Journal- International Journal of Nanobiotechnology

Title-Eco-Friendly Synthesis of Nanoparticles: Advancing Green Methods Using Plant Extracts

ISSN: 2456-0111

REVIEW

Volume:10

Issue:01

Year:2024

Article Received: 7 June, 2024

Article Accepted: 28 June, 2024

Article Published:

Anshu Tomar

Student

Department of Biotechnology, Chaudhary Charan Singh University, Meerut

anshuonline123@gmail.com

ABSTRACT

Nanotechnology, focusing on materials sized 1-100 nm, has garnered significant interest for its applications in agriculture, pharmaceuticals, and electronic devices. Nanomaterials, due to their unique properties, are pivotal in the development of advanced technologies such as drug delivery systems and nano-devices. Conventional nanoparticle synthesis methods, including sol-gel, chemical precipitation, microwave, and chemical vapor deposition, often involve hazardous chemicals, posing environmental risks. Therefore, there is a crucial demand for environmentally friendly and sustainable synthesis approaches.. Biological methods, utilizing microorganisms, enzymes, and plant extracts, have emerged as promising alternatives to conventional techniques. These methods offer a "greener" synthesis pathway, providing better control over crystal growth and nanoparticle stabilization. The biological synthesis of nanoparticles, particularly using plant biomass or extracts, is advantageous due to the presence of biomolecules such as proteins, vitamins, amino acids, and organic acids, which facilitate nanoparticle formation. This approach reduces the use of harmful solvents and reagents, ensuring milder reaction conditions and enhancing the biocompatibility of the synthesized nanoparticles.. Previously studies have demonstrated the potential of green synthesis in producing stable and functional nanoparticles for various applications. Consequently, the development of clean, cost-effective, and sustainable methods for nanoparticle synthesis is of paramount importance, aligning with environmental and health safety standards.

Keywords- Nanomaterials, Crystal growth, Plant biomass, Chemical precipitation, Nanoparticle

INTRODUCTION

In modern science Nanotechnology is a lighted field for researchers. Nanotechnology involves the creation of materials ranging in size from 1 to 100 nm in one dimension.
Nanomaterials have attracted tremendous interest due to their noticeable performance in many fields such as in agriculture, pharmaceuticals, and drug delivery system.They also serve a crucial role as interconnects and functional units in the manufacturing of electronic, optoelectronic, electrochemical, and electromechanical nano-devices
To avoid chemical synthesis, environmentally friendly processes have been developed**.** Biological methods of nanoparticle synthesis have enabled greener approaches, demonstrating superior characteristics such as lower kinetics, improved manipulation and control over crystal growth, and enhanced stabilization. Therefore, there is tremendous need for the development of clean and biocompatible as well as Cost effective and sustainable method for synthesizing nanoparticles. Numerous previous researchers have emphasized the green synthesis of silver nanoparticles using various biological materials[1]. Plant biomass or extracts possess several inherent advantages over other microorganisms in nanoparticle synthesis. Plant mediated biosynthesis of nanoparticles occurs through biomolecules (such as proteins, vitamins, amino acids, polysaccharides and organic acids such as citrates) present in the plant biomass. Plant synthesis offers several advantages, including the use of safer solvents, reduced reliance on hazardous reagents, milder reaction conditions, feasibility, and versatility in applications across medicine, surgery, and pharmaceuticals.
A nanoparticle or ultrafine particle typically refers to a particle of matter with a diameter ranging from 1 to 100 nm . The term is occasionally used for larger particles, up to 500 nm, or for fibers and tubes less than 100 nm in only two dimensions. At the smallest scale, metal particles smaller than 1 nm are commonly referred to as atom clusters.
Nanoparticles occur naturally and are also produced through human activities. Due to their extremely small size, they exhibit unique material properties, making them valuable for various applications in medicine, engineering, catalysis, and environmental remediation.

