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REVIEW ARTICLE
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Green Synthesis of Nanoparticles Using Plants: (Article Review)

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ABSTRACT

Green synthesis of nanoparticles using plants has rapidly emerged as an environmentally friendly, cost-effective, and sustainable approach within the expanding field of nanotechnology. This comprehensive review aims to thoroughly explore the potential of plant-mediated synthesis as a viable alternative to traditional chemical and physical methods of nanoparticle production, which often rely on toxic chemicals, hazardous reagents, and energy-intensive processes. These bioactive compounds play a crucial role in controlling the nanoparticles' size, shape, and stability, allowing for precise and efficient nanoparticle formation. Despite these advantages, the review also addresses several challenges and limitations associated with scaling up the process for industrial applications, such as standardisation, consistency, and cost-effectiveness. In addition, the review investigates the promising potential applications of plant-derived nanoparticles in various fields, including biomedicine, environmental restoration, agriculture, and energy. These applications illustrate the transformative potential of plant-mediated nanoparticle synthesis in addressing global sustainability challenges, underscoring the role of green nanotechnology in advancing eco-friendly and sustainable solutions for the future. Ultimately, the review emphasises the growing importance of plant-based approaches in developing next-generation nanoparticles and their potential to drive the future of sustainable nanotechnology.

***Keywords*:** Nanoparticles, nanotechnology, plant, biosynthesis.

INTRODUCTION

Nanoparticles are particles between 1 and 100 nanometers, with unique properties due to their small size and high surface area. Traditional methods for synthesising nanoparticles often involve toxic chemicals and high energy consumption, leading to environmental and health concerns [1]. Green synthesis methods, mainly plant extracts, have emerged as eco-friendly and sustainable alternatives. Plant-mediated synthesis utilises natural biomolecules found in plants to reduce metal ions into nanoparticles [2], offering a simple, cost-effective, and environmentally benign approach. Nanotechnology has emerged as a revolutionary field with applications in medicine, electronics, environmental science and agriculture [3]. One promising aspect of nanotechnology is the biosynthesis of nanoparticles (NPs) using biological organisms, including plants. This method is environmentally eco-friendly, cost-effective and sustainable compared to traditional physical and chemical synthesis methods [4].

Mechanisms of Plant-Mediated Biosynthesis Plants synthesise nanoparticles through biochemical reactions involving plant extracts. These extracts contain various biomolecules such as alkaloids, flavonoids, terpenoids, phenolic compounds, proteins and enzymes that act as reducing and limiting agents [5,6]. The general process of plant biosynthesis can be summarised as follows:

1. Selection of plant material: Leaves, roots, stems, flowers or fruits are selected based on their phytochemical composition.

2. Preparation plant extract material is cleaned, dried and ground into a fine powder, then extracted with solvents such as water, ethanol or methanol.

Solvent extraction: The powder is mixed with a suitable solvent (usually water, ethanol or methanol) and heated to extract the bioactive compounds. The mixture is then filtered to obtain a clear plant extract

3. Mix with a metal salt solution: The plant extract is mixed with a metal salt solution ((e.g. silver nitrate for AgNPs, chloroauric acid for AuNPs, zinc acetate for ZnONPs) is prepared in distilled water as a result of which metal ions are reduced to metal nanoparticles. [7]

4. Agitation: The plant extract is added to the metallic salt solution with constant stirring. The volume ratio and concentration of the plant extract to the metal salt solution are critical and can affect the size and shape of nanoparticles.
5. Reduction and Stabilization. Bio reduction: Phytochemicals such as flavonoids, alkaloids, terpenoids, phenolic acids and proteins in the plant extract act as reducing agents. They donate electrons to the metal ions, reducing them to their elementary nanoparticles
6. Formation of nanoparticles: Bio reduction of metal ions leads to the formation of nanoparticles, which are then stabilised by blocking agents in the plant extract.
7. Stabilization: The same phytochemicals also act as masking agents and adhere to the surface of nanoparticles. This coating prevents agglomeration by providing a protective layer around each nanoparticle, improving their stability and solubility [8]

