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Exploring Eco-Friendly Approaches: A Comprehensive Review on Green Synthesis of Nanoparticles

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Abstract

In recent times, there has been a growing scholarly interest in advancing Green Chemistry methodologies to effectively synthesize metal NPs. This research area has captured the scientific community's attention due to its potential applications across diverse fields, particularly in medical and biological research at the molecular and cellular levels. The use of this approach in NP biosynthesis is not only cost-effective but also environmentally sustainable, offering benefits such as minimized waste, utilization of natural products, and enhanced energy efficiency. The process of synthesizing NPs through this approach establishes a link between nanotechnology and plant biotechnology. In comparison to conventional chemical or biological methods, Green synthesis demonstrates a superior level of efficiency. The incorporation of nanotechnology into the realm of medicine presents innovative prospects for addressing a broad spectrum of health-related issues, including neurodegenerative disorders and cancers. Green NPs have gained popularity for their roles as adsorbents, antimicrobials, and photocatalysts. Distinguished by their low toxicity and excellent biocompatibility, these NPs are well-suited for various biomedical applications. The article provides a comprehensive overview of the growing interest in advancing Green Chemistry methodologies for the synthesis of metal nanoparticles (NPs).

Keywords: Green Synthesis, Nanoparticles, Nanometre

Abbreviation: NP- Nanoparticle

Introduction

The essential essence of green chemistry can be distilled into a practical definition: "Green Chemistry involves the efficient use of raw materials, minimizes waste, and abstains from employing toxic or hazardous reagents and solvents in the production and use of medical products." The term 'green chemistry' was introduced in the early 1990s by Anastas and colleagues at the US Environmental Protection Agency (EPA). This concept eventually led to the formulation of the 12 principles, recently organized into the mnemonic PRODUCTIVELY by Poliakoff et al [1].

The acronym P.R.O.D.U.C.T.I.V.E.L.Y represents a set of principles:
P - Minimize waste generation

R - Utilize renewable materials

O - Eliminate unnecessary derivatization steps

D - Promote the production of degradable chemical products
U - Adopt safe synthetic methods

C - Employ catalytic reagents

T - Operate under ambient temperature and pressure conditions
I - Implement in-process monitoring

V - Minimize the use of auxiliary substrates

E - Maximize feed efficiency in product formation (E factor)
L - Ensure low toxicity of chemical products
Y - Confirm safety in the process.

Nanotechnology involves the application of scientific principles to manipulate matter at the molecular level. The term "Nano" originates from the Greek word "Dwarf," signifying "a billionth." In 1974, Professor Norio Taniguchi from Tokyo Science University introduced the term "Nanotechnology" to describe the precise manufacturing of materials with nanometre-scale precision. Drexler later incorporated this term in his 1986 book, "Engines of Creation: The Coming Era of Nanotechnology." Notably, artisans in Mesopotamia utilized NPs as early as the ninth century to achieve a sparkling effect on pottery surfaces [2]. The exploration of nanometre-scale properties in metals was first documented by Michael Faraday in his influential 1857 paper. Subsequently, Turner highlighted that heating thin leaves of gold or silver mounted on glass to a temperature below red heat (~500 °C) disrupts the continuity of the metallic film. This results in the free transmission of white light, reduced reflection, and a significant increase in electrical resistivity [3-4]. Significant growth in this field has unveiled novel fundamentals in quantum dots, nanobiotechnology, Enhanced Raman scattering on surfaces, as well as its application in microbiology, which has been investigated extensively. The study of NPs is captivating because of their minute size and the remarkable ratio of surface area to volume, leading to distinctive physical and chemical characteristics. By altering the dimensions and structure of these particles on a nanometre scale, researchers can create materials with innovative applications [5]. In medicine and pharmacy, metal NPs, the field of nanobiotechnology is rapidly growing, with oligonucleotide-capped gold NPs being used to detect proteins through various methods including atomic force microscopy, surface plasmon resonance imaging, and Raman spectroscopy [6]. Furthermore, gold NPs have found applications in immunoassays, protein assays, cancer nanotechnology, and capillary electrophoresis. In the field of medicine, gold NPs serve as indicators for biological screening tests and have exhibited the capability to trigger apoptosis in B cell-chronic lymphocytic leukemia [7]. Conversely, silver NPs have displayed promising antimicrobial properties against various infectious organisms, including Bacillus subtilis, Escherichia coli, Vibrio cholera, Syphilis typhus, Pseudomonas aeruginosa, and Staphylococcus aureus [8]. The importance of green synthesis in the realm of nanotechnology is substantial, particularly in addressing contemporary environmental issues and advancing sustainable methodologies. This method entails creating nanomaterials through eco-friendly means, aiming to minimize the utilization of hazardous substances and decrease the overall environmental impact associated with nanomaterial manufacturing.