A (Table 1) tabular arrangement shown the diameter of different types of particles: -

Table 1 Diameter Range of different types of particles

Particle Type	Diameter Range
Atoms and small molecules	0.1 nm
Nanoparticles	1 – 100 nm
Fine particles (particulate matter)	100 – 2500 nm
Coarse particles (dust)	2500 – 10,000 nm
Thickness of paper	100,000 nm

There are some advantages of nanoparticles such as: -

- Nanoparticles have high drug loading efficiency.
- Enhance pharmacological activity.
- Nanoparticles decreased side effects compared to traditional drug delivery.
- Improved therapeutic effect.
- Enhancement of permeability
- Enhancement of solubility and bioavailability
- Protection from degradation
- Used in cosmetics as it absorbs much deeper into skin.
- Nanoparticles are less prone to microbes such as bacteria, fungus and viruses.
- Low immunosuppressive
- Have a large surface area.

Nanoparticles synthesis approaches

Top-down approach: -

In (figure1).This approach begin with larger particles which ate reduced to nanosized structures or particles. Top-down synthesis techniques extend from methods used to produce nano-sized particles. These approaches are inherently simpler, relying on the removal or division of bulk materials to create structures with specific properties.[2]
However, these methods tend to be expensive and are not suitable for large-scale production. They are more appropriate for laboratory settings. Top-down methods involve material grinding and are not suitable for soft samples

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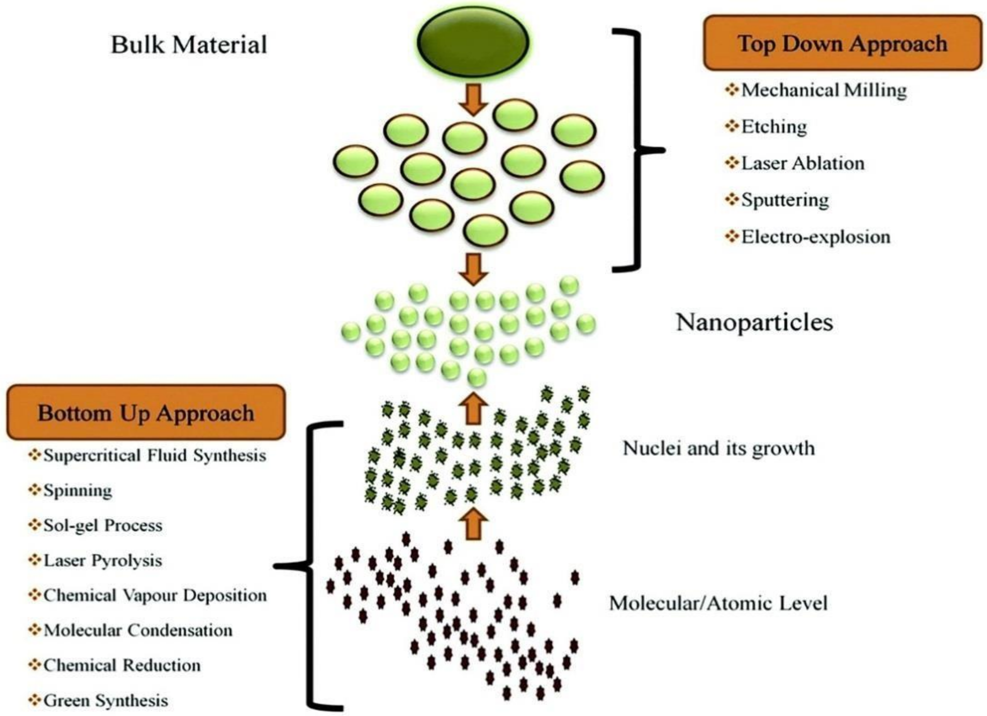

Fig. 1 Synthesis approaches of nanoparticles

Bottom-up approach :-

This method involves assembling nanostructures from smaller building blocks such as atoms, molecules, or clusters. These components come together to form nanometer-sized particles due to various interatomic or intermolecular forces, including Van der Waals forces, electrostatic forces, and other short-range interactions.
Chemical production of nanoparticles primarily employs the bottom-up method. The main advantages of this approach include the ability to create a wide range of nanoparticles with precise control over size distribution, from extremely small to large scales.