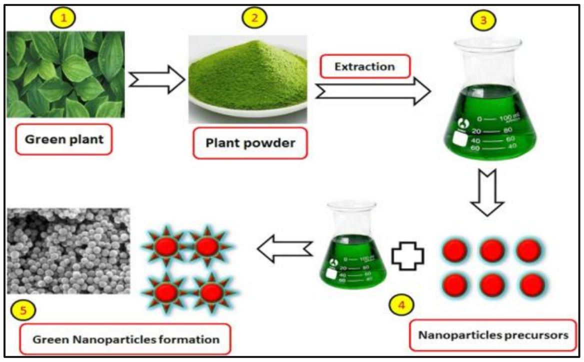

Figure: Green Synthesis of Nanoparticles from Plant Extracts 8. Ageing: The solution can mature, allowing the nanoparticles to develop and stabilise fully. This step can last from a few hours to several days, depending on the specific synthesis conditions and the desired properties of the nanoparticles.
9. Purification: The synthesised
nanoparticles are separated from the reaction mixture by centrifugation. This process involves spinning the solution at high speed to arrange the nanoparticles at the bottom of the centrifuge tube
10. Washing: The settled nanoparticles are washed several times with distilled water or ethanol to remove unreacted plant extract and metal ions.
11. Drying: purified nanoparticles are usually dried in powder form in a vacuum dryer or oven. [8.9]
12. Characterization: Physical and chemical analysis: The synthesised nanoparticles archaracterised by various techniques to determine their size, shape, structure and chemical composition. Standard techniques included the following
a) Scanning Electron Microscopy (SEM) provides images of the surface morphology of nanoparticles
b) Transmission Electron Microscopy (TEM): provides detailed images of nanoparticles' internal structure and size.
c) X-ray diffraction (XRD): identifies crystal structure and phase composition.[12]
d) Fourier transform infrared spectroscopy (FTIR): to analyse the functional groups involved in the reduction and stabilisation process.
e) UV-Visible Spectroscopy (UV-Vis): Monitors the formation and stability of nanoparticles by measuring their absorption spectra.[10]
Typessy nthesised nanoparticles
1. Metal Nanoparticles: Gold nanoparticles (AuNPs) are synthesised by extracts from plants such as tea (*Camellia sinensis*) and turmeric (). AuNPs are used in medical imaging and drug delivery.[11]
2. Metal oxide nanoparticles: Zinc oxide nanoparticles (ZnONPs) synthesised with green tea (*Camellia sinensis*) and eucalyptus (*Eucalyptus globulus*) extracts. ZnONPs are used in sunscreens and antimicrobial coatings[12,13].

Characterisation techniques synthesised nanoparticles

Synthesis plays a crucial role in understanding the properties of nanoparticles synthesised using plant extracts. Various methods are employed to characterise these nanoparticles, ensuring their size, shape, stability, and other essential parameters are determined accurately.[14] Standard techniques used for characterisation include X-ray Diffraction (XRD) analysis, Fourier Transform Infrared (FTIR) spectroscopy, UV-visible spectrophotometry, Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), Dynamic Light Scattering (DLS), Energy Dispersive X-ray (EDX) spectroscopy, and Transmission Electron Microscopy (TEM) [15,16]. These techniques provide valuable insights into the physical and chemical properties of the nanoparticles, aiding in their further applications in various fields. XRD analysis is utilised to determine the crystalline structure of the nanoparticles, while FTIR spectroscopy helps identify the functional groups on the nanoparticle surface [17]. UV-visible spectrophotometry is commonly employed for primary characterisation and monitoring of the stability of nanoparticles, as it is fast, simple, and does not require complex calibration.SEM and TEM are used to visualise the morphology and size of nanoparticles at the micro and nanoscale, respectively. AFM is crucial for assessing nanoparticle surface morphology, particle size, and roughness [18]. DLS is particularly suitable for measuring the hydrodynamic diameter and particle size distribution of nanoparticles in solution, providing insights into their dispersity [19,20]. These characterisation techniques collectively offer a comprehensive understanding of the synthesised nanoparticles, enabling researchers to tailor their properties for specific applications. By combining these techniques, researchers can ensure plant-synthesised nanoparticles' quality, stability, and functionality, paving the way for their diverse applications in fields such as medicine, agriculture, electronics, and materials science [21,22].

