Source	Typical Precursor	Reported Size Range	Key Reference
Ag	Lysiloma acapulcensis; Salvia spinosa; Azadirachta indica	AgNO ₃	~3–60 nm	Garibo et al., 2020; Pirtarighat et al., 2019
ZnO	Nyctanthes arbor-tristis; Swertia chirayita	Zinc nitrate/acetate	~20–50 nm	Jamdagni et al., 2018; Akhter et al., 2018
Cu/CuO	Camellia sinensis; Moringa oleifera; Aerva javanica	Copper sulfate/nitrate	Variable; often 20–80 nm	Das et al., 2020; Amin et al., 2021
Fe ₃ O ₄	Various leaf/fruit extracts (co-precipitation)	Fe ²⁺ /Fe ³⁺ salts	~10–30 nm	Getahun et al., 2022
Au	Elaeocarpus ganitrus seed extract	HAuCl ₄	Spherical, tens of nm	Vinay et al., 2021
TiO ₂	Mentha arvensis leaf extract	Titanium isopropoxide/sulfate	Nanocrystalline, anatase phase	Ahmad et al., 2020

6. Characterization Techniques

A mix of complementary characterisation approaches is needed to verify effective green synthesis and assess nanoparticle quality. The primary and most popular confirmatory method for identifying the surface plasmon resonance band typical of metal nanoparticles is UV-visible spectroscopy (Pirtarighat et al., 2019). By comparing the extract's absorption spectra before and

after nanoparticle production, Fourier-transform infrared spectroscopy (FTIR) determines the functional groups of phytochemicals in charge of reduction and capping (Ghosh, 2015). By using the Scherrer equation to estimate crystallite size, X-ray diffraction (XRD) verifies the nanoparticles' crystalline nature and phase composition. Particle size, shape, and elemental composition may be directly seen using electron microscopy methods such as transmission electron microscopy (TEM), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDX) (Ramesh et al., 2018). Zeta-potential measurements and dynamic light scattering (DLS) are used to evaluate colloidal stability in suspension and hydrodynamic particle size distribution, respectively. Many studies only use a portion of these methods or report values without sufficient replication, which restricts the direct comparability of particle size, shape, and stability data between independent syntheses (Mohamad et al., 2014). This is a common methodological issue observed throughout the literature.

7. Environmental Applications of Plant-Mediated Nanoparticles

7.1 Photocatalytic Degradation of Dyes

Large amounts of wastewater containing synthetic dyes that are resistant to traditional biological treatment are released by the textile and dye-processing industries. Under UV or sun radiation, green-synthesised semiconductor nanoparticles, especially ZnO and TiO₂, have shown significant photocatalytic activity against dyes including methyl orange, rhodamine B, and methylene blue (Isa, Shameli, Chng, Jusoh, & Hazan, 2021; El Golli et al., 2021). When light is absorbed, electron-hole pairs are created, which lead to the production of reactive oxygen species (superoxide and hydroxyl radicals) that may mineralize organic dye molecules into carbon dioxide and water. In a number of comparison investigations, plant-mediated ZnO nanoparticles have demonstrated degradation efficiencies surpassing 85–90% during a few hours of sun exposure, with the added advantage of being reusable across numerous treatment cycles (Gowthambabu, Balamurugan, Satheeshkumar, & Kanmani, 2021).

7.2 Adsorptive Removal of Heavy Metals

As adsorbents for heavy-metal ions including cadmium, chromium, lead, copper, and zinc in polluted water, iron oxide and other metal-oxide nanoparticles made from plant extracts have been extensively studied. These nanoparticles' large surface area and abundance of surface hydroxyl groups offer many binding sites for metal ion chelation, and their magnetic characteristics (in the case of iron oxides) enable simple recovery using an external magnetic field following treatment

(Getahun et al., 2022; Vishnu & Dhandapani, 2021). Solution pH, contact duration, adsorbent dose, and starting metal ion concentration all affect adsorption effectiveness in these systems; removal efficiencies of 90% have been reported in many experiments. under optimized conditions.

