

# Review of: "Synthesis of Nickel Nanoparticles Using Ionic Liquid-Based Extract from *Amaranthus viridis* and Their Antibacterial Activity"

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The synthesis of nickel nanoparticles using the extract of *Amaranthus viridis* (green amaranth) is an innovative and novel method in the field of green nanotechnology, offering several significant advantages over traditional chemical methods. This approach is developed as an environmentally friendly alternative that avoids the use of harmful chemicals. In this process, the plant extract acts as both a reducing agent and a stabilizing agent for the synthesis of nickel nanoparticles. Some of the key advantages of this method include: Environmental Sustainability, Simplicity and Cost-Effectiveness, and Antibacterial Activity.

Certainly, here is the English version of the comparison points that illustrate how the green synthesis of nickel nanoparticles using plant extracts is more environmentally sustainable than traditional methods:

## 1. Reduction in the Use of Toxic Chemicals:

- **Traditional Methods:** The synthesis of nickel nanoparticles via conventional chemical methods typically involves the use of toxic chemicals like strong reducing agents (e.g., hydrazine, sodium borohydride) and synthetic stabilizers. These chemicals, if released into the environment, can contaminate water and soil, leading to harmful effects on living organisms.
- **Green Method (Plant-Based):** In biosynthesis, plant extracts such as *Amaranthus viridis* are used as reducing and stabilizing agents. These extracts contain natural compounds like flavonoids, polyphenols, and alkaloids, which are non-toxic and biodegradable, posing minimal risk to the environment.

## 2. Reduced Production of Harmful By-products:

- **Traditional Methods:** Chemical synthesis of nickel nanoparticles often leads to the production of unwanted chemical by-products that are difficult to degrade and can harm the environment.
- **Green Method (Plant-Based):** The synthesis of nanoparticles using plant extracts generally produces biodegradable or harmless by-products. For example, the biological compounds in plant extracts are easily broken down in natural environments, reducing the pollution load.

## 3. Lower Energy Consumption:

- **Traditional Methods:** Many chemical methods require high temperatures, high pressures, or the use of complex equipment to produce nanoparticles, which consumes significant amounts of energy and increases the carbon footprint.
- **Green Method (Plant-Based):** The synthesis of nanoparticles using plant extracts is typically carried out under mild temperature and pressure conditions, significantly reducing energy consumption. This makes green synthesis more energy-efficient and environmentally sustainable.

#### 4. Renewability of Raw Materials:

- **Traditional Methods:** The raw chemical materials used in conventional synthesis may come from non-renewable resources, and their extraction can lead to environmental degradation.
- **Green Method (Plant-Based):** Plants like *Amaranthus viridis* are renewable and widely available resources. Using plant extracts for nanoparticle synthesis not only reduces the depletion of non-renewable resources but also promotes the preservation of renewable natural resources.

These comparisons clearly show that the synthesis of nanoparticles using plant extracts is more environmentally sustainable, helping to reduce pollution and conserve natural resources.

Here are the challenges and limitations of using plant extracts for nanoparticle synthesis that researchers should address:

#### 1. Lack of Uniformity in Plant Extract Composition:

- Plant extracts contain a variety of compounds, such as flavonoids, polyphenols, alkaloids, and other secondary metabolites, whose composition and concentration can vary depending on cultivation conditions, harvest season, and plant type. These variations can lead to inconsistencies in the properties of the nanoparticles produced.
- **Suggested Solution:** Improve the standardization of plant extracts or implement stricter quality control methods to minimize variations caused by environmental factors.

#### 2. Limited Control Over Particle Size and Shape:

- In biosynthesis processes, it is more difficult to achieve precise control over the size, shape, and distribution of nanoparticles compared to chemical methods. Inconsistent size and shape can affect the physical and chemical properties of the nanoparticles.
- **Suggested Solution:** Optimize synthesis parameters such as pH, temperature, and extract concentration to improve control over nanoparticle size and shape.

#### 3. Impact of Extract Complexity on Nanoparticle Purity:

- Plant extracts contain complex organic compounds that can affect the purity of the nanoparticles. These compounds may adhere to the surface of the nanoparticles, altering their properties.

