# Nanoparticles and its Applications- A Review

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## ABSTRACT

Nanoparticles are typically classified into three categories based on their composition: organic, inorganic, and carbon-based particles, all of which possess unique properties at the nanoscale. These particles exhibit enhanced qualities compared to the bulk material of the same substance, such as increased reactivity, strength, surface area, sensitivity, and stability due to their small size.Nanoparticles are synthesized using a range of techniques that can be categorized into three main processes: mechanical, chemical, and physical methods. Over time, these synthesis techniques have evolved significantly, offering more precise control over particle size, shape, and functionality. This review highlights the different types of nanoparticles, their key characteristics, various synthesis methods, and their applications in environmental contexts, showing the broad potential of nanotechnology in diverse fields.

**Keywords**-Nanoparticles, Green synthesis, Nanobiotechnology.

## 1. INTRODUCTION

Nanoparticle and nanostructures, usually ranging from 1 to 100 nm, based on the specific characteristics such as morphology. Metallic nanoparticles are of great interest due to their excellent physical and chemical properties, such as high surface-to-volume ratio and heat transfer (thermal conductivity) [1] The nanoparticles can be synthesized by physical, chemical, and biological methods.

The physical methods are laser ablation method, arc discharge method, high-energy ball milling method, and the chemical vapor deposition method. The chemical methods are coprecipitation method, sol-gel method, microemulsion method, hydrothermal method, chemical method, and microwave method.

The biosynthesis of nanoparticles is also considered to be a bottom-up technique. Metal compounds usually reduce into their respective nanoparticles because of microbial enzymes or the plant phytochemicals with antioxidant or reducing properties.

Although biosynthesis of copper nanoparticles—copper nanoparticles, due to their excellent physical and chemical properties and low cost of preparation, have been of great interest. Copper nanoparticles have wide applications as heat transfer systems and antimicrobial materials [2]. Copper nanoparticles can easily oxidize to form copper oxide. To protect copper nanoparticles from oxidation...

## 2. PROPERTIES OF NANOPARTICLES

- Size-dependent optical properties.
- High reactivity and catalytic efficiency.
- Enhanced mechanical strength.
- Increased surface energy..

Nanoparticles are used in guava leaves, seeds, and pulp, particularly from the plant *Psidium guajava*, which can be used to synthesize metallic nanoparticles due to the presence of phytochemicals like flavonoids, terpenoids, and phenolics, which act as reducing agents in *Psidium guajava*.

Nanobiotechnology is a field that integrates nanotechnology with biological sciences to develop solutions for medical, environmental, and industrial applications at the nanoscale (1-100 nm). Nanobiotechnology has emerged as a powerful tool for enhancing the applications of plant-based compounds in medicine and agriculture.

\Guava (*Psidium guajava*), a tropical fruit rich in bioactive compounds, has attracted significant research interest due to its antimicrobial, antioxidant, and medicinal properties.Green synthesis of nanoparticles is an eco-friendly and sustainable approach that utilizes biological sources such as plant extracts, microorganisms, and biomolecules to produce nanomaterials. This method differs from chemical and physical synthesis techniques, which often involve toxic reagents.Plant-based green synthesis has gained significant attention due to its cost-effectiveness and biocompatibility. Various plant components, such as leaves, seeds, and fruit pulp, contain natural phytochemicals that act as reducing and stabilizing agents for nanoparticle formation.

