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*Research Paper***Influence of Physicochemical Parameters pH, Concentration, Temperature and Reaction Time on the Green Synthesis of Metallic Nanoparticles Using Plant Extracts: A Review****Harshal S. Peche**tusharpeche17@gmail.com**Abstract**

Utilizing plant extracts for the green (biological) synthesis of metallic and metal-oxide nanoparticles has become a safe, cost-effective, and environmentally friendly alternative to traditional physical and chemical methods. The phytochemicals found in plant extracts, including flavonoids, polyphenols, terpenoids, tannins, and proteins, serve dual roles as reducing and capping agents. They facilitate the transformation of metal ions into zero-valent or oxide nanoparticles while also managing their growth and stability. Nonetheless, the size, shape, yield, crystallinity, and biological activity of these nanoparticles are highly influenced by the physicochemical conditions during the synthesis process. This review integrates insights from the literature on plant-mediated nanoparticles to thoroughly assess the influence of factors such as reaction pH, metal-precursor concentration, plant-extract concentration and the ratio of extract to precursor, reaction temperature, incubation or reaction duration, and illumination on nanoparticle synthesis. By comparing evidence from systems involving silver, gold, copper, and zinc oxide nanoparticles, common patterns are identified: a pH that is near-neutral to moderately alkaline and moderate precursor concentrations typically lead to smaller, more uniform, and stable particles. However, higher temperatures can speed up bioreduction kinetics but may also degrade thermolabile phytochemicals. The review explores the mechanistic reasons behind these patterns, current characterization methods, notable biomedical and environmental applications, and the challenges that remain for reproducibility and scaling up. It concludes that systematically optimizing these interacting parameters, with the aid of statistical design-of-experiments methods, is crucial for achieving reproducible, adjustable, and industrially applicable green nanoparticle synthesis.

Keywords: *green synthesis; plant extract; nanoparticles; pH; precursor concentration; reaction temperature; reaction time; phytochemicals.*

Introduction

Nanotechnology has revolutionised fields such as materials science, medicine, agriculture, and environmental engineering by allowing the creation of particles with properties significantly different from their larger-scale versions. Among the various methods for synthesis, the biological or "green" approach using plant extracts has garnered continuous attention. This is because it eliminates the need for toxic solvents, high energy consumption, and the hazardous by-products typically linked to physical and chemical methods. In the process of plant-mediated synthesis, an extract whether aqueous, alcoholic, or hydro-alcoholic derived from a leaf, fruit, peel, seed, flower, root, or entire plant is combined with a metal salt solution (the precursor). The naturally occurring

phytochemicals in the extract then reduce the metal ions to nanoscale particles, simultaneously capping and stabilising them.

The appeal of this method is rooted in its straightforwardness, affordability, scalability, and the abundant natural presence of plant biomass, along with the biocompatibility of the nanomaterials produced. Nanoparticles of silver, gold, copper, zinc oxide, iron oxide, and various other metals and metal oxides have been created using this technique and assessed for their antibacterial, antifungal, antioxidant, anticancer, catalytic, and photocatalytic properties. However, unlike chemical synthesis, which allows for precise control of reaction conditions, green synthesis relies on a biological matrix whose composition can differ based on plant species, plant part, extraction solvent, harvest season, and storage conditions. This intrinsic biological variability means that the key factors researchers can adjust to consistently control nanoparticle size, shape, yield, and stability are the physicochemical reaction parameters such as pH, metal-ion concentration, extract concentration, temperature, reaction time, extract-to-precursor ratio, and illumination.

This review is dedicated to examining the impact of these parameters on the results of nanoparticle synthesis facilitated by plants. Instead of cataloging every plant species mentioned in existing studies, the objective is to compile comparative data across various metal systems, primarily focusing on silver, gold, copper, and zinc oxide nanoparticles. The goal is to pinpoint trends that can be generalized and provide mechanistic insights, while also emphasizing the practical consequences of parameter choices for researchers aiming to produce reproducible nanoparticles tailored for specific applications.