7.3 Antimicrobial Water Disinfection

The broad-spectrum antibacterial and antifungal activity of silver, copper oxide, and zinc oxide nanoparticles made from plant extracts is attributed to mechanisms such as disruption of microbial cell membranes, production of reactive oxygen species, and interference with intracellular enzymatic and genetic machinery (Azam et al., 2012; Amin et al., 2021). These characteristics have encouraged their investigation as parts of antimicrobial filtering media and point-of-use water disinfection systems, providing a less expensive, biodegradable substitute for chlorination byproducts of concern in traditional water treatment.

7.4 Agricultural and Pesticidal Applications

In addition to treating water, plant-derived nanoparticles have demonstrated efficacy against phytopathogens and agricultural pests, potentially lowering the need for synthetic pesticides and the environmental persistence that goes along with them. Particularly, copper and copper oxide nanoparticles have shown antifungal activities against a number of plant diseases and serve as sources of micronutrients, demonstrating a dual agronomic and environmental advantage (Amin et al., 2021).

8. Comparative Efficiency: Green versus Conventional Synthesis

According to the reviewed studies, plant-mediated green synthesis outperforms chemical and physical approaches in a number of efficiency metrics related to environmental sustainability. Many plant-mediated syntheses have reaction durations (minutes to a few hours) that are similar to—and sometimes quicker than—chemical reduction techniques, but they do not require dangerous reducing agents like hydrazine or sodium borohydride (Ahmed et al., 2016; Raveendran et al., 2003). Since most plant-mediated reactions occur at ambient or slightly raised temperatures rather than the high temperatures or vacuum conditions required by many physical approaches, energy needs are often reduced (Mittal et al., 2013). Due to the additional bioactivity provided by residual phytochemical capping layers, green-synthesised nanoparticles have been shown in multiple comparative antimicrobial and photocatalytic studies to perform on par with or better than their chemically synthesized counterparts (Vanlalveni et al., 2021).

However, because plant extract composition varies with species, growing conditions, harvest time, and extraction method, chemical and physical methods continue to have an advantage in reproducibility and fine control over particle size and shape. This introduces batch-to-batch variability that is less noticeable in purely chemical systems (Mohamad et al., 2014).

9. Challenges and Limitations

- **Batch-to-batch variability:** It is challenging to accurately replicate synthesis results across laboratories due to variations in the phytochemical content of plant extracts caused by species, geographic origin, seasonal timing, and extraction process (Mohamad et al., 2014).
- **Inadequate mechanistic understanding:** For many plant species, the exact phytochemical mechanisms in charge of reduction and capping are still only partially understood, which makes rational process optimization more difficult.
- **Scale-up challenges:** The majority of documented processes have only been tested at laboratory scale (milliliter to liter quantities), and there is still much to be done to translate them to continuous, industrial-scale production.
- **Inconsistent characterisation practices:** Direct comparisons of particle quality across research are hampered by differences in the characterization methods used and a lack of statistical replication (Mohamad et al., 2014).
- **Long-term environmental fate:** Considering how quickly plant-synthesized nanoparticles are being used in remediation research, comprehensive information on their ecotoxicological behavior and long-term environmental persistence is still lacking.

10. Future Directions

Standardized reporting procedures that include plant part, extraction solvent, and concentration along with complete characterisation information would be beneficial for future research and allow for more thorough cross-study comparisons. More mechanistic research might increase repeatability and enable the logical design of synthesis processes for certain particle sizes and morphologies, possibly through the targeted separation of individual phytochemicals rather than crude extracts. To determine the technological and economic viability of producing green nanoparticles on an industrial scale, pilot-scale and continuous-flow reactor experiments are required. Finally, before plant-synthesised nanoparticles are widely used in water treatment and

agricultural applications, it will be crucial to validate their long-term environmental safety through broader life-cycle and ecotoxicological evaluation.

11. Conclusion

A relatively quick, inexpensive, and ecologically safe substitute for traditional physical and chemical techniques of producing nanoparticles is plant-extract-mediated green synthesis. Plant-mediated methods have repeatedly shown the capacity to generate nanoparticles with beneficial photocatalytic, antimicrobial, and adsorptive qualities appropriate for environmental remediation across silver, zinc oxide, copper/copper oxide, iron oxide, gold, and titanium dioxide systems, while significantly lowering reliance on dangerous chemical reagents. Expanded scale-up and safety studies, more standardization of synthesis processes, and a deeper mechanistic understanding of phytochemical-mediated bio-reduction are all need to fully realize this approach's promise for large-scale environmental use.

