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RESEARCH ARTICLE

Diversity and Green Synthesis of Various Metal Nanoparticles (MNPs)

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Abstract

The review provides a comprehensive overview of metal nanoparticles (MNPs) synthesized using green methods, including gold, silver, copper, zinc oxide, and other metallic nanoparticles. The synthesis of MNPs has become a cornerstone of nanotechnology, given their unique physicochemical properties and vast applications. Traditional methods for MNP synthesis often involve hazardous chemicals and energy-intensive processes, raising environmental and safety concerns. In response, green synthesis has emerged as a sustainable and eco-friendly alternative. This review explores the diversity of green synthesis approaches for producing MNPs, emphasizing their advantages, challenges, and potential applications. The article highlights the role of biomolecules, in mediating the reduction of metal ions and stabilizing nanoparticles. This article underscores the transformative potential of green synthesis in advancing the sustainable production of MNPs while minimizing ecological impact.

Keywords: Green synthesis, Metal Nanoparticles, AgNPs, AuNPs, ZnNPs, CuNPS.

Introduction

The advancement in nanotechnology has represented a major milestone in history. Nanotechnology encompasses creation, management, structure visualization that measure between 1 and 100 nanometres (Kumar *et al*., 2017). Nanotechnology has opened up innovative possibilities across various sectors, including food packaging, livestock management, electronics, agriculture, medicine, and healthcare. Furthermore, it represents one of the latest advancements in industry (Balachandar *et al*., 2019). The area of Nanotechnology has emerged as a revolutionary technology in the twenty-first century. It is a multidisciplinary domain focused on processing that are less than 100 nm in scale. It operates at a molecular level and has recently expanded into a wide range of applications. In recent times, a variety of innovative technologies that rely significantly on nanotechnology have come to the forefront, including areas like various sectors of industries and photo-electrochemical applications. There is specific attention on nanoparticles due extremely minute size changes properties compared to larger counterparts and uses (Ray, 2010). Nanoparticles exhibit superior characteristics due to molecular level reactions occurring at its surfaces, ensuring a lower synchronization compared to major contents.

Nanoparticles classified on either non-metallic or metallic depending upon their fundamental compositions. Metallic nanoparticles typically consist of materials such as Au, Ag, Cu, and other substances like Co and Ni, as well as semiconducting elements. Extensive invention carried out because of due to their unique characteristics. Various techniques, such as thermal decomposition and chemical reduction, are available for synthesizing nanoparticles. However, these methods frequently involve expensive and hazardous chemicals. Recently, biological methods have gained popularity as a safer, more cost-effective, and environmentally friendly alternative. Nano-biotechnology, which focuses on creating tiny particles, has considerable potential in the fields of medicine. Such tiny material possess distinctive characteristics, rendering useful to a

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variety of utilities. Various particles such as Ti, Mg, Fe, Zn, and Ag showcase different properties. In particular, silver nanoparticles are essential in cellular processes, serving as analytical and diagnostic tools to detect health issues and influence cellular functions.

Green Synthesis of MNPs

Nanotechnology involves applying technical hypothesis for synthesis materials, such method expands possibilities to explore the occurrence at the cellular level, facilitating the delivery of therapeutic substances, enhancing cancer diagnosis through imaging techniques, developing artificial implants, suppressing HIV, and purifying water (John *et al*., 2008). Various photochemical techniques can employed to create different types of nanoparticles. These methods include number of synthesis techniques. Noble metal nanoparticles (MNPs) have attracted considerable attention recently because of its remarkable characteristics, offering unique advantages. Among these benefits, MNPs has remarkable importance for biomedical and pharmaceutical industries because it appealing physico-chemical properties. Historically, Ag used in the treatment & prevention of different infectious diseases and other disorders (Shankar *et al*., 2004).