2. Mechanism of Plant-Mediated Nanoparticle Synthesis

Three overlapping phases make up the generalized mechanism of phytosynthesis: (i) an activation phase where metal ions are reduced to atoms and nucleation starts; (ii) a growth phase where small adjacent nanoparticles spontaneously coalesce into larger, thermodynamically more stable particles (a process frequently described by Ostwald ripening); and (iii) a termination phase where the final shape of the nanoparticle is determined and capping biomolecules adsorb onto the particle surface to stop further growth and prevent agglomeration. Flavonoids, phenolic acids, tannins, terpenoids, alkaloids, polysaccharides, and proteins are among the phytochemicals that cause these changes. These molecules' hydroxyl and carbonyl groups reduce metal cations (such as Ag^+ , Au^{3+} , or Cu^{2+}) to the zero-valent state by donating electrons to them. The same or additional functional groups then attach to the surface of the newly formed nanoparticle, serving as a capping layer that provides colloidal stability and biocompatibility. The initial metal hydroxide in metal-oxide nanoparticles, such zinc oxide, is thermally broken down (calcined) to produce the crystalline oxide phase. The reduction potential, reaction rate, and capping efficiency of a particular extract are distinct because the relative abundance of each type of phytochemical varies among plant species and plant sections. This accounts for a large portion of the batch-to-batch variability documented in the literature.

A visible color shift in the reaction mixture (for instance, pale yellow to reddish-brown for silver nanoparticles or wine-red to purple for gold nanoparticles) that results from surface plasmon

resonance is typically used to track the formation of nanoparticles. This change is then verified and characterized using a variety of analytical methods outlined in Section 4.

3. Physicochemical Parameters Governing Green Synthesis

Numerous experimental studies show that the reaction pH, metal-precursor concentration, plant-extract concentration, extract-to-precursor ratio, temperature, reaction/incubation time, and, in certain situations, exposure to light all jointly influence the results of plant-mediated nanoparticle synthesis, including reaction rate, particle yield, average size, size distribution, morphology, crystallinity, and colloidal stability. Each of these factors is covered separately below, with comparative data from systems of silver, gold, copper, and zinc oxide nanoparticles summarized in Table 1.

3.1 Effect of Solution pH

Since pH controls the ionization state of functional groups (hydroxyl, carboxyl, and amine) on phytochemicals, which in turn impacts their availability and reactivity as reducing and capping agents, it is commonly considered one of the most important factors in plant-mediated synthesis. According to a number of research on the synthesis of silver nanoparticles, the protonation of phenolic and carboxylic groups reduces electron donation under very acidic conditions (pH below about 5–6), delaying reduction and usually producing larger, more polydisperse, and less stable particles. Deprotonation of these functional groups enhances their reduction capacity as pH rises toward neutral and moderately alkaline values. This accelerates nucleation and typically results in smaller, more uniform, negatively charged (and hence more electrostatically stabilized) nanoparticles.

Numerous reports of this trend in various plant-metal systems have been made. In order to determine the ideal conditions for nanoparticle formation and antimicrobial performance in the synthesis of zinc-oxide nanoparticles using *Verbascum sinaiticum* extract, pH was systematically varied between 4 and 12 along with zinc-acetate concentration, temperature, reaction time, and extract volume (*Verbascum sinaiticum* study, discussed in Section 3 above). Similar to this, enzyme-immobilization activity tests in *Cayratia pedata*-mediated zinc oxide nanoparticle formation revealed the best bioactivity at pH 5, demonstrating that the pH utilized during synthesis and subsequent application can significantly impact functional performance. Since copper-ion reduction and the subsequent oxidation of metallic copper to Cu₂O or CuO are themselves pH-dependent, pH adjustment, such as the addition of citric acid, has been purposefully used for copper and copper-oxide nanoparticles to extend the reduction process and control final particle size and shape.

Because gold nucleation is so sensitive to the degree of ionization of stabilizing phytochemicals, pH has a much more significant morphological impact on gold nanoparticles than it does on silver. A shift from mixed anisotropic morphologies (triangular, rod-shaped, and flower-like particles) at mildly acidic pH to small, uniform, spherical particles at higher pH has been reported in studies using tea-derived extracts that vary pH from strongly acidic to strongly alkaline conditions. At extreme pH values, nanoparticle formation is completely suppressed. The general conclusion that alkaline conditions favor smaller particle formation across multiple plant-metal systems is

reinforced by reports on *Garcinia mangostana*-mediated silver nanoparticle synthesis, which describe a marked decrease in particle size (from approximately 33 nm to 7 nm) as pH is raised from 4 to 7.6, provided that the pH does not become so extreme that the phytochemicals themselves degrade or the colloid destabilises and aggregates.