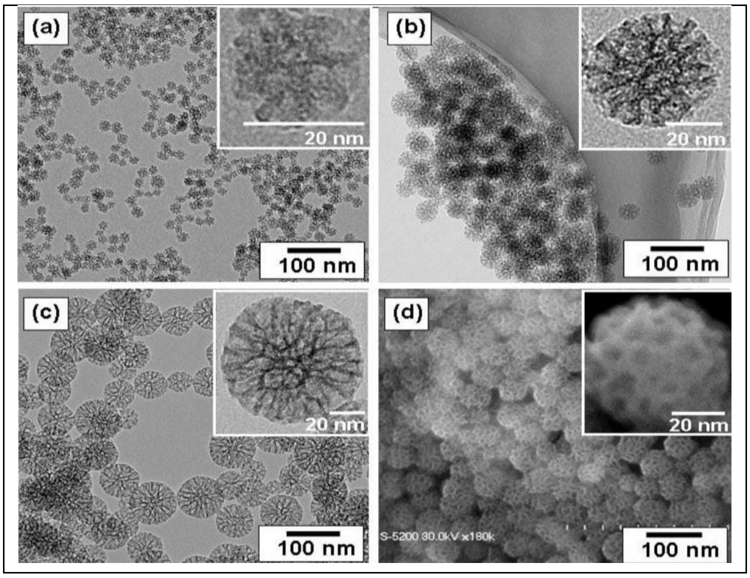


**Fig.1 Particle size of nanoparticle in nm**

**Biological data visualization wikipedia**

**Advantages**

- **Antibacterial Properties:** Nanoparticles synthesized from guava leaves, such as silver nanoparticles, exhibit strong antibacterial activity against both Gram-positive and Gram-negative bacteria.
- **Antioxidant Activity:** Nanoparticles like zinc oxide and titanium dioxide can reduce oxidative damage, thereby enhancing the shelf life of fruits and vegetables.
- **Green Synthesis:** The bio-reduction process using guava extracts is eco-friendly, cost-effective, non-toxic, and sustainable.
- **Extended Shelf Life:** Nanoparticle coatings can act as barriers to prevent microbial growth, oxygen, and moisture, thereby extending the shelf life of guava fruits.
- **Versatile Applications:** These nanoparticles can be used in various applications, including antibacterial coatings, food preservation, and even in ceramics.

**Disadvantages**

- **Toxicity Concerns:** Some nanoparticles, such as lead oxide, can be toxic and hazardous to human health and the environment.
- **Manufacturing Challenges:** The production of nanoparticles can be complex and expensive, requiring precise control over the synthesis process.
- **Regulatory Hurdles:** The use of nanoparticles in food and other consumer products is subject to stringent regulations and safety assessments.
- **Environmental Impact:** The disposal and long-term environmental impact of nanoparticles need to be carefully considered to avoid potential ecological harm.

## 3. APPLICATIONS OF NPS

The unique properties discussed in the section 2, NPs can be used in a variety of applications. Some important ones are given below.

### 3.1 Applications in drugs and medications

Nano-sized inorganic particles of either simple or complex nature display unique physical and chemical properties and represent an increasingly important material in the development of novel nanodevices, which can be used in numerous physical, biological, biomedical, and pharmaceutical applications [3]

NPs have drawn increasing interest from every branch of medicine for their ability to deliver drugs in the optimum dosage range,[4] often resulting in increased therapeutic efficiency of the drugs, weakened side effects, and improved patient compliance [5] Iron oxide particles such as magnetite ($Fe_3O_4$) or its oxidized form maghemite are the most commonly employed for biomedical applications [6] The selection of NPs for achieving efficient contrast for biological and cell imaging applications, as well as for photothermal therapeutic applications, is based on the optical properties of NPs. Mie theory and the discrete dipole approximation method can be used to calculate absorption and scattering efficiencies and optical resonance wavelength for the commonly used classes of NPs, i.e., AuNPs, silica-AuNPs, and Au nanorods [7].

The development of hydrophilic NPs as drug carriers has represented an important challenge over the last few years. Among the different approaches, polyethylene oxide (PEO) and polylactic acid (PLA) NPs have been revealed as very promising systems for the intravenous administration of drugs [8] Iron oxide nanoparticles with chemically compatible regions can be used for many *in vivo* applications, including increased MRI contrast, tissue recovery, immune analysis recovery, and biological fluid detoxification. Hyperthermia, medication administration, and cell separation are also possible applications. All these biomedical applications require that the NP has a high magnetization value, a size of less than 100 nm, and a narrow distribution of particle sizes.

The detection of analytes in tissue sections can be accomplished through antigen-antibody interactions using antibodies labelled with fluorescent dyes, enzymes, radioactive compounds, or colloidal Au [9]Over the past few decades, there has been considerable interest in developing biodegradable NPs as effective drug delivery devices [10] Various polymers have been used in drug delivery research as they can effectively deliver drugs to the target site, thus increasing the therapeutic benefit while minimizing side effects. The controlled release of pharmacologically active drugs to the precise action site at the therapeutically optimum degree and dose regimen has been a major goal in designing such devices.