Table 1: Summary of Characterization Techniques for Nanoparticles

Technique	Purpose	Advantages	Example Reference
Scanning Electron Microscopy (SEM)	Surface morphology and size	High-resolution images, 3D appearance	[Iravani, 2011][1]
Transmission Electron Microscopy (TEM)	Internal structure and crystallinity	High magnification, atomic scale	[Jha et al., 2009][2]
X-ray diffraction (XRD)	Crystalline structure and phase	Non-destructive, detailed structure	[Iravani, 2011][3]
Fourier Transform Infrared Spectroscopy (FTIR)	Functional groups in plant extract	Chemical interactions, stabilisation	[Raghunandan et al., 2011][4]
UV-Visible Spectroscopy (UV-Vis)	Formation and stability of nanoparticles	Simple, quick, non-destructive	[Raghunandan et al., 2011][5]

Types of Nanoparticles Synthesized using different plant extracts

1-SilverNanoparticles (AgNPs): **Ocimum sanctum**: Synthesis of silver nanoparticles using *Ocimum sanctum* (holy basil) leaf extract was reported by [23]. The nanoparticles exhibited significant antimicrobial activity. **Azadirachta indica**: Ahmad et al. (2011) used neem (*Azadirachta indica*) leaf extract to synthesise AgNPs. These nanoparticles showed potential as an antimicrobial agent [24]. **2-GoldNanoparticles (AuNPs)**: **Pelargonium graveolens**: Shankar et al. (2003) demonstrated the synthesis of gold nanoparticles using geranium (*Pelargonium graveolens*) leaf extract. The AuNPs were found to be stable and had a spherical shape.

Cinnamon zeylanicum: Li et al. (2011) synthesised gold nanoparticles using *Cinnamon zeylanicum* bark extract. The nanoparticles exhibited good catalytic activity [25].

3-ZincOxideNanoparticles (ZnONPs): **Aloe vera**: Singh et al. (2014) used *Aloe vera* leaf extract for the green synthesis of ZnONPs. The nanoparticles showed excellent antibacterial properties. **Calotropis gigantea**: Rajiv et al. (2013) reported the synthesis of zinc oxide nanoparticles using *Calotropis gigantea* latex. The ZnONPs exhibited photocatalytic activity [26].

4-Titanium dioxide nanoparticles (TiO2NP): synthesised by extracts of plants such as Moringa oleifera. TiO2NPs are used in photocatalysis and solar cells

5-Bimetallic nanoparticles (e.g., Ag-AuNPs) are synthesised with extracts from plants such as rose (Rosa indica) and clove (Syzygium aromaticum). These nanoparticles have better catalytic and antimicrobial properties. [27]

Table 2: Types of Nanoparticles Synthesized Using Plant Extracts

Type of Nanoparticle	Plant Extract Used	Reference
Silver (AgNPs)	Neem (*Azadirachta indica*)	Raghunandan et al., 2011

Gold (AuNPs)	Tea (*Camellia sinensis*)	Jha et al., 2009
	Turmeric (*Curcuma longa*)	Iravani, 2011
Zinc Oxide (ZnONPs)	Green tea (*Camellia sinensis*)	Jha et al., 2009
	Eucalyptus (*Eucalyptus globulus*)	Iravani, 2011
Titanium Dioxide (TiO_2NPs)	*Moringa oleifera*	Iravani, 2011
Bimetallic (Ag-AuNPs)	Rose (*Rosa indica*)	Jha et al., 2009
	Clove (*Syzygium aromaticum*)	Iravani, 2011

Factors Influencing Plant-Based Synthesis of Nanoparticles

1. Type of Plant and Plant Extract

1.1Plant species

Different plant species contain different concentrations of phytochemicals (e.g. phenols, flavonoids, terpenoids and alkaloids), which act as reducing and limiting agents. These phytochemicals significantly affect the synthesis and properties of nanoparticles.[28]

1.2 The plant part (e.g., leaves, stems, roots, fruits, and seeds) affects the type and amount of phytochemicals used, affecting the synthesis process. For example, leaf extracts are often used because of their high phytochemical content. [29]