Biological methods for synthesis of nanoparticles

Method for Green Synthesis of Nanoparticles Using Plant Extracts

Plant extracts play a crucial role in nanoparticle production, known as green synthesis or a green technique.[3]

Materials Required:

- Geranium plant leaves (Pelargonium graveolens)

- 1 mmol aqueous silver nitrate solution
- Alcoholic extract of the plant
- Shaker set to 150 rpm
- Dark environment

Steps:

1. **Preparation of Plant Extract:**
   - Collect fresh leaves from the geranium plant (Pelargonium graveolens).
   - Wash the leaves thoroughly with distilled water to remove any impurities.
   - Grind the leaves to obtain a fine paste.
   - Use appropriate solvent (water or alcohol) to extract the plant compounds.
2. **Synthesis of Silver Nanoparticles Using Aqueous Extract:**
   - Measure 5 ml of the aqueous plant extract prepared from the leaves.
   - Take 1 ml of a 1 mmol aqueous silver nitrate ($AgNO_3$) solution.
   - Add the 1 ml of silver nitrate solution to the 5 ml of aqueous plant extract.
3. **Synthesis of Nanoparticles Using Alcoholic Extract:**
   - Follow the same steps as above but use the alcoholic extract of the plant instead of the aqueous extract.
   - Measure 5 ml of the alcoholic plant extract.
   - Add 1 ml of a 1 mmol aqueous silver nitrate solution to the 5 ml of alcoholic plant extract.
4. **Shaking and Incubation:**
   - Place the mixture in a shaker.
   - Set the shaker to 150 rpm.
   - Incubate the mixture in the dark to prevent any photochemical reactions that might interfere with nanoparticle synthesis.
5. **Observation and Analysis:**
   - After an appropriate incubation period, observe the color change indicating the formation of nanoparticles.
   - Further analysis can be performed using techniques like UV-Vis spectroscopy, TEM, or SEM to confirm the synthesis and characterize the nanoparticles.

Method for Green Synthesis of Nanoparticles Using Algal Extracts

Preparation of algal extract in an organic or aqueous solvent through heating or boiling for a set amount of time.[4]

Materials Required:

- Algal biomass
- Organic or aqueous solvent
- Heating or boiling apparatus
- Ionic metallic complex (e.g., silver nitrate, gold chloride)
- Shaker or stirring apparatus
- Dark environment

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Steps:

1. **Preparation of Algal Extract:**
    - Collect the algal biomass from a reliable source.
    - Wash the algae thoroughly with distilled water to remove any impurities.
    - Use an organic or aqueous solvent to extract the algal compounds.
    - Heat or boil the algae in the chosen solvent for a set amount of time to obtain the algal extract.
    - Filter the extract to remove any solid residues.
2. **Preparation of Ionic Metallic Complex Solution:**
    - Prepare a molar solution of the desired ionic metallic complex (e.g., 1 mmol aqueous silver nitrate solution or gold chloride solution).
3. **Incubation and Reaction:**
    - Mix the prepared algal extract with the molar solution of the ionic metallic complex.
    - Ensure the ratio of algal extract to the metallic solution is appropriate for the desired synthesis (this ratio may need optimization based on preliminary results).
4. **Stirring or Static Incubation:**
    - Incubate the mixture under suitable conditions:
        - Option A: Continuously stir the mixture using a shaker or stirring apparatus set to an appropriate speed (e.g., 150 rpm).
        - Option B: Leave the mixture undisturbed to allow the reaction to proceed naturally.
    - Ensure the incubation is carried out in the dark to prevent any photochemical reactions that might interfere with nanoparticle synthesis.
5. **Observation and Optimization:**
    - Monitor the mixture for any visible color changes indicating the formation of nanoparticles.
    - The method of creating nanoparticles is dose-dependent and varies with the type of algae used. Optimize the conditions (e.g., concentration, incubation time, temperature) to achieve the best results.
6. **Role of Biomolecules:**
    - Recognize that biomolecules such as peptides, pigments, and polysaccharides in the algal extract are responsible for the reduction of metals and the stabilization of nanoparticles.
7. **Efficiency:**
    - Note that algae may produce nanoparticles more quickly than other types of living organisms.
8. **Analysis and Characterization:**
    - After the incubation period, perform further analysis using techniques such as UV-Vis spectroscopy, TEM, or SEM to confirm the synthesis and characterize the nanoparticles.

