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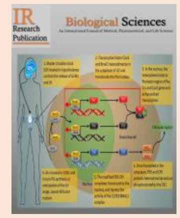

Green synthesis of metallic nanoparticles: Advancements and future perspectives

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ABSTRACT

As an alternative to chemical and physical approaches, green synthesis of metal nanoparticles is a developing area in the field of bio-nanotechnology and offers economic and environmental benefits. In the field of health and hygiene, engineered metal nanoparticles have increased their popularity due to their effectiveness in penetrating living systems. Metal nanoparticles can be efficiently biosynthesized using a range of microbes and plant extracts. Green synthesis of these nanoparticles and their use in diverse technologies have a bright future due to the shifting perspectives of the international community on sustainable development, environmental improvement, and the reduction of dangerous man-made waste. The focus of the current review was primarily on various methods employed for the green synthesis of metal nanoparticles, which is a more environment-friendly technique for creating metallic nanocarriers and altering their surfaces, use these metal nanoparticles, including metal sulfides, zinc oxide, copper, gold, platinum, and palladium, as well as nano metal-organic frameworks, in drug delivery systems.

Introduction

Due to the widespread usage of nanosized metal in industries including engineering, medicine, nd the environment, the topic of nanoscale metal synthesis is one that is currently relevant (1,2). Currently, the majority of nanoscale metals are created chemically, which has unforeseen consequences such as environmental contamination, high energy usage, and significant health issues (3). Green synthesis which substitutes plant extracts for industrial chemical agents to reduce metal ions, was created in response to these difficulties (4). Because it is less expensive, produces less pollution (5), and enhances environmental and human health safety, green synthesis is more advantageous than conventional chemical synthesis (1). In this review, the most recent advancements in the environmentally friendly synthesis of gold, silver, copper, palladium, iron, and iron oxide nanoparticles (Au, Ag, Pd, Cu, and Fe NPs) were assessed (3). Important discoveries show how plants' seasonal and geographical distributions are complex, and how time is a constraint on green synthesis (6). Significant research has shown that green synthesis is constrained by the time and

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location of production as well as problems with low purity and poor yield due to the complexity in geographical and seasonal distributions of plants and their compositions (7). Green synthesis, on the other hand, offers alternative development prospects and prospective uses while taking into account present environmental issues and pollution linked to chemical synthesis.

Metals and alloys that produce nanocrystalline grains with a particle size of between 5 and 100 nm are known as nano metallic materials (8). Compared to their bulk or non-nano counterparts, metals in the nanoscale have a larger surface area. Additionally, they possess unusual physical and chemical properties not present in non-nano metals because of the tiny size effect, surface effect, interface effect, and quantum impact. Numerous types of nanoscale metals are used extensively in biology (9), medicine, and engineering (8). Au nanoparticles, for instance, have biological uses for the regulation of enzymes, as well as for antibacterial and muscle relaxant properties (10).

The capacity of each biological system to produce metallic nanoparticles differs. However, because of their enzymatic activity and innate metabolic processes, not all living species can create nanoparticles. Since bio-reduction of metallic particles results in the synthesis of nanoparticles, biological entities or their extracts are used for the environmentally friendly synthesis of metallic nanoparticles. These biosynthesized metallic nanoparticles have countless therapeutic uses, such as gene or medication delivery, protein or pathogen detection, and tissue engineering. Many different types of nanoparticles, such as silver nanoparticles, demonstrate extensive applications in the healthcare field, such as the ability to heat tumors, deliver drugs, perform medical imaging, use chemical sensors, catalyze reactions, and function as wireless electronic logic, computer transistors, memory chips, and antimicrobial agents (11). Translational research about pharmaceutical goods and their applications has greatly benefited from the efficient medication delivery and tissue engineering made possible by the use of nanotechnology (12,13).

Approaches for the synthesis of nanoparticles (14,15)

- In a top-down method, the bulk material is broken down into nanoscale structures or particles. Top-down synthesis methods are an extension of those that have been utilized to create particles with a diameter of less than a micron.
- The bottom-up approach, or self-assembly, methods of nanofabrication combine fundamental units into more complex ones using chemical or physical forces that act at the nanoscale.

Green synthesis of metallic nanoparticles

For the creation of nanoparticles, both physical and chemical methods are used. The use of harmful substances may result in risks such as carcinogenesis, toxicity, and environmental toxicity. Due to the usage of potentially harmful compounds including reducing agents, organic solvents, and stabilizers, the toxicity issues are extremely noticeable. These substances stop colloids from adhering together. The use of nanoparticles in many clinical and biomedical applications is constrained by the usage of harmful solvents and chemical contamination. Therefore, it is necessary to create nanoparticles using a dependable, clean, physiologically suitable, and environmentally benign method. Due to their adaptable physicochemical properties, such as thermal and electrical conductivities, light absorption, melting point, and the enhancement of catalytic activity by varying the surface-to-volume ratio, nanoparticles have recently revolutionized their application in the healthcare sector. The creation of nano-dimensional particles with a variety of shape- and size-dependent properties falls under the umbrella of nanotechnology.