Based upon natural metabolism capabilities, different microorganisms like bacteria, fungi, as well as plant parts utilized in the environmentally friendly fabrication of MNPs. Generally, such microbes aid in conversion for metallic components. Although, numerous techniques in generating AgNPs, synthesis aided by microorganisms is currently challenging due to the need for highly sterile conditions and upkeep (Kalishwaralal *et al*., 2010). Plants serves like wonderful platform in synthesizing material due to they does not contain harmful synthetic materials. Currently, researchers are increasingly focusing on green chemistry through biological procedures in the MNPs fabrication. In contrast, traditional procedures for synthesizing nanoparticles often result in the release of various toxic chemicals that pose risks. This highlights the importance of utilizing green methods for nanoparticle synthesis. Green synthesis presents a straightforward, economical, and eco-friendly approach for creating nanoparticles. Nanoparticles can be synthesized using various parts of plants and algae (Rai *et al*., 2021). Typically, NPs could be fabricated by different methods. This encompasses physical, chemical, and biological techniques. If the electron source is a physical entity like electric current, it is termed physical, and if it comes from an organism, the method is considered biological, includes various techniques (Okpara *et al*., 2021).

MNPs have been developed through different synthesis processes. Chemical reducing agents used in creating Pt, Ag & Au NPs (Karunakaran *et al*., 2023). While MNPs can be produced effectively and cost-effectively using chemical and physical methods, recent research aims to develop environmentally friendly MNPs through biological processes. This shift can be attributed to the harmful byproducts and significant energy demands combinations of chemical fabrications for MNPs. Appling chemical solvents during the fabrication process raises concerns about potential contamination of MNPs intended for medical applications. The residues from chemical solvents may themselves pose carcinogenic, mutagenic, and cytotoxic risks (Nath and Banerjee, 2013). Moreover, differences in the physicochemical properties and shapes of MNPs produced through chemical and physical means are correlated with varying levels of toxicity. Gold nanoparticles (15 nm) have been found to be deadly for fibroblast (Sukhanova *et al*., 2018). Furthermore, certain nanocomponents exhibit higher toxicity because of its superior capability to penetrate cell membranes, leading to significant cytotoxic effects. Similarly, nano spike titanium dioxide nanoparticles have been shown to activate inflammasomes (Wang *et al*., 2018).

Certainly, some of the techniques mentioned earlier are straightforward and dependable; however, many of these approaches rely on harsh, toxic, and costly chemicals that can have detrimental effects on medical sciences, biosciences, and environmental factors. However, such techniques demonstrated high efficiency in synthesizing nanoparticles (NPs), their associated drawbacks cannot be ignored. Furthermore, it tends to be quite expensive, and there is also the potential for the development of surface structural imperfections (Fig. 1) (Okpara *et al*., 2021).

The biogenic fabrication for NPs, an area for knowledge, which is MNPs lethality, fast advancing within realm for bio nanotechnology (Biresaw and Taneja, 2021). Moreover, in the light of environment friendly considerations, appropriate, straightforward synthesis method because of its safe nature with environmental sustainability, its benefits regarding simple reaction setups and cost-effective parameters, to our knowledge. Utilizing water as a solvent helps decrease lethal effect, making this approach beneficial for pharmaceutical and biomedical uses. The biosynthesis method offers improved alternatives of traditional procedures. As per the current scenario, biogenic NPs fabrication becomes increasingly popular because of its numerous benefits over traditional processes (Siddiqui *et al*., 2020).

According to green chemistry principles, different fabrication procedures for metal nanoparticles. Green synthesis offers natural alternatives for synthesis process. Process for reducing MNPs from metal salts is effective, non-toxic, as well as easy to carry out. Nanoparticles produced from biological sources of plant extracts serve as reservoirs for plant secondary metabolites enhances their properties and broad utilities (Atri *et al*., 2023). Consequently, development for environmentally friendly protocols has become crucial in the synthesis of nanomaterials, because it is clean, safe, straightforward, economic and rapid, hence highly favourable (Khara *et al*., 2017).