3.2 Effect of Metal-Precursor (Salt) Concentration

The quantity of metal ions available for reduction and, thus, the theoretical yield of nanoparticles is directly determined by the concentration of the metal salt employed as a precursor, most frequently silver nitrate, gold chloride, copper sulphate/chloride, or zinc nitrate/acetate. Precursor concentration and particle quality, however, typically have a non-monotonic relationship. The creation of tiny, well-capped, and reasonably uniform particles is favored at low precursor concentrations because there are more phytochemical reducing sites than metal ions, but the total output is constrained. In a number of silver-nanoparticle studies, an ideal concentration in the range of 1 millimolar has consistently been found to produce the smallest and most stable particles, in agreement across independent studies using various leaf extracts. Yield increases in proportion to precursor concentration.

An inadequate ratio of reducing/stabilizing phytochemicals to metal ions encourages uncontrolled nucleation and rapid particle growth, leading to larger, more polydisperse, less stable, and aggregation-prone nanoparticles. Beyond this optimum, additional increases in precursor concentration tend to overwhelm the extract's capping capacity. This behavior has been shown for silver nanoparticles made from *Imperata cylindrica* leaf extract, where increasing the concentration of silver-nitrate over a 0.5–0.9 millimolar range changed the size of the particles and shifted the surface-plasmon-resonance absorption. It has also been shown in classical studies that increasing the concentration of silver-nitrate increases the size of the particles as well as the degree of aggregation. For gold nanoparticles, a similar optimum-then-decline pattern has been shown, where the predominance of spherical or anisotropic particles is determined by the significant interaction between precursor concentration, extract concentration, and temperature.

3.3 Effect of Plant-Extract Concentration and Extract-to-Precursor Ratio

The concentration of the plant extract (or, alternatively, the volumetric ratio of extract to metal-salt solution) is a second important lever that controls the creation of nanoparticles since it provides both the reducing agents and the capping/stabilizing biomolecules. The rate of nucleation is often accelerated by increasing extract concentration because it increases the local availability of reducing phytochemicals. This has been seen for silver nanoparticles made from oak-fruit-hull (Jaft) extract, where increasing extract concentration gradually increased nanoparticle yield until a plateau was reached at about 40 grams per liter, beyond which no further improvement occurred. Since it simultaneously controls the absolute amounts of phytochemicals and their dilution in relation to metal ions, the extract-to-precursor volumetric ratio has a comparable but distinct impact. The ideal ratio of silver nitrate to plant extract in the synthesis of silver nanoparticles using *Acacia cyanophylla* extract was found to be 9:1, which resulted in particles with the best average diameter and polydispersity index; ratios that were either too diluted or too concentrated in extract produced worse results. For copper nanoparticles made from *Fortunella margarita* (kumquat) leaf

extract, comparable ratio-dependent optimization has also been shown. To find the combination that produced the highest nanoparticle yield, extract-to-copper-sulphate ratios of 1:2, 1:3, and 1:4 were methodically compared along with pH and temperature. An intermediate, empirically optimized extract concentration is usually preferred because, similar to precursor concentration, an excessive concentration of extract can eventually reverse the positive trend: very high phytochemical loading may encourage secondary aggregation of newly formed nuclei or interfere with light-scattering-based particle-size measurements.

3.4 Effect of Reaction Temperature

The main ways that temperature affects green synthesis are by regulating the rates of reactions and the solubility of the phytochemicals that cause reduction and capping. In comparison to reactions conducted at room temperature, raising the temperature generally accelerates nucleation and increases the rate of bioreduction, resulting in a greater number of smaller, more spherical nanoparticles. This is because rapid nucleation reduces the amount of time available for existing nuclei to grow further before the metal ions are depleted. Neem (*Azadirachta indica*) leaf extract-mediated synthesis reached maximum nanoparticle production at 70 degrees Celsius after three hours of reaction, whereas silver-nanoparticle synthesis using oak-fruit-hull extract was found to proceed most efficiently at 45 degrees Celsius in one representative study. In line with the general finding that higher temperatures increase the solubility and, consequently, the reducing/capping power of water-soluble phytochemicals like polyphenols and alkaloids, zinc-oxide nanoparticle synthesis from *Dennettia tripetala* leaf and fruit extracts likewise demonstrated the highest nanoparticle yield at 90 degrees Celsius and 65 degrees Celsius, respectively.