An appealing alternative would be the biological production of nanoparticles. Adoption of bacteria, actinomycetes, viruses, and yeasts, as well as other multicellular and unicellular living organisms. Regarding their form, size, composition, and physicochemical characteristics, the biologically created nanoparticles have a wide range of qualities to be studied. Furthermore, the construction, synthesis, and organization of materials at the nanoscale scale may follow a pattern found in biological beings. The current paper discusses the use of biological methods for the synthesis of metal oxide and metal nanoparticles, as well as the many variables impacting their synthesis, potential mechanisms used, and potential applications of nanoparticles produced by biological factories. Figure 1 depicts a flow diagram showing various strategies for the green synthesis of metal nanoparticles.

Green Synthesis of metal nanoparticles using plant extracts

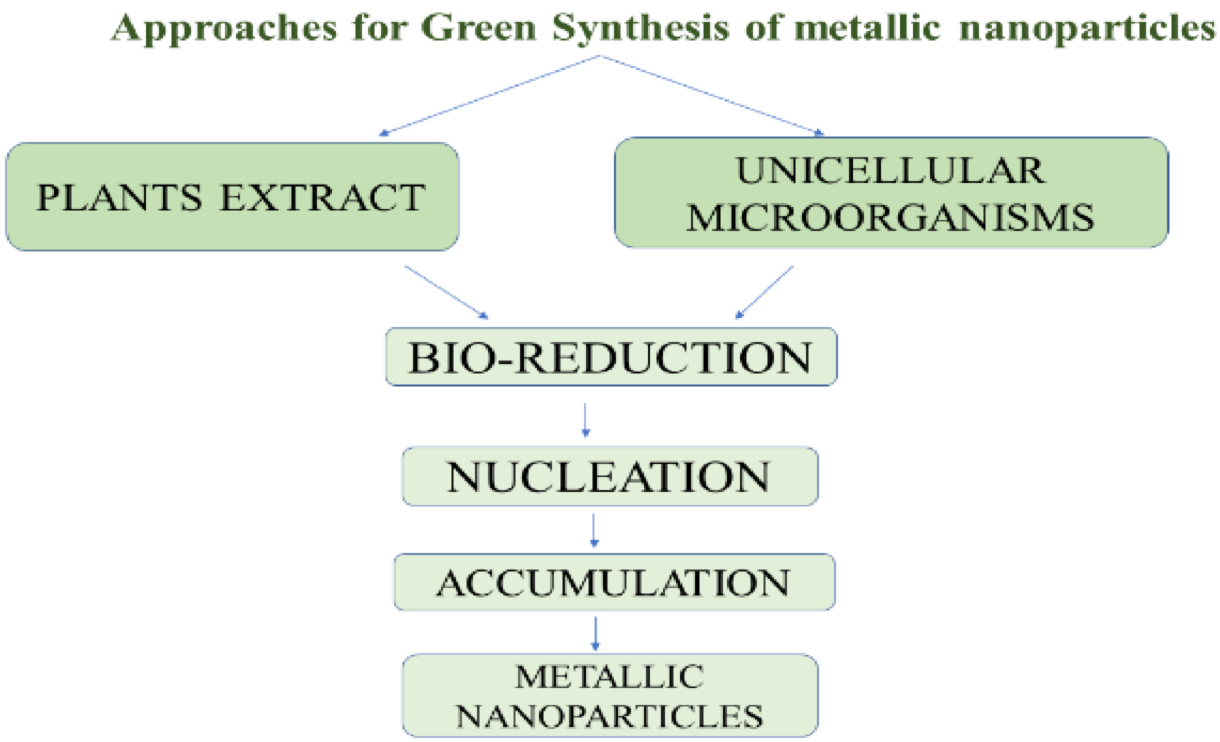

Figure 1. Various approaches for green synthesis of Nanoparticles.

The uptake and detoxification of heavy metals by plants have considerable promise (16). Heavy metals and metalloids that are trace elements are significant environmental contaminants because they are harmful even in extremely low quantities. using plants biomass for metal extraction from water-based solutions has been demonstrated to be extremely encouraging for removing pollutants from effluents in a sustainable strategy (17). The organic occurrence of heavy metals in plants even at large amounts has created interest in the biological principles underlying plants' resistance to metals as well as their physiology. Biomolecules found in plants, such as proteins, coenzymes, and carbohydrates, have a remarkable capacity to transform metal salts into nanoparticles (18). It has been demonstrated that compared to other creatures, plants create more stable metal nanoparticles (19). Plants, and particularly plant extracts, can lower than bacteria or fungus, metal ions. Additionally, to scale up industrial processes using a simple and secure green technique well-distributed metal nanoparticle manufacturing with plant extracts are unquestionably superior to living plants or plant biomass (20). The creation of nanoparticles is significantly influenced by the reduction potential of ions and the reducing capacity of plants, which depend on the availability of polyphenols, enzymes, and other chelating agents in plants (21,22).