Nanoparticles as pest control

Pests and insects pose the greatest risks to a nation's economy since they significantly reduce the yield of crops that are profitable. Insect and disease resistance, residue build up in produce, and environmental contamination are all effects of frequent use of insecticides and pesticides. Therefore, different methods of pest and pathogen management are required. New perspectives on biotechnology and agriculture are provided by nanotechnology[10]. The use of nanotechnology in crop protection has great potential for managing insects and diseases through controlled and targeted agrochemical administration as well as by offering diagnostic tools for early detection. Herbicides, nanopesticides, fertilizers, or genes may be included in nano-particles, which act as "magic bullets" that target certain cellular organelles in plants and unleash their contents. Since nano-particles are highly stable and biodegradable active compounds enclosed in capsules, they can be used to treat plants with fewer active compounds while still having a positive environmental impact because they do not degrade when exposed to outside factors or the crop plant itself

Advantages or benefits of nanopest control

- ☐ Solubility of water-insoluble operative constituents is enhanced.
- ☐ Stability of the formulation is elevated.
- ☐ Eradicates dangerous organic solvents.
- ☐ Ability to liberate operative constituents slowly.
- ☐ Improvement in stability prevents early deterioration.
- ☐ High mobility and insecticidal efficacy are ascribed to nano size.
- ☐ Large surface area is said to promote endurance.

Different nanoparticles as pest control Silica nanoparticles

Given silicon's ability to increase plants' resistance to abiotic and biological challenges, the use of silica-based nanoparticles (SNPs) for pest management in agriculture is logically advised [8]. Similar to how diatoms are employed to safeguard grain storage, silica particles are physically absorbed by lenticular lipids, destroying the protective cuticle and killing insects solely via physical methods.

Silver nanoparticles

Pests are becoming a greater danger to the agricultural industry, resulting in lower crop yields and consequently lower product quality. Additionally, the synthetic pesticides used on plants or soil have a harmful effect on the environment [9Nanotechnology offers potential applications in pest management. Furthermore, pesticide formulations based on silver nanoparticles deliver concentrated doses of insecticides to target plants, highlighting nano-silver as a safe and effective alternative in pest control. improved weapon to battle pests The biological agents used in the environmentally friendly way of producing silver nanoparticles can be either bacteria or plants, however the flavinoids found in plants are harmful to them. Thus, the pesticide activity of silver nanoparticles help to control pest [11]

Silver nanoparticles have been reported to exhibit antifungal activity, contributing to the elimination of fungal pathogens affecting plants. Additionally, [12] highlighted the efficacy of UV-irradiated silver nanoparticles in biocontrolling pests like mosquito larvae.

Chitosan nanoparticles

Chitosan nanoparticles have hydrophobic characteristics, which makes them poorly soluble in water. Chitosan is frequently used with both organic and inorganic substances to increase solubility as a consequence. The following three mechanisms describe how chitosan inhibits fungi:-

(i)It is hypothesized that chitosan can enter the cell wall of fungi, bind to their DNA, and prevent mRNA synthesis, which in turn affects the production of protin and essential enzymes.).

(ii)As a potential antibacterial action method,

(ii) chitosan chelates with metal ions [13]

(iii) Positively charged chitosan interacts with the negatively charged phospholipid components of fungal membranes, altering the permeability of the plasma membrane and causing leakage of cellular components, ultimately leading to cell death. Chitosan nanoparticles have demonstrated antifungal activity in vitro and have shown potential in protecting finger millet plants from blast disease caused by Pyricularia grisea.

Zinc nanoparticles

In agriculture, ZnO is primarily used as a micronutrient fertilizer, though its antibacterial properties are also well recognized.We have shown that the mechanism of action of zinc nitrate-derived nano-ZnO against the important pathogen Aspergillus fumigatus is via fungal- mediated hydroxyl and superoxide radicals to induce cell wall deformation, ultimately leading to death by high-energy transfer. ZnO nanoparticles (ZnO-NPs) have also been reported to be effective against two post-harvest his pathogenic fungi (Botryticinerea and Penicillium expansum), contributing to agricultural and food safety applications. ZnO nanoparticles interfered with the development of P. expansum conidiophores and conidia, ultimately killing the fungal hyphae.