A crucial aspect of this approach is the mitigation of environmental pollution and health risks linked to conventional synthesis techniques. Conventional methods often entail the employment of harmful chemicals, solvents, and substantial energy consumption, resulting in the generation of detrimental by-products. Conversely, green synthesis techniques utilize harmless agents like plant extracts, microorganisms, or other environmentally friendly sources, leading to a more hygienic and secure production process.

Instances illustrating the successful application of green synthesis for diverse nanomaterials can be found. For instance, scientists have utilized plant extracts rich in phytochemicals to produce nanoparticles with antimicrobial properties. This not only tackles concerns about antibiotic resistance but also highlights the potential of sustainable practices in devising solutions for urgent global health issues.

Moreover, green synthesis is in harmony with sustainability principles by promoting the judicious use of resources. Utilizing renewable sources, such as agricultural waste or bio-based precursors, for nanomaterial production helps minimize the environmental impact. This becomes especially crucial given the escalating demand for nanotechnology applications in various industries, from medicine to electronics, where sustainability is increasingly becoming a paramount consideration. Examining the practical implications in the field of energy storage reveals promising outcomes from green-synthesized nanomaterials for batteries and capacitors. For instance, the incorporation of nanocellulose derived from sustainable sources in battery electrodes not only enhances energy storage capacity but also ensures biodegradability at the conclusion of the device's life cycle.

In summary, the significance of green synthesis in nanotechnology transcends its technical aspects. It signifies a shift towards sustainable and environmentally conscious practices, addressing the urgent requirement for cleaner and safer manufacturing processes. Through instances and practical applications, it is evident that green synthesis not only contributes to resolving environmental challenges but also lays the foundation for a more sustainable and responsible future in nanotechnology.

Fundamentals of Green Chemistry

In 1998, John Warner and Paul Anastas established a set of 12 green chemistry principles focused on reducing or eliminating the use of hazardous materials and chemical processes. These principles exhibit specificity, practicality, and significance, enhancing their applicability and implementation.

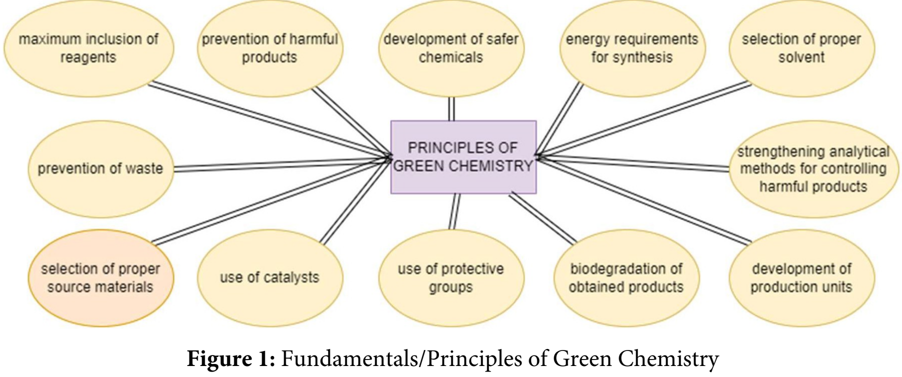

Figure 1: Fundamentals/Principles of Green Chemistry

The outlined principles (depicted in Figure 1) are as follows:

- Waste Prevention: Focus on designing chemical syntheses that generate minimal waste instead of disposing of excess materials.
- Atom Economy: Maximize the quantity of raw materials contributing to the final product, minimizing waste.
- Safer Chemical Syntheses: Prioritize the use and creation of substances that are minimally or non-toxic.
- Design of Safe Chemicals and Products: Strive for effective chemicals without harmful side effects.
- Safe Solvents and Reaction Conditions: Aim to use the safest solvents and chemicals, or eliminate them if possible.
- Increased Energy Efficiency: Be mindful of energy consumption during chemical synthesis, striving to initiate reactions at room temperature and pressure.
- Use of Renewable Raw Materials: Utilize agricultural products or sustainable waste for replenishable sources.
- Avoidance of Chemical Derivatives: Minimize or eliminate the use of blocking or protective groups and temporary modifications when feasible.
- Non-Stoichiometric Catalysts: Implement catalytic reactions using effective catalysts in small quantities that can repeatedly promote the reaction.
- Design of Degradable Chemicals and Products: Formulate nonpersistent compounds for safe decomposition.
- Real-Time Pollution Analysis: Minimize or eliminate by-products by intervening during the synthesis process.
- Accident Minimization: Prioritize safety by designing chemicals and physical forms that reduce the risk of accidents such as releases, explosions, and fires.

Properties of Nanoparticles

- Offers large surface area.
- Show unique optical properties including fluorescence and coloration.
- Exhibits improved electrical and thermal conductivity.
- Demonstrates elevated Raman scattering, catalytic activity, chemical stability, and nonlinear optical behaviour.
- Can be used for target or controlled drug delivery by encapsulating the drug.
- Particular type of NPs displays superparamagnetic activity, which indicates that they do not have a magnetic moment at rest but gain magnetism when they come into contact with an external magnetic field.

Advantages of Using Nanoparticles

- Due to their minute size, NPs can infiltrate small capillaries and be absorbed by cells, facilitating effective drug deposition at specific target sites.
- Easy to prepare.

- Protection of the encapsulated drug.
- Improves the therapeutic efficiency and bioavailability of the entrapped drug.
- No problems are depicted during large-scale production and sterilization.
- Enhanced diagnostic techniques.

Disadvantages of Using Nanoparticles

- The accessibility and destructive power of atomic weapons can be increased.
- Products developed by nanotechnology are expensive.
- Has increased the risk of health issues owing to their small size which can lead to inhalation problems easily along with alveolar inflammation and cytotoxicity.
- The regulation of NPs continues to be a challenge that is yet to be resolved and there are no comprehensive regulations developed yet.
- NPs tend to aggregate or clump together, which can reduce their effectiveness
- in certain applications, managing their dispersion is often a challenging task.
- Can be sensitive to changes in environmental conditions like temperature and pH which may have an impact on their stability and performance. Exhibit particle enlargement, unpredictable gelation inclination, undesired polymeric transitions, and consistent burst release [9].

Synthesis of Nanoparticles

Important attributes to be taken into consideration for the production of highly stable and delineated NPs:

O Identification and culling of the best organisms based on their intrinsic properties.

O Providing exemplary conditions for cell growth and enzyme activity like inoculum size, nutrients, temperature, pH, etc.

O Optimal reaction conditions involving optimizing bio-reduction conditions of reduction mixture.

Improving these crucial characteristics allows for the regulation of NP morphologies and other properties, contributing to environmentally friendly preparation methods.

There are two primary methods employed in the production of NPs, which can originate from natural or synthetic sources and display distinctive characteristics at the nanoscale. The first method is referred to as the "top-down" approach, which entails breaking down solid materials into smaller fragments through the

application of external force. Various physical, chemical, and thermal techniques are utilized to supply the necessary energy for NP formation in this method.

The second approach, known as "bottom-up," involves assembling andcombining atoms or molecules from gases or liquids. Each of these techniques has its own set of advantages and drawbacks. Although the top-down method tends to be more expensive to implement, it faces challenges in achieving perfect surfaces and

edges due to the presence of cavities and roughness in NPs. Conversely, the bottom-up approach offers the advantage of producing excellent NP synthesis results. Moreover, this method generates no waste materials require removal, and it allows for the production of NPs with smaller sizes [10].