- Suggested Solution: Employ appropriate purification and washing methods to remove excess compounds and improve nanoparticle purity.

#### 4. Stability and Reproducibility of the Process:

- Reproducibility and stability of nanoparticle synthesis using plant extracts can be challenging. Synthesis outcomes may vary between experiments due to differences in the quality and quantity of the extract.

- Suggested Solution: Optimize production processes and increase precision in controlling experimental variables to ensure reproducibility and consistency of results.

#### 5. Scalability:

- While the use of plant extracts works well at the laboratory scale, scaling up this method for mass production of nanoparticles remains a challenge. Producing sufficient and consistent plant extract for industrial-scale synthesis requires significant resources.

- Suggested Solution: Research optimization techniques for scalability and industrial extraction of plant extracts for nanoparticle synthesis.

#### 6. Compatibility with Specific Applications:

- For certain specialized applications, nanoparticles synthesized using plant extracts may require modifications in their physical or chemical properties to meet specific industrial or medical needs.

- Suggested Solution: Modify and enhance the synthesis process by incorporating additional techniques such as encapsulation or coating to improve the nanoparticles' properties for specific applications.

Researchers should address these challenges in their studies and propose suitable solutions to improve the efficiency, stability, and scalability of biosynthetic processes.

Standardizing plant extracts for consistent nanoparticle synthesis is crucial for ensuring uniformity in the properties of the produced nanoparticles. Here are specific examples of how this standardization can be achieved:

##### 1. Controlled Plant Growth Conditions:

- Example: Cultivate the plants used for extract preparation under controlled conditions such as hydroponics or in greenhouses. By regulating factors like light, temperature, humidity, soil nutrients, and watering schedules, the composition of secondary metabolites in the plants can be kept consistent. For instance, regulating the light exposure for *Amaranthus viridis* could help maintain a steady concentration of flavonoids and polyphenols that play key roles in nanoparticle synthesis.

- Impact: This reduces variability in the chemical composition of the extracts across different harvests, ensuring reproducibility.

## 2. Standardized Extraction Procedures:

- Example: Develop a standard operating procedure (SOP) for the extraction process, specifying key parameters such as:
- Solvent type and concentration: Using the same solvent (e.g., water, ethanol) with a controlled concentration ensures that the same compounds are extracted consistently.
- Extraction time and temperature: Maintain consistent extraction times (e.g., 2 hours) and temperatures (e.g., 60°C) to ensure that the yield of active compounds such as polyphenols or terpenoids remains uniform.
- Solvent-to-plant ratio: Standardizing the ratio (e.g., 10 grams of plant material per 100 mL of solvent) ensures consistency in the concentration of bioactive molecules.
- Impact: This minimizes variability in the concentration of the bioactive compounds responsible for nanoparticle formation, providing more consistent nanoparticle size and shape.

## 3. Chemical Profiling of Plant Extracts:

- Example: Use analytical techniques such as high-performance liquid chromatography (HPLC), gas chromatography-mass spectrometry (GC-MS), or UV-Vis spectroscopy to regularly profile the chemical composition of the plant extracts before using them in nanoparticle synthesis. This ensures that the concentrations of key bioactive molecules (e.g., polyphenols, flavonoids) are within a certain range.
- Impact: Chemical profiling helps to ensure the reproducibility of nanoparticle synthesis by confirming that the necessary compounds for reduction and stabilization are consistently present.

## 4. Quantification of Active Compounds:

- Example: Regularly quantify the concentration of active compounds (e.g., polyphenols, flavonoids) using assays like the Folin-Ciocalteu method for total phenolic content or the aluminum chloride assay for flavonoid content. Extracts with concentrations outside of the standardized range can either be discarded or adjusted by dilution or concentration.
- Impact: This approach ensures that the concentration of reducing and stabilizing agents in the plant extract remains consistent, leading to uniform nanoparticle characteristics.