Liposomes have been used as carriers for potential drugs in place of traditional forms due to their unique benefits, including the ability to protect drugs, target sites of action, and reduce toxicity and other side effects. However, liposome development work is limited due to challenges such as low encapsulation efficiency, rapid leakage of blood components, and mediocre storage stability. NP polymers, on the other hand, promise an important advantage over liposomes.

For example, NPs have the ability to improve drug solubility and controlled release properties of certain regulatory drugs. Most semiconductor and metallic NPs have great potential for the diagnosis and therapy of cancer due to their surface plasmonic resonance (SPR), which improves the diffusion and absorption of light. NPs can effectively convert absorbed light into localized heat, which can be used for selective laser-based therapy of cancerous cells [11] Additionally, the anti-tumor effect of NPs is also effectively used to inhibit tumor growth. Multi-hydroxylated NPs have shown anti-tumor activity with good efficiency and lower toxicity [12].

Silver-based antimicrobial agents (AGNPs) are increasingly used in wound dressings, catheters, and various household products due to their antimicrobial activity. Antimicrobial agents are extremely important in textiles, drugs, water disinfection, and food packaging. Consequently, the antimicrobial characteristics of inorganic NPs add more effectiveness to this field compared to organic compounds, which are relatively toxic to biological systems [13]. These NPs are functionalized with various groups to selectively target microbial species. ZnO, and Cu- and Ni-based NPs have been used for this purpose due to their strong antibacterial efficiency [14].

### 3.2 Applications in manufacturing and materials

Nanocrystalline materials provide materials of great interest to material science as they deviate from each loose material in a size-dependent manner. The manufacture of NPs has physicochemical properties that induce unique electrical, mechanical, optical, and imaging properties that are highly sought after for specific applications within the medical, commercial, and ecological sectors [15] NPs focus on the characterization, design, and engineering of biological and non-biological structures.

### 3.3 Applications in the environment

The increasing area of engineered NPs in industrial and household applications leads to the release of such materials into the environment. Assessing the risk of these NPs in the environment requires an understanding of their mobility, reactivity, ecotoxicity, and persistency [16] Engineering materials can increase NP concentrations in groundwater and soil. This represents the most important possibility for assessing [17]

Due to the high mass ratio, natural NPs play an important role in the solid/water distribution of contaminants absorbed on the surface of the NPs and the surface-absorbed NPs that may be absorbed by the defined NPs during the formation of the NPs.[18] The interaction of contaminants with NPs depends on the properties of the NPs, including size, composition, morphology, porosity, aggregation/disaggregation, and aggregation structure. In the environment, it is not safe and is protected from the oxygen environment when assigned to a silicon network [19].

The removal of heavy metals such as mercury, lead, thallium, cadmium, and arsenic in natural water has attracted considerable attention due to their undesirable effects on the environment and human health. Superparamagnetic Iron Oxide NPs are an adsorbent material that is effective for these toxic materials.

Thus, without measuring the engineering of NPs in the environment, it was difficult to assess their presence due to the absence of analytical methods that can quantify the concentration of NP tracers [20]. NP photography is also a very common practice, and many nanomaterials are used for this purpose. NiO/ZnO modified is used in tandem for photography, providing high NP surface area from a very small size.

### 3.4 Applications in electronics

Printed electronics are attractive to traditional silicon technology, and there has been a growing interest in the development of printed electronics in recent years as it offers the potential for low-cost, large-scale area electronics and sensors for flexible displays. Printed electronic devices[21] with a variety of functional links, including NPs such as metal NPs, organic electronic molecules, CNTs, and ceramic NPs, are expected to flow rapidly as a mass production process for new types of electronic equipment [22].

The unique structural, optical, and electrical properties of dimensioned semiconductors [23]and metals become important structural blocks for new generations of electronics, sensors, and photon materials [24]. A good example of the synergistic effect of scientific discovery and technological development is the electronics industry, where the discovery of new semiconductor materials led to the revolution in vacuum cleaning pipes with diodes and transistors, ultimately leading to miniature chisels [25] Important NPs properties are simple handling and reversible assembly that allow NPs to be used in electrical, electronic, or optical devices such as "low" or "self-assembly" approaches, and they are the brand of nanotechnology [26]

### 3.5 Applications in Energy Harvesting

Recent studies have warned us of the limitations and scarcity of fossil fuels in the coming years because of their non-renewable nature. That is why scientists have moved their research strategies to generate renewable energies from easily available resources at low costs. They discovered that NPs are the best candidates for this purpose because of their large surface, optical behaviour, and catalytic nature. Especially in photocatalytic applications, NPs are widely used to generate energy from photo-electrochemical processes, such as water splitting [27] In addition to splitting water, electrochemical CO2 reduction to fuels, solar cells, and piezo-electric generators also offer advanced options for generating energy [28] The NPs also use applications in energy accumulation to reserve energy in various modules at a nanoscale level[29] Nanogenerators are recently created, which can convert mechanical energy to electricity with the help of piezoelectric properties.