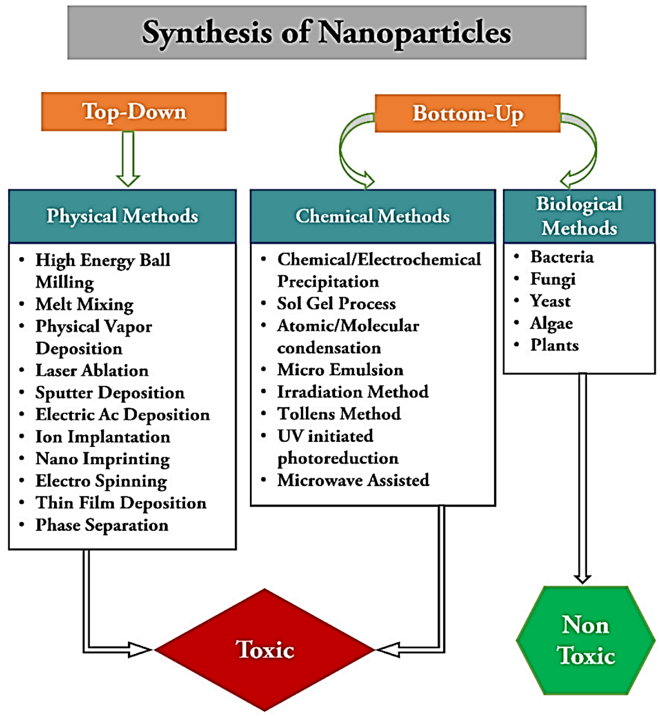

Fig. 1: Fabrication of various NPs using various techniques (Raj *et al*., 2021).

Process of using biological entities in nanoparticle fabrication referred to biosynthesis. This approach is contemporary another type of nanoparticle production (Manasa *et al*., 2021). Green synthesis stands out as an important appropriate procedure of NPs generation. Nanoparticles can be fabricated from different sources, like algae, microbes, fungi, plants, utilized in nanoparticle synthesis process. Medicinal plants are particularly favoured for the NPs fabrication due to its effective capacity against ailments like diabetes, ulcers, cancer, inflammation, and asthma. Moreover, medicinal plants are commonly employed for remedies due to their lower side effects and cost efficiency.

Plants are capable of bio-mineralizing materials such as calcium carbonate, silica, and even magnetite within their structures. Like microorganisms, certain plants can also be utilized to cleanse soil and water contaminated with heavy metal ions. Some species are known for their ability as they provoked for gather them in specific parts of the plant. Potential for biogenic material, along with existence for binding agents within them, attracts materials scientists to explore the use of plants for NPs fabrication, as well as for investigating the formation of nanoparticles made from metals with low reduction potential. The ability to create NPs using non-biological techniques, addressing growing concerns about environmental degradation and biological risks. Furthermore, this process is cost-effective and has the potential for scalability in large-scale synthesis (Chau *et al*., 2021).

Diversity of MNPs

The emergence of nanotechnology has represented a crucial moment in history. This field includes production, management, visualization of minute constructions measuring between 1 and 100 nm. Small materials exhibit improved characteristics due to molecular level exchanges at surfaces, leading to fewer synchronization compared to large molecules. It could be classified as either metallic or non-metallic upon fundamental structure. Literature survey for will provide readers with a concise understanding of the methodologies, reaction conditions, and optimization techniques involved. Phytochemicals with reducing capabilities can aid in transforming metal ions (Rana *et al*., 2020). Such phytoconstituents, facilitating their reduction, resulting in development of specific materials. The reduction process is often supported by suitable reaction parameters. Various phytoconstituents possess differing level's efficiency during the processes (Yuliarto *et al*., 2019). Because of elevated surrounding energy& potentiality, metallic materials prone to aggregation or oxidation.