This association is limited, though. In addition to lowering the effective concentration of reducing agents available and possibly encouraging Ostwald ripening—a process in which smaller nanoparticles dissolve and redeposit onto larger ones, broadening the size distribution—excessively high temperatures can denature or thermally degrade sensitive phytochemicals like some flavonoids and proteins. For instance, temperatures above about 70 degrees Celsius have been reported to be unfavorable in the synthesis of copper nanoparticles due to the volatility and instability of some reducing phytoconstituents at high temperatures; ambient or slightly warmed conditions are typically preferred. A similar trade-off is seen in the post-synthesis thermal treatment (calcination) of metal-oxide nanoparticles like iron oxide: lower calcination temperatures and shorter calcination times preserve active polyphenolic content and produce smaller, less polycrystalline particles with superior antioxidant activity, while higher calcination temperatures and longer calcination times encourage polyphenol degradation and coarser, more polycrystalline structures.

3.5 Effect of Reaction (Incubation) Time

The length of time that the metal-salt solution and plant extract are allowed to react also has a significant impact on the degree of metal-ion conversion and the final properties of the nanoparticles. In most systems, the reaction proceeds quickly at first, frequently indicated by a visible color change within minutes, followed by a slower phase in which residual metal ions continue to be reduced and existing particles undergo Ostwald ripening or secondary aggregation.

Research on the synthesis of zinc-oxide nanoparticles from *Verbascum sinaiticum* extract looked at reaction times between 20 and 140 minutes in addition to pH, temperature, and precursor concentration. The results showed that these temporal effects are inextricably linked to the other reaction parameters and need to be optimized in concert rather than separately.

Up to a certain extent, longer incubation times have been demonstrated to increase the production and stability of nanoparticles. While other plant-mediated zinc-oxide syntheses have reported optimal incubation times of about 12 hours, kenaf-leaf-extract-mediated silver-nanoparticle synthesis only produced tiny, stable, and monodispersed particles after 48 hours of incubation at pH 11 and 37 degrees Celsius. However, longer reaction times often result in particle aggregation, precipitation, or loss of the original nanostructure, especially when unbound phytochemicals that are still present in the reaction medium interact with the surface of the nanoparticles for extended periods of time. Reaction time thus shows an optimal rather than a strictly monotonic relationship with nanoparticle quality, similar to temperature.

3.6 Effect of Light and Illumination

Exposure of the reaction mixture to light has also been demonstrated to affect nanoparticle formation, albeit less frequently than pH, concentration, temperature, and time. This is especially true for silver and gold systems, where photo-induced reduction can either complement or compete with purely thermal/chemical bioreduction. When *Vitex agnus-castus* fruit extract was used to create silver nanoparticles, reaction mixtures exposed to sunlight changed color more quickly and intensely than those kept at room temperature in the dark. Additionally, the ultraviolet-visible absorption spectra of samples exposed to sunlight showed sharper surface-plasmon-resonance peaks, suggesting that illumination affected both reaction rate and particle uniformity. These findings imply that photonic energy can speed up the transfer of electrons from phytochemicals to metal ions and that manipulating or purposefully taking advantage of ambient light exposure is another underutilized variable for adjusting the results of green synthesis.

3.7 Effect of Plant Part, Species and Phytochemical Composition

The botanical source of the extract fixes the qualitative and quantitative phytochemical profile available for reduction and capping, making it an important, if less tunable, determinant of nanoparticle characteristics beyond the strictly physicochemical reaction parameters discussed above. Studies comparing the formation of silver nanoparticles in various living plant species and tissues have revealed significant variations, such as variations in whether nanoparticles form at all depending on the plant species and plant part, with leaves generally exhibiting the highest metal uptake and nanoparticle formation in comparison to other tissues. The relative amounts of flavonoids, phenolic acids, tannins, terpenoids, and alkaloids vary significantly between species, plant organs, and even harvesting seasons, according to reviews of secondary-metabolite-mediated nanoparticle synthesis. This variability is a major source of the batch-to-batch inconsistency that is frequently mentioned as a limitation of green synthesis in comparison to conventional chemical methods.