### 3.6 Applications in Mechanical Industries

As revealed by their mechanical properties, thanks to excellent young modulus, constraint, and other mechanical properties, NPs have many applications in mechanical industries, in particular in coatings, lubricants, and adhesives. In addition, this property can be useful for making stronger nanofins mechanically for various purposes. The tribological properties can be controlled on a nanometric scale by integrating NPs into the metal and polymer matrix to increase mechanical forces. This is because the NP rolling mode in the lubricated contact area could provide very low friction and wear. In addition, the NPs offer good shift and dilapidation properties, which could also affect low friction and wear, thereby increasing the lubrication effect[30]. Coating can lead to various mechanically strong characteristics because it improves toughness and wear resistance. NPs based on aluminium oxide, titania, and carbon have successfully demonstrated that they get the desired mechanical properties in coatings [31]

## 4. **Toxicity of NPs**

In addition to many industrial and medical applications, there are certain toxicities that are associated with NPs and other nanomaterials [32] and basic knowledge is required to encounter these toxic effects. NPs can secretly enter the environment through water, soil, and air during various human activities. However, the application of NPs for environmental treatment intentionally injects or dumps manipulated NPs into the soil or aquatic systems. This has resulted in an increasing concern among all stakeholders. The advantages of magnetic NPs, such as their small size, high reactivity, and large capacity, can be potentially deadly factors by inducing adverse cellular toxic and harmful effects, unusual in comparison to micron-sized particles. Studies have also illustrated that NPs can enter organisms during ingestion or inhalation and move through the body to various organs and tissues, where they have the possibility of exercising the effects of reactivity in toxicology.

Although some studies have also discussed the toxicological effects of NPs on animal cells and vegetable cells, toxicological studies with magnetic NPs on plants to date are still limited. The uses of NPs in many consumer products lead them to be released into the aquatic environment and become a source of dissolved AG, thus having toxic effects on aquatic organisms, in particular bacteria, algae, fish, and daphnia [33].

The respiratory system represents a unique target for the potential toxicity of NPs due to the fact that, in addition to being the entrance portal for inhaled particles, it also receives the entire cardiac flow [34]NPs are widely used in organic applications, but despite the rapid progress and early acceptance of nanobiotechnology, the potential for harmful effects on health due to prolonged exposure at various concentrations in humans and the environment has not yet been fully established. However, the environmental impact of the NPs should increase in the future.

One of the NP toxicity issues is the ability to organize themselves around protein concentrations that depend on the size of the particles, the curvature, the shape, the properties of the loaded surface, the functionalized groups, and free energy. Because of this link, some particles generate adverse biological results explaining proteins, fibrillation, cross-linking, and loss of enzymatic activity. Another paradigm Sis the release of toxic ions when the thermodynamic properties of the materials prefer the solution of the particles in a suspended or organic form [35] The NPs tend to join in hard water and seawater and are strongly influenced by the specific type of organic matter or other natural particles (colloids) present in freshwater. The state of dispersion will change ecotoxicity, but many abiotic factors that influence this, such as the value of the pH, the salt content, and the presence of organic materials, must be systematically examined in the context of ecotoxicological studies.

## 5. **SYNTHESIS OF COPPER NANOPARTICLES**

The biosynthesis of copper nanoparticles involves four stages. Copper sulphate (0.02M) was prepared in deionised water and a blue solution was obtained. Polyethylene glycol 6000 (0.01M) was dissolved in water and added to the aqueous solution containing the copper salt with vigorous stirring. In this step, the colour of the solution changed from blue to white. In the third step, guava extract was added to the copper sulphate solution containing PEG. The colour of the solution remains the same. Finally, 0.1M sodium hydroxide was added in drops to the solution under continuous rapid stirring. The colour of the aqueous phase changed from white to green. The appearance of this colour indicates that the reduction has started. The formation of copper nanoparticles is confirmed by the colour change from green to brown when it is kept on the water bath under 80°C. The formation of copper nanoparticles is inferred by visual observation followed by UV-Visible spectrum, FTIR, SEM, XRD, and EDAX studies [15]. Fixation of parameters for biosynthesis of copper nanoparticles

Biosynthesis of copper nanoparticles using different ratios. The biosynthesis of copper nanoparticles was carried out at different ratios of extract and copper 1:4, 1:5) at pH 10. Time taken for the colour change in the reaction mixture as well as the formation of nanoparticles.