As AgNPs having distinctive properties, have been extensively researched. As a result, AgNPs possess utilities in biosensing, nanodevice creation, medical uses (Jain *et al*., 2008). Biosynthesizing process is straightforward and involves the interaction between silver nitrate ($AgNO_3$) with phytoconstituents. Formation occurs in three main stages: an ion reduction reaction initiates the clustering. Every phase exhibits distinct characteristics based on factors like the type of reducing agent, its concentration, $AgNO_3$ levels, and pH.

Table 1: Studies carries out to synthesis various metal nanoparticles using green route and their applications.

No.	*Green source*	*Source part*	*Type of NPs*	*Application*	*References*
1	Nigella sativa	Seeds	Ag	Antimicrobial activity	Ferdous *et al*., 2024
2	Oxalis griffithii	Leaf	Ag	Antimicrobial activity	Single *et al*., 2022
3	Citrus limetta	Peel	Au	Antioxidant & catalytic activity	Sivakavinesan *et al*., 2022
4	Echinacea angustifolia	Flower	Au	Antibacterial activity	Attar *et al*., 2018
5	Pluchea sericea	Leaf	Cu	Insecticide activity	Leon-Jimenez *et al*., 2019
6	Jasmin sambac	Leaf	CuO	Dye degradation	Nouren *et al*., 2024
7	Arctium lappa	Whole plant	ZnO	Cytotoxic activity	Dobrucka *et al*., 2020
8	Eucalyptus globulus	Leaves	Zn	Industrial paint	Majeed *et al*., 2024
9	Acacia nilotica	Leaf	NiO	Electrochemical and biological properties	Hussain *et al*., 2023
10	Aegle marmelos	Leaves	FeO	Chromium stress and anti-oxidative potential	Zafar *et al*., 2024
11	Ageratina altissima	Leaf	TiO	Photocatalytic degradation activity	Ganesan *et al*., 2016
12	Artemisia abrotanum	Whole plant	MgO	Antioxidant and photocatalytic activity	Dobrucka 2016
13	Artemisia chamaemelifolia	Aerial	Se	Anticancer and antibacterial	Keshtmand *et al*., 2023
14	Azadirachta indica	Leaf	AlO	Optical	Ikhioya and Nkele, 2024
15	Curcuma longa	Root	Pd	Antioxidant, antimicrobial, and anticancer	Sattar *et al*., 2024
16	Portulaca oleracea	Leaves	CeO	Photocatalytic activity	Hkiri *et al*., 2024
17	Syzygium cumini	Leaf	CdO	Anti-corrosive electrochemical performance	Sivalingam *et al*., 2024
18	Taraxacum officinale	Leaf	CoO	Catalytic activity	Rasheed *et al*., 2019
19	Terminalia bellirica	Fruits	MgO	Antioxidant and anticancer	Patil *et al*., 2024

Ag: Silver; Au: Gold; Cu: Copper; CuO: Copper oxide; Zn: Zinc; ZnO: Zinc oxide; AlO: Aluminium oxide; CdO: Cadmium oxide; CeO: Cerium oxide; CoO: Cobalt oxide; Fe: Iron; FeO: Iron oxide; MgO: Magnesium oxide; NiO: Nickel oxide; Pd: Palladium; Se: Selenium; TiO: Titanium oxide

$AgNO_3$ concentration has very important contribution in AgNPs production. Higher $AgNO_3$ concentrations affects on nanoparticle production. Additionally, it may lead to larger nanoparticles (Bar *et al*., 2009). The biosynthetic approach is considered green, non-toxic, compatible with biological systems, and environmentally sustainable for synthesis. Various material of plant like, stems, buds, peels, rhizomes, were employed in nanoparticle fabrication, based on the specific phytochemicals in their extracts (Abdelghany *et al*., 2023). In biomedical fields, silver nanoparticles (AgNPs) are frequently utilized as active ingredients in antibacterial, anti-diabetic medications, cancer therapies, and wound healing treatments (Table 1).