Green synthesis of metal nanoparticles using microorganisms

In contrast to physical and chemical approaches, the use of microbial enzymes and proteins as a potential reducing agent for the synthesis of NPs has expanded quickly (23). It is a quick, cost-efficient, and environmentally safe method. Fungi and bacteria are preferred among biogenic sources because they can produce a higher concentration of the reductase enzyme needed to transform ionic forms into their nano forms (24). They are also preferred because they are easy to cultivate and control the size and morphology of synthesized NPs, which can significantly lower the cost of large-scale manufacturing. As the process can be regulated by adjusting the culture parameters, such as nutrition, pH, pressure, and temperature, the green synthesis of NPs uses microbial cells like fungi, yeast, and bacteria. The microbial system has an internal mechanism for producing nanoparticles from metallic salts (25). An effective and environmentally friendly way for further utilizing microorganisms as nano factories in the manufacture of metal nanoparticles using plants and microbes. A method for cleaning up metal wastes and contaminations is microbial metal reduction. Metals can be mobilized and immobilized by bacteria, and in some instances, bacteria that can decrease metal ions can precipitate metals at the nanoscale scale. Around the world, the biosynthesis of nanoparticles using bacteria has emerged as an area of research that is rapidly developing in green nanotechnology (26). Various biological entities are constantly being employed in the synthesis of NPs, constituting an impute alternative to traditional chemical and physical methods. The procedures can be

Table 1. Green synthesis of metallic and metal oxide nanoparticles

Source for Green synthesis	Some Examples	Type of Metal nanoparticles synthesized	Morphology and size range	Applications	References
Plants	Aloe vera extracts, Azadirachta indica, Cinnamomum camphora, Datura metel, Emblica Officinalis, Ocimum sanctum, Sesbania drummondii, Syzygium cumini, Terminalia catappa	Gold, Silver, Palladium, Bi-metallic gold-silver, Zinc oxide, iron oxide, cadmium sulfide, titanium dioxide	The majority of spherical shapes (Size 5 to 50 nm), some nanoparticles obtained were triangular, hexagonal, prismatic, octahedral, round, crystalline or of irregular shape	Antibacterial, Anticancer, Biomedical imaging, targeted drug delivery, formation of thin-film, as a metallic catalyst, for bio labeling, biosensors, coating,	(18,32–34)
Bacteria	*Bacillus cereus, Pseudomonas proteolytica*, *Bacillus cecembensis, Klebsiella pneumonia*, *Escherichia coli*, *Enterobacter cloacae, Magnetospirillum magnetotacticum*				(35–39)
Fungus	*Rhizopus nigricans, Aspergillus fumigates, Phanerochaete chrysosporium, Cladosporium cladosporioides, Penicillium brecompactum, Alternata alternate*				(28,31,37, 40,41)
Yeast	MKY3, *Saccharimyces cerevisae*				(38,39,42)
Algae	*Plectonema boryanum, Calothrix pulvinate, Spirulina platensis*				(43)

optimized to produce a quick and clean synthesis of NPs with desired morphologies and controlled sizes. The procedures can be optimized to produce a quick and clean synthesis of NPs with desired morphologies and controlled sizes. In contrast to the intracellular process, which involves the initial electrostatic attraction of metal ions by carboxyl groups of the microbial cell wall, passage of metal ions through the cells, and reduction by intracellular proteins and cofactors to produce NPs, the extracellular process involves reduction of metal ions for NPs synthesis by microbial enzymes and proteins, bacterial or fungal cell wall components, or organic molecules present in the culture medium (27,28). As a component of microbial resistance mechanisms for cellular detoxification, biochemical pathways involving microorganism-mediated nanoparticle formation can be considered. In this, the solubility of inorganic and hazardous ions is altered through enzymatic reduction and/or nanostructure-based precipitation (1,29). Oxidoreductase enzymes and cellular transporters play a major role in both the extracellular and intracellular bio-catalytic synthesis pathways that have been postulated (30,31). Various types of plant extracts and unicellular as well as multicellular organisms utilized for the green synthesis of nanoparticles are summarized in Table 1

Future perspective

It should be noted that future research may focus on improving reaction conditions and creating recombinant organisms that produce large quantities of the proteins, enzymes, and biomolecules needed for nanoparticle formation and stabilization (44). Improved nanoparticle production will result from a better understanding of the biochemical mechanisms/pathways behind plant heavy metal detoxification, accumulation, and resistance. Future strategies to boost these organisms' productivity in nanoparticle manufacturing include genetically modifying (45). In addition to identifying and characterizing the biomolecules involved in the synthesis of metallic nanoparticles, researchers have concentrated on comprehending the biological mechanisms and enzymatic processes of nanoparticle formation(46). When compared to their chemically created counterparts, microbiologically synthesized nanoparticles are considered to be more favorable because the former do not require as strict of requirements, such as a pure starting material. Microbiologically produced nanoparticles are more commercially viable due to the requirement of ideal circumstances and clement temperatures (20-30°C). Additionally, certain microbiogenic nanoparticles have biological capping agents attached to them as a shield against oxidation, agglomeration, and aggregation, which increases their stability (47). As a result, nanoparticles produced through microbiological synthesis are frequently thought of as a superior choice for antibacterial treatments

Contribution of authors

Smriti Ojha did the planning, drafting, writing, and analysis.

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Conflict of interest

None.

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