The classification for NP synthesis methods is outlined in Figure 2

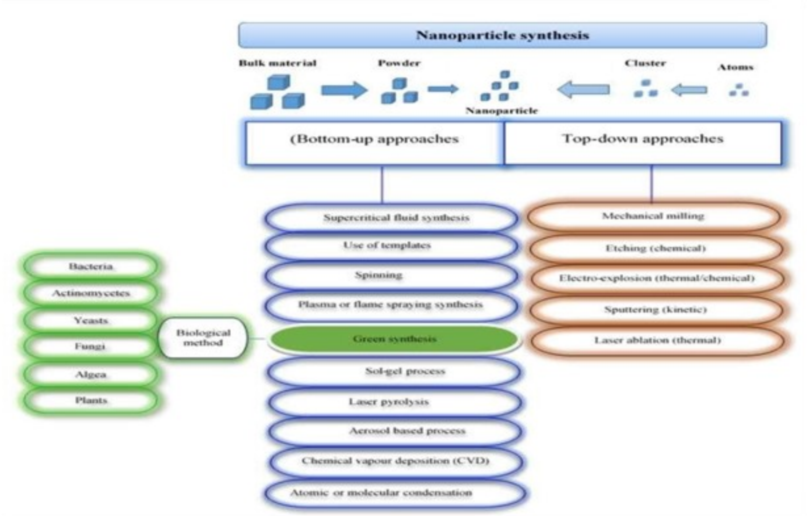

Figure 2: Synthesis methods of NPs10

Some important synthetic methods for various NPs synthesis are provided in Table 1

Table 1: Synthetic methods for NP synthesis

Gold NP	Chemical reduction of salts, exposure to ultraviolet radiation, aerosol technologies, laser ablation, ultrasonic fields, and photochemicalNP
Silver NP	Evaporation-condensation, laser ablation, electrochemical methods, NP photochemical reduction, gamma irradiation, electron irradiation, and microwave processing are some techniques utilized.
zinc Oxide	sol-gel process, vapor phase oxidation, sonochemical reduction, Oxide precipitation, polyol and hydrothermal techniques, thermal vapor NP transport and condensation are used.
Copper	Thermal reduction, metal vapor synthesis, radiation methods, laser NP ablation, mechanical attrition, and chemical reduction are used.

Green Synthesis of Nanoparticles

NPs created through environmentally friendly technology surpass those generated through physical and chemical means. Employing green methods eliminates the need for costly chemicals, promotes energy conservation, and yields environmentally sustainable products and by-products. The 12 principles of green chemistry have emerged as a crucial framework for researchers, scientists, chemical technologists, and chemists globally, guiding them in the development of safer and less potentially harmful chemical products and byproducts.

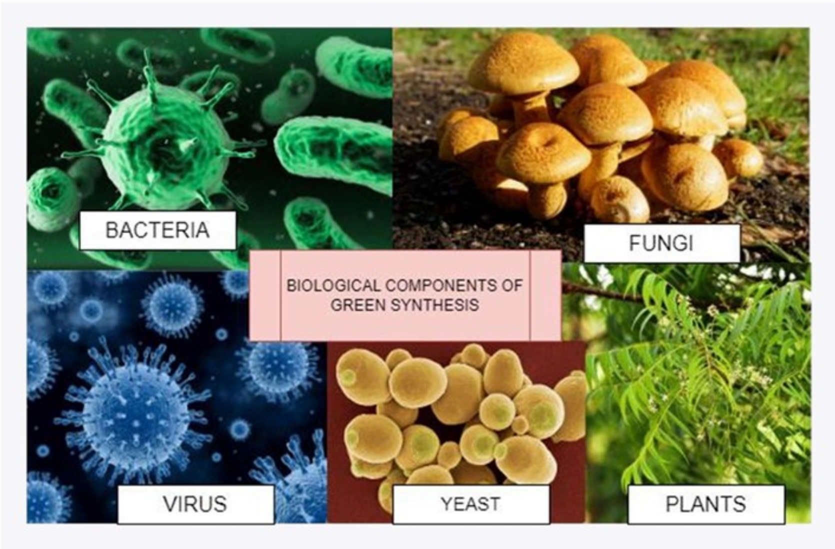

Figure 3: Biological Components of Green Synthesis

The cellular membranes of key biological entities are intricate structures comprising amphiphilic lipids. They play a central role in numerous biochemical conversions facilitated by the oxidation-reduction mechanism, making them pivotal locations within cellular structures. The process hinges on the electrostatic attraction between the negatively charged phospholipids in microorganism membranes and the positively charged metal ions found in combined form in salts intentionally introduced into the culture media11. The selection of an appropriate culture medium for a specific organism holds significant importance as it directly influences the NP formation process and ultimately determines the specific yield.

This is because the interaction between the biological component and the corresponding metal salt serves as the foundation for the formation process.