References

1. Ahmad, W., Jaiswal, K. K., & Soni, S. (2020). Green synthesis of titanium dioxide (TiO₂) nanoparticles by using *Mentha arvensis* leaves extract and its antimicrobial properties. *Inorganic and Nano-Metal Chemistry*. <https://doi.org/10.1080/24701556.2020.1732419>
2. Ahmed, A., Usman, M., Liu, Q.-Y., Shen, Y.-Q., Yu, B., & Cong, H.-L. (2019). Plant mediated synthesis of copper nanoparticles by using *Camellia sinensis* leaves extract and their applications in dye degradation. *Ferroelectrics*, 549(1), 61–69.
3. Ahmed, Q., Gupta, N., Kumar, A., & Nimesh, S. (2016). Antibacterial efficacy of silver nanoparticles synthesized employing *Terminalia arjuna* bark extract. *Artificial Cells, Nanomedicine, and Biotechnology*. <https://doi.org/10.1080/21691401.2016.1215328>
4. Ahmed, S., Ahmad, M., Swami, B. L., & Ikram, S. (2016). A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: A green expertise. *Journal of Advanced Research*, 7(1), 17–28.
5. Ahmed, S., Annu, Chaudhry, S. A., & Ikram, S. (2017). A review on biogenic synthesis of ZnO nanoparticles using plant extracts and microbes: A prospect towards green chemistry. *Journal of Photochemistry and Photobiology B: Biology*, 166, 272–284.
6. Ahmed, S., Annu, Ikram, S., & Yudha S, S. (2016). Biosynthesis of gold nanoparticles: A green approach. *Journal of Photochemistry and Photobiology B: Biology*, 161, 141–153.
7. Ahmed, S., Saifullah, Ahmad, M., Swami, B. L., & Ikram, S. (2016). Green synthesis of silver nanoparticles using *Azadirachta indica* aqueous leaf extract. *Journal of Radiation Research and Applied Sciences*, 9, 1–7.
8. Akhter, S. M. H., Mahmood, Z., Ahmad, S., & Mohammad, F. (2018). Plant-mediated green synthesis of zinc oxide nanoparticles using *Swertia chirayita* leaf extract, characterization and its antibacterial efficacy against some common pathogenic bacteria. *BioNanoScience*, 8. <https://doi.org/10.1007/s12668-018-0549-9>
9. Amin, F., Khattak, B., Alotaibi, A., Qasim, M., Ahmad, I., Ullah, R., Bourhia, M., Gul, A., Zahoor, S., & Ahmad, R. (2021). Green synthesis of copper oxide nanoparticles using *Aerva javanica* leaf extract and their characterization and investigation of in vitro antimicrobial potential and cytotoxic activities. *Evidence-Based Complementary and Alternative Medicine*, 2021, 5589703.