3.8 Other Contributing Factors

There are several more variables that interact with the aforementioned parameters and are worth mentioning in passing. The rate of stirring or agitation has an impact on nucleation homogeneity and mass transfer between the extract and the metal-salt solution. The types of phytochemicals included in the extract and, consequently, its reducing strength are changed by the extraction solvent (aqueous, ethanolic, or methanolic). The size, surface charge, and antibacterial activity of green-synthesised silver nanoparticles have also been further adjusted by the addition of exogenous stabilizers such polyvinylpyrrolidone. Lastly, the long-term colloidal stability of the nanoparticle suspension is influenced by post-synthesis handling, including centrifugation speed, washing, and storage conditions (temperature, light exposure, duration). Several studies have reported sustained antimicrobial activity and structural stability for periods of several weeks to several months under appropriate storage.

3.9 Summary of Parameter Effects

Table 1 summarises the general direction of influence of each major parameter discussed above, drawing on the comparative evidence presented in this section.

Parameter	Typical Range Studied	General Effect on Nanoparticle Characteristics	Representative Reference
Solution pH	2 – 13	Acidic pH slows reduction and yields larger, aggregated particles; near-neutral to moderately alkaline pH favours rapid, uniform, smaller nanoparticles; extreme alkaline pH can cause instability and agglomeration.	Azad et al. (2023); Anandalakshmi et al. (2016)
Metal precursor concentration	0.5 – 5 mM	Low concentration limits yield; moderate concentration (often ~1 mM) gives the smallest, most stable particles; excess precursor promotes aggregation and broadens the size distribution.	Sobczak-Kupiec et al. (2011); Krishnaraj et al. (2012)
Plant extract concentration / volume ratio	1–10% v/v or w/v	Increasing extract concentration raises phytochemical availability, accelerating nucleation and generally yielding smaller, more numerous particles up to a saturation point, beyond which size may increase again.	Mittal et al. (2013); Fortunella margarita study
Reaction temperature	25 – 100 °C	Higher temperature accelerates bio-reduction kinetics, favouring rapid nucleation and smaller, more spherical particles; excessive heat can degrade	Song & Kim (2009); Dennettia tripetala study

Parameter	Typical Range Studied	General Effect on Nanoparticle Characteristics	Representative Reference
		thermolabile phytochemicals and promote Ostwald ripening.	
Reaction / incubation time	Minutes to 48 h	Longer contact time increases conversion of metal ions and can improve monodispersity, but prolonged exposure may cause secondary aggregation or Ostwald ripening.	Verbascum sinaiticum study; Kenaf leaf study
Extract-to-precursor ratio	1:1 – 1:10	A balanced ratio maximises reducing/capping agent availability relative to metal ions; extreme ratios either starve the reaction of reductant or leave excess unreduced metal ions.	Acacia cyanophylla study
Light / illumination	Dark, ambient, sunlight, UV	Light can accelerate photo-induced reduction and alter particle morphology and yield, with sunlight often producing faster colour change than dark incubation.	Vitex agnus-castus study
Plant part / phytochemical profile	Leaf, fruit, peel, root, seed	Different plant parts contain distinct concentrations of flavonoids, phenolics, tannins and alkaloids, causing marked differences in reduction rate, capping efficiency, and resulting nanoparticle morphology.	Marchiol et al. (2014); Marslin et al. (2018)

It is crucial to stress that these factors do not function independently: pH affects an extract's effective reducing strength at a particular temperature; temperature affects phytochemical solubility, which in turn affects the effective extract concentration; and reaction time determines whether a particular combination of pH, temperature, and concentration is allowed to reach completion or is stopped at an intermediate stage. As demonstrated by studies optimizing temperature, pH, reaction time, extract concentration, and salt concentration simultaneously for zinc-oxide nanoparticle synthesis from *Silybum marianum* seed extract, a growing number of recent studies use statistical design-of-experiments techniques, such as response-surface methodology and central composite design, to identify jointly optimal parameter combinations rather than varying one factor at a time.

4. Characterisation of Green-Synthesised Nanoparticles

A uniform set of analytical procedures is usually used for the confirmation and characterization of plant-synthesised nanoparticles. As a first-line, quick confirmation method, ultraviolet-visible spectroscopy takes advantage of the excitonic absorption edge of semiconducting metal oxides like zinc oxide and the distinctive surface-plasmon-resonance absorption of metallic nanoparticles (such as 400–450 nanometers for silver and 520–540 nanometers for gold). By identifying the functional groups of the capping phytochemicals adsorbed on the nanoparticle surface, Fourier-transform infrared spectroscopy offers indirect proof of the biomolecules in charge of stabilization and reduction. While transmission and scanning electron microscopy (typically in conjunction with energy-dispersive X-ray spectroscopy) offer direct visualization of particle shape, size distribution, and elemental content, X-ray diffraction verifies the crystalline phase and crystallite size of the nanoparticles. Hydrodynamic particle size, polydispersity index, and surface charge are measured via dynamic light scattering and zeta-potential tests. The latter is a crucial sign of colloidal stability resulting from electrostatic repulsion between capped particles.