## 5. Batch-to-Batch Monitoring and Adjustments:

- Example: After each batch of plant extract is prepared, test a small sample in a trial nanoparticle synthesis to assess the resulting nanoparticle size, shape, and distribution. If the nanoparticles do not meet the required specifications, the extraction process or extract concentration can be adjusted before proceeding with large-scale synthesis.
- Impact: Batch-to-batch consistency can be maintained by making real-time adjustments, ensuring that each batch of nanoparticles produced has similar properties.

## 6. Freeze-Drying and Long-Term Storage of Extracts:

- **Example:** To prevent degradation of active compounds and ensure consistent quality, plant extracts can be freeze-dried and stored as powders under controlled conditions (e.g., low humidity, low temperature). These dried extracts can later be reconstituted in a solvent under standardized conditions when needed.
- **Impact:** Freeze-drying stabilizes the active compounds, preventing degradation over time, which can affect the nanoparticle synthesis process.

## 7. Use of Reference Extracts:

- **Example:** Create reference standards by using extracts with known and optimal concentrations of active molecules for nanoparticle synthesis. These reference extracts can be used as benchmarks to compare new batches of extracts.
- **Impact:** Reference extracts provide a reliable standard to ensure that new extracts meet the required specifications for nanoparticle synthesis.

By implementing these standardization techniques, researchers can minimize variations in the plant extracts and achieve more consistent and reproducible nanoparticle synthesis.

Enhancing the properties of nanoparticles for specific applications often requires modifying their size, shape, surface chemistry, and functionality. Below are several techniques that can be applied to improve nanoparticle properties for targeted applications:

### 1. Surface Functionalization:

- **Technique:** Attach specific functional groups or molecules to the surface of the nanoparticles to improve their interaction with biological systems, increase stability, or enhance targeting capabilities.
- **Example:**
  - **Biomedical Applications:** Conjugating nanoparticles with antibodies, peptides, or ligands can enable targeted drug delivery to specific cells or tissues, such as cancer cells. For example, attaching folic acid to gold or silver nanoparticles enhances targeting of cancer cells that overexpress folate receptors.
  - **Environmental Applications:** Grafting hydrophobic or hydrophilic coatings on nanoparticles can control their dispersion in water, which is useful for the environmental remediation of pollutants.
- **Impact:** Functionalization allows nanoparticles to be customized for specific interactions or behaviors, improving their efficacy in areas like drug delivery, biosensing, or catalysis.

### 2. Core-Shell Nanostructures:

- **Technique:** Synthesize core-shell nanoparticles by coating the core nanoparticle with a different material. This structure

can enhance the stability, biocompatibility, or performance of the nanoparticle.

- Example:

- Biomedical Imaging: Coating iron oxide nanoparticles (used in magnetic resonance imaging) with gold enhances their biocompatibility and allows further functionalization for targeted imaging.

- Catalysis: Core-shell structures (e.g., platinum-coated palladium nanoparticles) improve catalytic efficiency and durability in fuel cells.

- Impact: Core-shell structures offer enhanced protection of the core material, tunable optical or magnetic properties, and improved chemical reactivity for applications in drug delivery, imaging, and catalysis.

### 3. Size and Shape Control:

- Technique: Control the size and shape of nanoparticles during synthesis to optimize properties such as surface area, reactivity, or cellular uptake.

- Example:

- Drug Delivery: Smaller nanoparticles (<100 nm) are more efficiently taken up by cells and can evade the immune system, making them ideal for therapeutic delivery.

- Catalysis: Nanoparticles with large surface-to-volume ratios (e.g., nanowires or nanorods) exhibit enhanced catalytic activity due to increased active surface area.

- Impact: Tailoring size and shape is crucial for optimizing nanoparticle performance in areas like medicine (e.g., higher bioavailability in drug delivery) or energy (e.g., higher catalytic efficiency in fuel cells).

### 4. Doping:

- Technique: Introduce small amounts of foreign atoms (dopants) into the nanoparticle structure to modify its electrical, optical, or magnetic properties.

- Example:

- Optoelectronics: Doping zinc oxide (ZnO) nanoparticles with aluminum or gallium enhances their conductivity and makes them useful for transparent conductive films in solar cells.