10. Azam, A., Ahmed, A. S., Oves, M., Khan, M. S., Habib, S. S., & Memic, A. (2012). Antimicrobial activity of metal oxide nanoparticles against Gram-positive and Gram-negative bacteria: A comparative study. *International Journal of Nanomedicine*, 7, 6003–6009.
11. Balachandar, R., Gnanasekaran, D., Anbalagan, S. et al. (2019). Plant-mediated synthesis, characterization and bactericidal potential of emerging silver nanoparticles using stem extract of *Phyllanthus pinnatus*: A recent advance in phytonanotechnology. *Journal of Cluster Science*, 30(6), 1481–1488.
12. Breijyeh, Z., Jubeh, B., & Karaman, R. (2020). Resistance of gram-negative bacteria to current antibacterial agents and approaches to resolve it. *Molecules*, 25(6), 1340.
13. Daphne, J., Francis, A., Mohanty, R., Ojha, N., & Das, N. (2018). Green synthesis of antibacterial silver nanoparticles using yeast isolates and its characterization. *Research Journal of Pharmacy and Technology*, 11(1), 83–92.
14. Das, M., & Chatterjee, S. (2019). Green synthesis of metal/metal oxide nanoparticles toward biomedical applications: Boon or bane. In A. K. Shukla & S. Iravani (Eds.), *Green Synthesis, Characterization and Applications of Nanoparticles* (pp. 265–301). Elsevier.
15. Das, P. E., Abu-Yousef, I. A., Majdalawieh, A. F., Narasimhan, S., & Poltronieri, P. (2020). Green synthesis of encapsulated copper nanoparticles using a hydroalcoholic extract of *Moringa oleifera* leaves and assessment of their antioxidant and antimicrobial activities. *Molecules*, 25(3), 555.
16. El Golli, A., Contreras, S., Dridi, C., et al. (2021). Wastewater remediation with ZnO photocatalysts: Green synthesis and solar concentration as an economically and environmentally viable route to application. *Journal of Environmental Management*, 286, 112226.
17. Garibo, D., Borbón-Núñez, H. A., De León, J. N. D., García Mendoza, E., et al. (2020). Green synthesis of silver nanoparticles using *Lysiloma acapulcensis* exhibit high-antimicrobial activity. *Scientific Reports*, 10, 12805.
18. Getahun, Y. W., et al. (2022). Green synthesized superparamagnetic iron oxide nanoparticles for water treatment with alternative recyclability. *Journal of Molecular Liquids*, 356, 118983.

19. Ghosh, S. (2015). Plant-mediated synthesis of silver nanoparticles using parsley (*Petroselinum crispum*) leaf extract: Spectral analysis of the particles and antibacterial study. *Applied Nanoscience*, 5(8), 945–951.
20. Gnanasangeetha, D., & Sarala Thambavani, D. (2013). One pot synthesis of zinc oxide nanoparticles via chemical and green method. *Research Journal of Material Sciences*, 1, 1–8.
21. Gowthambabu, V., Balamurugan, A., Satheeshkumar, S., & Kanmani, S. S. (2021). ZnO nanoparticles as efficient sunlight driven photocatalyst prepared by solution combustion method involved lime juice as biofuel. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 258, 119857.
22. Heera, P., Shanmugam, S., & Ramachandran, J. (2015). Green synthesis of copper nanoparticle using *Gymnema sylvestre* by different solvent extract. *International Journal of Current Research and Academic Review*, 3(10), 268–275.
23. Hulkoti, N. I., & Taranath, T. C. (2014). Biosynthesis of nanoparticles using microbes—A review. *Colloids and Surfaces B: Biointerfaces*, 121, 474–483.
24. Iravani, S. (2011). Green synthesis of metal nanoparticles using plants. *Green Chemistry*, 13(10), 2638–2650.
25. Isa, E. D. M., Shameli, K., Chng, H. J., Jusoh, N. W. C., & Hazan, R. (2021). Photocatalytic degradation of selected pharmaceuticals using green fabricated zinc oxide nanoparticles. *Advanced Powder Technology*, 32, 2398–2409.
26. Jamdagni, P., Khatri, P., & Rana, J. S. (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, 168–175.
27. Jyoti, K., & Singh, A. (2016). Green synthesis of nanostructured silver particles and their catalytic application in dye degradation. *Journal of Genetic Engineering and Biotechnology*, 14(2), 311–317.
28. Mahmoudvand, H., et al. (2020). Antinociceptive effects of green synthesized copper nanoparticles alone or in combination with morphine. *Annals of Medicine and Surgery*, 51, 31–36.
29. Makarov, V. V., Love, A. J., Sinitsyna, O. V., Makarova, S. S., Yaminsky, I. V., Taliansky, M. E., & Kalinina, N. O. (2014). "Green" nanotechnologies: Synthesis of metal nanoparticles using plants. *Acta Naturae*, 6(1), 35–44.