Biosynthesis of copper nanoparticles at different temperatures. The biosynthesis of copper nanoparticles for the fixed composition was done at different temperatures namely; room temperature and by heating in the water bath at 60°C and 80°C. The time taken for visual colour change from green to brown was recorded followed by recording UV-Visible spectrum.Biosynthesis of copper nanoparticles at different pH The biosynthesis of copper nanoparticles for 1:3 ratios of extract and copper sulphate was carried out at different pH. The time taken for colour change as well as the UV-Visible spectrum for the reaction mixture was monitored. Biosynthesis of copper nanoparticles at different intervals of time The synthesis was carried out at pH 10 in the ratio 1:3 (extract: CuSO4) and the time taken for the formation was noted at an every 10 minutes and completion of the reaction was monitored by the colour change as well as the UV-Visible spectrum. Biosynthesis of copper nanoparticles in the presence of PEG Biosynthesis of copper nanoparticles was carried at pH 10 in the ratio 1:3 with and without PEG 6000 and completion of the reaction was monitored by the colour change as well as by recording the UV-Visible spectrum.Stability of copper nanoparticles [36] The stability of the colloidal aqueous solution of copper nanoparticles was determined at room temperature at an interval of 24hrs for 15 days.

Characterisation of biosynthesized copper nanoparticle Visual inspection the bio-reduction of the aqueous solution of copper sulphate using guava extract was monitored and the appearance of brown colour indicates the formation of copper nanoparticles.

pH analysis the pH of the extract, precursor as well as the resulting mixture after addition of PEG 6000 and NaOH was determined using digital pH meter.

UV spectroscopy the reduction of copper sulphate to copper was monitored by recording UV-Visible spectrum of the reaction mixture after diluting a small aliquot of the sample with deionised water. [37] The measurements are recorded on Shimadzu dual beam spectrometer (model uv-1650pc) operated at a resolution of 1nm.

FT-IR analysis of bio-mass before and after bio-reduction FT-IR measurement was carried out for both the extract and copper nanoparticles to identify[38] the possible bioactive molecules responsible for the reduction of the copper ions and the capping of the copper nanoparticles by the guava extract pellet and the spectrum was recorded in the wavelength interval 4000 to 400 $cm^{-1}$. The FT-IR spectrum was also recorded for the solid copper nanoparticles isolated after centrifugation. [39]

X-Ray diffraction studies X-ray diffraction (XRD) measurement of the guava reduced copper nanoparticles was carried out using powder x-ray diffractometer instrument (SEIFERT JSODEBYE FLEX-2002) in the angle range of 10°-70° operated at a voltage of 40kV and a current of 30mA with Cu Kα radiation in a θ-2θ configuration. [40] The crystallite domain size was calculated by using Debye-Scherrer formula.

## 6. DISCUSSION

Nanoparticles are playing a crucial role in addressing antimicrobial resistance (AMR), which is a major global health concern. Traditional antibiotics are becoming less effective due to the rise of resistant bacterial strains. Nanoparticles offer a promising alternative due to their unique properties and mechanisms of action. In the pharmaceutical industry, nanoparticles are used to enhance the delivery and efficacy of antimicrobial agents. They can target specific bacterial cells, disrupt bacterial membranes, inhibit enzymes, and produce reactive oxygen species that kill bacteria.

## 7. CONCLUSION

Nanotechnology stands at the forefront of pioneering solutions to antimicrobial resistance. Nanoparticles offer multifaceted approaches to circumvent bacterial defences mechanisms, enhance antibiotic potency, and facilitate novel therapies. While challenges persist in toxicity environmental impact, and regulatory landscapes, ongoing research and interdisciplinary collaboration are paving the way for nanoparticles to become integral in the next generation of antimicrobial agents.


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