Gold nanoparticle were produced through many techniques like lithography, reduction, physical process (Shah *et al*., 2014). Although each technique effectively creates metallic nanoparticles, they come with various drawbacks, such as the need for toxic chemicals in the synthesis process, high pressures and costs, and potential environmental toxicity (Thakkar *et al*., 2010). Therefore, it's crucial to establish new, eco-friendly methods for synthesizing AuNPs. Biological synthesis of AuNPs using plants, algae, fungi, and microorganisms addresses the challenges associated with traditional methods, as these approaches are simpler, diminish the dependence on harmful chemicals, and adhere to green chemistry principles. Hence, researchers applying plants for the biosynthesis of AuNPs, leading to efficient and rapid production. AuNPs possess various biomedical properties, which exhibit potential effects (Table 1) (Santoshkumar *et al*., 2017).

The green method is favoured due to its benefits compared to alternative methods. This approach utilizes eco-friendly reactants in place of harmful chemicals, requires less energy, lowers synthesis costs, and facilitates large-scale production. CuONPs are also preferred because of their low band gap energy, allowing them to be used effectively with sunlight, their durability for reuse, and the affordability of copper salts, making them economically advantageous for broader applications (Table 1) (Singh *et al*., 2018).

Zinc oxide has surfaced as a prominent and efficient candidate in photocatalysis, showing significant promise in eco-friendly strategies for green management systems (Waghchaure *et al*., 2022). Its unique characteristic of having a more negative conduction band and a positive valence band compared to other metal oxide photocatalysts makes ZnO the preferred choice for inhibiting water and CO_2. Various techniques, such as green synthesis, doping or co-doping, the creation of nanocomposites, and the development of heterojunctions with other semiconductors, provide feasible methods to alter the ZnO band structure. These modifications are aimed at enhancing its redox capability and light absorption, thereby improving its performance in photocatalysis (Batra *et al*., 2022). In-depth studies in this realm have increased applications for metal NPs for an innovative oxidation approach in photocatalysis, attracting considerable interest. ZnO-NPs are affordable, non-toxic, safe, biocompatible, mineralize quickly, demonstrate superior efficiency, efficiently generate H_2O_2, and feature a higher band gap of 3.37 eV, all of which enhance their distinct photocatalytic abilities (Maghsoudi *et al*., 2023). Numerous studies have utilized ZnO nanoparticles as antioxidants and antibacterial agents capable of inhibiting bacterial growth, functioning as photocatalysts, removing dyes, and aiding in water treatment (Table 1) (Vindhya *et al*., 2023).

Inorganic nanoparticles are typically produced through chemical and physical processes that demand considerable energy, financial resources, and the use of hazardous substances, which restricts their biological applications (Akhtar *et al*., 2013). To mitigate this challenge, recent studies have concentrated on "green synthesis," promoting safe & sustainable nanoparticle production process. Several earlier investigations have employed such fabrication for nanoparticles intended for magnetic hyperthermia applications, like Fe_3O_4 nanoparticles utilizing *Punica granatum* peel extract (Yusefi *et al*., 2021), α-Fe_2O_3 derived from gardenia resinifera (Karade *et al*., 2019), Mg0.93Na0.07O using lemon juice (Bhoi *et al*., 2022), and $CoFe_2O_4$ and $NiFe_2O_4$ synthesized with *Aloe vera* (Hermosa *et al*., 2022). Secondary metabolites from natural sources used as efficient reducing sources for green fabrication approach, containing a range of metabolites such as flavonoids, amines, phenolics, terpenoids, and proteins, making them suitable for serving as stabilizing and reducing agents for Fe_3O_4 and Ag nanoparticles (Matinise *et al*., 2017). In addition, Fe_3O_4/chitosan NPs created from natural sources for surface plasmon resonance (SPR)-based sensor applications through green synthesis methods (Cuana *et al*., 2022). Alongside the effectiveness of green synthesis techniques in producing nanoparticles for different applications also (Table 1).

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