30. Mittal, A. K., Chisti, Y., & Banerjee, U. C. (2013). Synthesis of metallic nanoparticles using plant extracts. *Biotechnology Advances*, 31(2), 346–356.
31. Mohamad, N. A. N., Arham, N. A., Jai, J., & Hadi, A. (2014). Plant extract as reducing agent in synthesis of metallic nanoparticles: A review. *Advanced Materials Research*, 832, 350–355.
32. Mohamed, E. A. (2020). Green synthesis of copper & copper oxide nanoparticles using the extract of seedless dates. *Heliyon*, 6(1), e03123.
33. Nasrollahzadeh, M., & Sajadi, S. M. (2015). Green synthesis of copper nanoparticles using *Ginkgo biloba* L. leaf extract and their catalytic activity for the Huisgen [3+2] cycloaddition of azides and alkynes at room temperature. *Journal of Colloid and Interface Science*, 457, 141–147.
34. Pal, G., Rai, P., & Pandey, A. (2019). Green synthesis of nanoparticles: A greener approach for a cleaner future. In A. K. Shukla & S. Iravani (Eds.), *Green Synthesis, Characterization and Applications of Nanoparticles* (Chapter 1). Elsevier.
35. Pirtarighat, S., Ghannadnia, M., & Baghshahi, S. (2019). Green synthesis of silver nanoparticles using the plant extract of *Salvia spinosa* grown in vitro and their antibacterial activity assessment. *Journal of Nanostructure in Chemistry*, 9, 1–9.
36. Rajkumar, P., Prakasam, A., Rajeshkumar, S., Gomathi, M., Anbarasan, P. M., & Chandrasekaran, R. (2020). Green synthesis of silver nanoparticles using *Gymnema sylvestre* leaf extract and evaluation of its antibacterial activity. *South African Journal of Chemical Engineering*, 32, 1–4.
37. Ramesh, A. V., Devi, D. R., Battu, G., & Basavaiah, K. (2018). A facile plant mediated synthesis of silver nanoparticles using an aqueous leaf extract of *Ficus hispida* Linn. f. for catalytic, antioxidant and antibacterial applications. *South African Journal of Chemical Engineering*, 26, 25–34.
38. Raveendran, P., Fu, J., & Wallen, S. L. (2003). Completely "green" synthesis and stabilization of metal nanoparticles. *Journal of the American Chemical Society*, 125(46), 13940–13941.
39. Shah, M., Fawcett, D., Sharma, S., Tripathy, S. K., & Poinern, G. E. J. (2015). Green synthesis of metallic nanoparticles via biological entities. *Materials*, 8, 7278–7308.

40. Vanlalveni, C., Lallianrawna, S., Biswas, A., Selvaraj, M., Changmai, B., & Rokhum, S. L. (2021). Green synthesis of silver nanoparticles using plant extracts and their antimicrobial activities: A review of recent literature. *RSC Advances*, 11, 2804–2837.
41. Vijayaraghavan, K., Nalini, S. P. K., Prakash, N. U., & Madhankumar, D. (2012). One step green synthesis of silver nano/microparticles using extracts of *Trachyspermum ammi* and *Papaver somniferum*. *Colloids and Surfaces B: Biointerfaces*, 94, 114–117.
42. Vinay, S. P., Udayabhanu, H. N., Shashank, M., Nagaraju, G., & Chandrasekhar, N. (2021). In-vitro antibacterial, antioxidant and cytotoxic potential of gold nanoparticles synthesized using novel *Elaeocarpus ganitrus* seeds extract. *Journal of Science: Advanced Materials and Devices*, 6(1), 127–133.
43. Vishnu, D., & Dhandapani, B. (2021). Synthesis of novel adsorbent by incorporation of plant extracts in amino-functionalized silica-coated magnetic nanomaterial for the removal of Zn^{2+} and Cu^{2+} from aqueous solution. *Journal of Environmental Health Science and Engineering*, 19(2), 1413–1424.
44. Wang, Y., Maksimuk, S., Shen, R., & Yang, H. (2007). Synthesis of iron oxide nanoparticles using a freshly-made or recycled imidazolium-based ionic liquid. *Green Chemistry*, 9(10), 1051.
45. Yassin, M. T., Mostafa, A. A. F., Al-Askar, A. A., & Al-Otibi, F. O. (2022). Facile green synthesis of silver nanoparticles using aqueous leaf extract of *Origanum majorana* with potential bioactivity against multidrug resistant bacterial strains. *Crystals*, 12(5), 603.