Copper nanoparticles

Copper-based compounds have been used to combat plant pathogens for centuries. The earliest metal-based fungicides developed to control crop diseases were made from copper and copper-containing compounds, including copper oxychloride, copper hydroxide, and Bordeaux mixture are still used today to prevent bacterial invasion of pomegranates. A Bordeaux mixture of lime, copper sulfate and water used to control downy mildew on grapes caused by the oomycete pathogen Plasmopora viticola. Nanoparticles have proven to be effective in controlling bacterial diseases, particularly mongoose spot and rice leaf blight.

Copper nanoparticles showed an inhibitory effect against Pseudomonas syringae at a concentration of 200 mg/L, but the particles had no biocidal effect against rhizobia species.

Impact of silver nanoparticles on agriculture

Nanosilver is the most studied and most widely used nanoparticle in biological systems. Silver nanoparticles (Ag NPs) are renowned for their potent inhibitory and bactericidal effects, displaying broad-spectrum antibacterial activity. The high surface area and significant surface atom fraction of silver nanoparticles enhance their antibacterial efficacy compared to solid silver. Beyond their antibacterial capabilities, Ag NPs exhibit a range of therapeutic properties. They are known for their antioxidant activity, which helps in neutralizing harmful free radicals. Additionally, Ag NPs possess antifungal, antiviral, and anti-inflammatory properties, making them versatile agents in combating various pathogens and reducing inflammation. These multifaceted properties of silver nanoparticles highlight their potential in medical and pharmaceutical applications, offering a robust approach to disease prevention and treatment. Although it is often said that the use of silver nanoparticles in agriculture is mostly theoretical, in the near future researchers will have diverse applications of silver nanoparticles. Ag NPs have been used as potential candidates to increase crop yields by promoting seed germination and plant growth. The concentration of Ag nanoparticles (AgNPs) positively or negatively affects plant growth responses. Using different concentrations of silver nanoparticles showed maximum seed germination, germination rate, root length, fresh root weight and dry root weight. Exposing plants to certain concentrations of AgNPs can promote plant growth compared to unexposed plants, but both high and low concentrations can have an inhibitory effect on plant growth [14]

Silver nanoparticles have been tested as insecticides to reduce the pest burden on crops. It requires pest control and fortification. This reduces the frequent use of chemical fertilizers in conventional agriculture. It can destroy unwanted microorganisms in soil and hydroponic systems. Used as a foliar spray to control plant diseases caused by fungi, mold, rot and some other microorganisms.

Researchers have had remarkable success in using AgNPs to control plant diseases. DNA-targeted silver NPs grown on graphene oxide were examined for antibacterial activity against Xanthomonas perforans, the pathogen of tomato bacterial spot. They also investigated the antifungal activity of AgNPs against pathogenic fungi. We have used Fusarium oxysporum, Alternaria alternata and Aspergillus flavus and achieved promising results. Antifungal activity of colloidal nanosilver (mean diameter 1.5nm) against rose powdery mildew caused by Sphaerotheca pannosa var rosa. The insecticidal activity of silver nanoparticles is very useful for pest control. Because in the environmentally friendly method of producing silver nanoparticles, the biological agents used for their synthesis are microorganisms or plants, and the flavonoids present in plants turn out to be toxic to plants. The use of his AgNPs in pest control has been reported. AgNPs are used to control rice weevil and diseases of grasses. It is hypothesized that AgNP can also be used as an excellent seed protectant, as AgNP-treated stored rice remains free of infection even after 2 months of treatment.

Conclusion

In conclusion, the shift towards eco-friendly and sustainable methods for nanoparticle synthesis is crucial. Biological approaches, particularly those using plant extracts, offer a promising alternative to traditional chemical methods, reducing environmental hazards and improving biocompatibility. These green synthesis techniques leverage natural biomolecules to produce stable and functional nanoparticles, paving the way for advancements in agriculture, pharmaceuticals, and nanotechnology. The development of such methods is essential for aligning technological progress with environmental sustainability and health safety standards.

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