5. Representative Applications of Plant-Mediated Nanoparticles

The aforementioned process parameters indirectly control the functional performance of green-synthesised nanoparticles in downstream applications as they directly affect nanoparticle size, shape, and surface chemistry. Strong antibacterial and antifungal activity against both Gram-positive and Gram-negative pathogens have been repeatedly shown by silver and copper nanoparticles synthesized under ideal pH, concentration, and temperature conditions. This activity is typically attributed to disruption of bacterial cell membranes, production of reactive oxygen species, and interference with microbial DNA replication. The size and crystallinity established during synthesis determine the degradation efficiency of zinc-oxide and copper-oxide nanoparticles, which have demonstrated antibacterial, antifungal, and, in many investigations, photocatalytic dye-degradation activity important to wastewater treatment. The anticancer, antioxidant, and anti-inflammatory properties of gold and silver nanoparticles made under particular pH and temperature regimes have also been studied, as have colorimetric sensing applications like ammonia detection that depend on precisely regulated particle size and aggregation behavior. Green-synthesised metal and metal-oxide nanoparticles have been investigated in environmental remediation as adsorbents and photocatalysts for the removal of dyes and heavy metals from water, as well as in agriculture as nano-fertilizers, nano-pesticides, and seed-treatment agents.

6. Challenges and Future Perspectives

Despite the significant advancements outlined above, a number of obstacles prevent plant-mediated nanoparticle production from being widely used in industry. First, the phytochemical composition of plant extracts varies with species, geographic origin, harvest season, plant age, and extraction technique, making it challenging to transfer optimized parameters from one batch of extract to another without re-optimization. This is why reproducibility is still a persistent concern. Second, a broader use of response-surface methodology and other design-of-experiments approaches is required to find robust, jointly optimal conditions. The majority of published optimization studies vary one parameter at a time, which cannot fully capture the interactive effects

between pH, concentration, temperature, and time. Third, additional heat- and mass-transfer factors are introduced when laboratory-scale (usually milliliter-to-liter) reactions are scaled up to industrially relevant quantities. These factors may change the effective reaction conditions that the extract and precursor encounter. Lastly, even though green synthesis is typically thought to be safer than chemical reduction methods, there are still relatively few thorough toxicological and environmental-fate studies of green-synthesised nanoparticles, and more research is needed to establish safe-by-design principles for their widespread use in food, agriculture, and medicine. In order to improve cross-study comparability, future research directions include developing standardized reporting protocols for plant-extract preparation and reaction conditions; increasing the use of statistical optimization and machine learning-assisted prediction of nanoparticle properties from reaction parameters; and continuing mechanistic investigation using methods like liquid-cell electron microscopy and in-situ spectroscopy to better resolve the nucleation and growth pathways that link reaction conditions to final nanoparticle architecture.

7. Conclusion

A sustainable, affordable, and biocompatible substitute for traditional chemical and physical production techniques is the green synthesis of metallic and metal-oxide nanoparticles from plant extracts. The evidence reviewed here shows that the size, shape, yield, crystallinity, and stability of the resultant nanoparticles are determined by a combination of reaction pH, metal-precursor concentration, plant-extract concentration and extract-to-precursor ratio, temperature, reaction time, and, to a lesser extent, illumination. Broadly consistent trends are seen across silver, gold, copper, and zinc-oxide systems: moderate, near-neutral-to-alkaline pH, an intermediate precursor concentration (typically close to 1 millimolar for silver systems), sufficient but not excessive extract concentration, a moderately elevated temperature, and an empirically determined optimal reaction time. The most promising path toward repeatable, application-tailored green nanoparticle synthesis suitable for eventual industrial-scale production is through systematic, statistically designed optimization studies rather than single-factor experiments because these parameters interact strongly with one another and with the particular phytochemical profile of the plant source used.

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