- Magnetic Applications: Doping iron oxide nanoparticles with cobalt enhances their magnetic properties, making them useful for data storage or magnetic resonance imaging (MRI).

- Impact: Doping allows fine-tuning of nanoparticle properties to meet the requirements of specific applications, such as improved conductivity for electronic devices or enhanced magnetism for MRI contrast agents.

### 5. Encapsulation and Controlled Release:

- **Technique:** Encapsulate nanoparticles within polymers or liposomes to control the release of drugs, active compounds, or agrochemicals over time.

- **Example:**

- **Drug Delivery:** Encapsulating drugs within liposomes or biodegradable polymers allows for sustained release at a targeted site, reducing the need for frequent dosing and minimizing side effects. Polymeric nanoparticles like PLGA (poly(lactic-co-glycolic acid)) are commonly used for this purpose.

- **Agriculture:** Encapsulating pesticides or fertilizers within nanoparticles enables slow and controlled release, reducing environmental impact and increasing efficiency.

- **Impact:** Encapsulation improves the delivery and bioavailability of active compounds, making it particularly useful in pharmaceuticals, agriculture, and environmental applications.

#### 6. Multifunctional Nanoparticles:

- **Technique:** Design multifunctional nanoparticles that combine multiple properties (e.g., targeting, imaging, and therapy) in a single nanoparticle system.

- **Example:**

- **Theranostics:** Develop nanoparticles that can be used for both imaging and therapy, such as gold nanoparticles coated with drug molecules and imaging agents. These particles allow for simultaneous cancer imaging and treatment (photothermal therapy combined with drug delivery).

- **Magnetic-Optical Nanoparticles:** Magnetic nanoparticles coated with fluorescent dyes can be used for both MRI and fluorescence imaging, enhancing diagnostic accuracy.

- **Impact:** Multifunctional nanoparticles enable more efficient and targeted treatments or diagnostics by combining several functionalities into a single platform.

#### 7. pH-Responsive and Stimuli-Responsive Nanoparticles:

- **Technique:** Create nanoparticles that respond to specific environmental stimuli such as pH, temperature, light, or magnetic fields to release their cargo or change behavior.

- **Example:**

- **Cancer Therapy:** pH-responsive nanoparticles that release drugs specifically in the acidic environment of tumor cells help in reducing side effects and improving treatment efficacy.

- **Photothermal Therapy:** Gold nanoparticles that absorb near-infrared light can be used to generate localized heat for the destruction of cancer cells (photothermal therapy).

- Impact: Stimuli-responsive nanoparticles provide controlled activation or release in specific environments, improving precision in targeted therapies or environmental sensing.

#### 8. Ligand Exchange and Surface Modification:

- Technique: Modify the surface of nanoparticles by exchanging ligands (molecules attached to the surface) to change their interaction with cells or other materials.

- Example:

- Drug Delivery: Replacing hydrophobic ligands with hydrophilic ones can improve the dispersibility of nanoparticles in biological environments, making them more suitable for intravenous drug delivery.

- Catalysis: Changing surface ligands can enhance the catalytic activity of nanoparticles by exposing more active sites.

- Impact: Surface modification improves the interaction of nanoparticles with their environment, enhancing their effectiveness in applications like drug delivery or catalysis.

#### 9. Magnetic and Optical Property Enhancement:

- Technique: Engineer nanoparticles to enhance their magnetic or optical properties for use in advanced imaging, sensors, or data storage.

- Example:

- Magnetic Hyperthermia: Iron oxide nanoparticles designed with optimal magnetic properties can generate heat when exposed to alternating magnetic fields, useful for hyperthermia-based cancer treatments.

- Plasmonics: Engineering gold or silver nanoparticles to exhibit specific optical properties (plasmon resonance) can enhance their use in sensors, imaging, and photothermal therapy.

- Impact: Enhanced magnetic and optical properties improve nanoparticle functionality in medical diagnostics, imaging, and cancer treatment.

By using these techniques, the properties of nanoparticles can be fine-tuned for a wide range of applications, from drug delivery and diagnostics to energy production and environmental remediation.