2. Extraction conditions

2.1Type of solvent

The choice of solvent (e.g. water, ethanol, methanol) used to extract plant phytochemicals plays a critical role in the efficiency and effectiveness of the synthesis. Water is usually used because it is environmentall friendly and can extract various phytochemicals.[30]

2.2Temperature and time of extraction

The temperature and duration of the extraction process affect the concentration of phytochemicals in the extract. Higher temperatures and longer extraction times generally increase the yield of phytochemicals but may also degrade some compounds.[31]

3. Concentration of plant extract

The concentration of plant extract used in the synthesis process affects the size and shape of the nanoparticles. Higher extract concentrations typically result in smaller nanoparticles due to the greater availability of reducing agents.[32]

4. Metal ion concentration

The concentration of metal ions (e.g., silver nitrate, gold chloride) in the reaction mixture is crucial for the synthesis of nanoparticles. An optimal concentration is required to achieve the desired nanoparticle size and morphology.[33]

5. pH of the reaction mixture

The pH of the reaction mixture significantly affects the reduction process and the stability of the nanoparticles. Different pH levels can cause the formation of nanoparticles of different shapes and sizes. A neutral or slightly alkaline pH is usually preferred for most plant synthesis processes

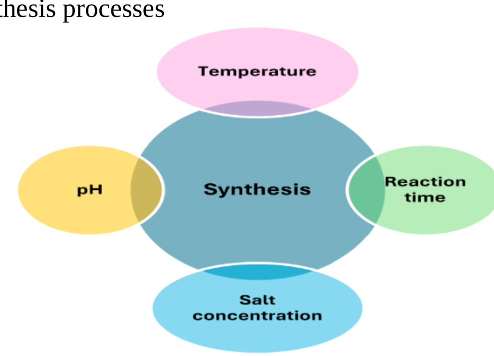

Figure: Key Factors Influencing Synthesis

6-Reaction temperature

The temperature at which the synthesis reaction takes place affects the reduction of metal ions and the growth rate of nanoparticles. Higher temperatures speed up the reduction process, leading to faster synthesis and potentially smaller nanoparticles.[34,35].

7. Reaction time

The duration of the synthetic reaction affects the nanoparticles' size and aggregation. Longer reaction times allow complete reduction of metal ions but can also lead to nanoparticle aggregation if not adequately controlled.

8. Agitation
The method of agitation during the synthesis process can affect the uniformity and size distribution of the nanoparticles. Adequate mixing ensures a uniform distribution of metal ions and plant extracts, leading to a more uniform synthesis of nanoparticles.

Applications of Plant-Synthesized Nanoparticles

Medical Applications:

1-Antimicrobial agents: plant-synthesized nanoparticles have shown broad-spectrum antimicrobial activity against various pathogens, including bacteria, fungi and viruses.

Drug delivery: Nanoparticles can be used as carriers for drug delivery, improving the bioavailability and targeted delivery of therapeutic agents.

2. Environmental Applications:

Pollution Control: Metal nanoparticles synthesized by plants can remove pollutants from water and air through adsorption and degradation mechanisms.

Wastewater treatment: Nanoparticles such as ZnONPs and AgNPs are effective in wastewater treatment by breaking down organic pollutants and disinfecting pathogens.

3. Agricultural Applications:

Insecticides and Fertilizers: Nanoparticles can develop nanopesticides and nanofertilizers that offer controlled release and better efficacy than conventional products. [36]

Plant-based synthesis of nanoparticles has attracted significant interest due to its Advantages

1. Environmentally Friendly Process

Plant-based synthesis is considered environmentally friendly because it avoids using toxic chemicals usually required in conventional synthesis methods. The process uses natural plant extracts that are biodegradable and less harmful to the environment

2. Cost-effective

Using plants as a source for nanoparticle synthesis can be more cost-effective than traditional methods. The plants are readily available and can be grown quickly, thus reducing the total cost of production. [36]

3. Scalability

The process can be easily scaled up for large-scale production. Because it uses plant extracts, the synthesis can be done in bulk without special equipment.

4. Biocompatibility

Nanoparticles synthesised with plant extracts are generally biocompatible and less toxic, making them suitable for medical and pharmaceutical applications.

5. Different reducing agents

Plants contain different biomolecules (e.g., alkaloids, terpenoids, flavonoids, phenols) that can act as reducing and stabilising agents, forming nanoparticles of different shapes and sizes. [37]

Disadvantages

1. Lack of control over particle size and shape. Biological methods can result in nanoparticles of widely varying sizes and shapes, which may not be suitable for applications that require uniform particles.

2. Variability of Plant Extracts

The composition of plant extracts can vary depending on several factors, such as season, geographic location, and part of the plant used, leading to inconsistencies in the synthesis process. [38]

3. Purification Challenges

Extraction and purification of nanoparticles from plant-based synthesis can be harrowing and require additional steps that can increase the complexity and cost of the process

4. Possibility of contamination

There is a risk of contamination by plant pathogens or other biological entities that can affect the purity and quality of the synthesised nanoparticles. While scalability is generally an advantage, some of the equipment used for nanoparticle synthesis may not be available in large quantities, limiting mass production. [39]

Conclusion

Plant-mediated nanoparticle biosynthesis is a promising field of research that offers a green and sustainable approach to the production of nanomaterials. With continued development and research, this method could revolutionise several fields, including medicine, environmental science, and agriculture. The synthesis of nanoparticles using plant extracts is influenced by many factors, including the type of plant and plant part used, extraction conditions, plant extract and metal ion concentrations, pH, temperature, reaction time and mixing conditions. Understanding and optimising these factors can lead to efficient production of nanoparticles with desired properties, making plant-based synthesis a profitable and environmentally friendly alternative to traditional chemical methods. Continued research in this area will further improve the process and increase its applicability in various industrial and medical fields. By paying attention to these influencing factors, scientists can better control the synthesis process, producing more uniform and higher-quality nanoparticles. Characterisation of nanoparticles synthesised using plant extracts is essential for understanding their properties and potential applications. Techniques such as SEM, TEM, XRD, FTIR, and UV-Vis spectroscopy provide comprehensive information on the nanoparticles' size, shape, structure, and chemical composition. This understanding helps optimise the synthesis process and tailor the nanoparticles for specific uses**.**

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التخليق الأخضر للجسيمات النانوية باستخدام النباتات: (مقالة مراجعة).

كوثر حكيم ابراهيم
قسم التربة والموارد المائية. كلية الزراعة. جامعة كركوك. كركوك. العراق.

الخلاصة
ظهر التخليق الأخضر للجسيمات النانوية من النباتات كنهج صديق للبيئة ومستدام في مجال تقنية النانو. تستعرض هذه المراجعة الشاملة إمكانات التخليق النباتي كبديل فعال للطرق الكيميائية والفيزيائية التقليدية، التي غالبًا ما تتضمن موادًا خطرة واستهلاكًا عاليًا للطاقة. تعمل المستخلصات النباتية الغنية بالمركبات النشطة بيولوجيًا، مثل القلويدات والتربينويدات والفلافونويدات والفينولات، كعوامل مختزلة ومثبتة في عملية تخليق الجسيمات النانوية.
تتناول هذه المراجعة الأنواع النباتية المختلفة المستخدمة في تخليق الجسيمات النانوية المعدنية، بما في ذلك الذهب والفضة والبلاتين والنحاس، كما تناقش الآليات المتبعة في تكوين هذه الجسيمات. بالإضافة إلى ذلك، تسلط المراجعة الضوء على مزايا التخليق الأخضر، مثل التوافق الحيوي، وانخفاض السمية، والاستدامة البيئية، إلى جانب التحديات والقيود المرتبطة بتوسيع العملية لتطبيقات صناعية. كما يتم استكشاف التطبيقات المحتملة للجسيمات النانوية النباتية في مجالات الطب الحيوي، واستعادة البيئة، والزراعة، مع التأكيد على دور تقنية النانو الخضراء كمحفز للاستدامة.

الكلمات المفتاحية: التخليق الأخضر، الجسيمات النانوية، تقنية النانو.