Microorganismal Routes for Nanoparticle Synthesis

General Mechanism for Micro organismal-based Nanoparticle Synthesis:

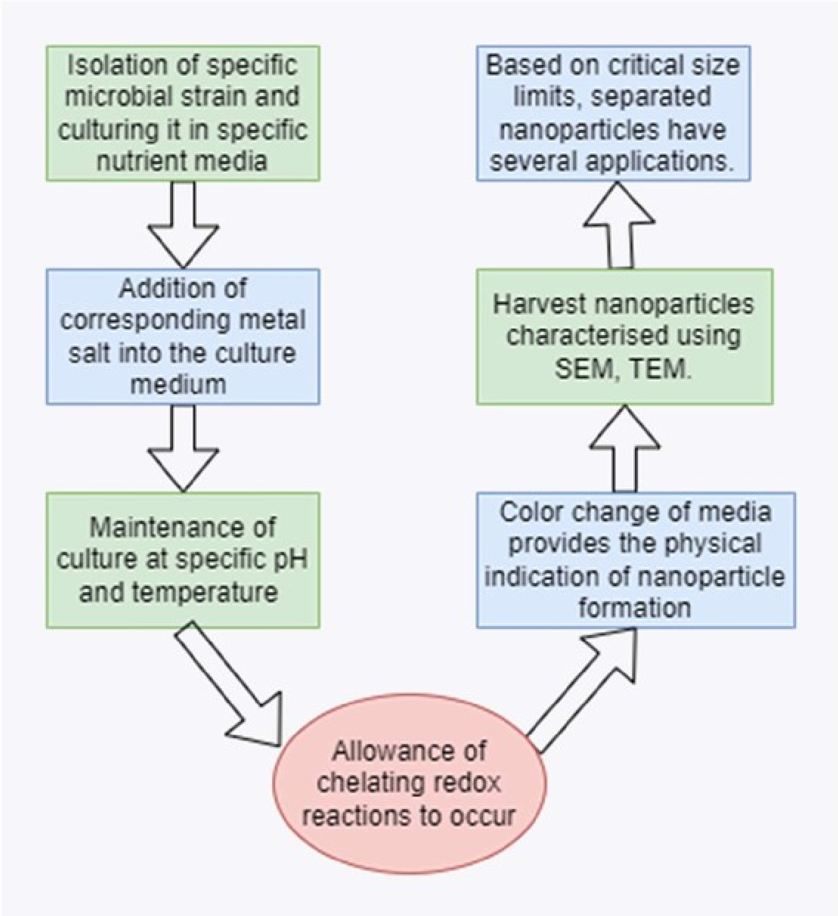

Figure 4: General mechanism for microorganismal-based NP synthesis

The process of NP synthesis through this approach appears to offer several benefits compared to synthetic methods. Not only is it more cost-effective, but it is also less cumbersome, time-intensive, and complex. Crucially, it is non-toxic, enhancing safety. Moreover, it yields exceptionally well, surpassing what is achievable within a specific timeframe using synthetic methods. Additionally, there is reduced input wastage and better control over constituent ingredients is achievable due to more precise regulation of the molecular units needed for NP formation.

Bacterial Mediated NP Synthesis: Prokaryotes and actinomycetes are frequently employed in the manufacture of metal or metal oxide NPs. The synthesis of a particular NP type is highly dependent on operational parameters such as pH and temperature. Minor adjustments in these conditions can lead to variations in the size of the synthesized particles. Bacteria play a vital role as biocatalysts in the synthesis process. The intracellular proteins of bacteria and the chelating function of DNA subunits are critical attributes facilitating the production of NPs.

Table 2: Bacterial species used for NP synthesis

Bacterial strains	NP synthesized	Size range (in nm)
Pseudomonas stutzeri	Silver	200
Lactobacillus	Titanium dioxide	15-35
Acinetobacter spp.	Magnetite	14885
Pseudomonas aeruginosa	Gold	15-30

Escherichia coli	Cadmium sulphide	2-5

The capacity of microbial genomes to generate metallic NPs, both within and outside their cells, is a captivating phenomenon. Recent research reveals that certain microbial species thriving in industrial mines possess the ability to accumulate metal within their bodies through enzymatic processes at metallurgical sites. For example, pedomicrum bacteria, which utilizes budding for reproduction, have been identified as depositing iron and manganese oxide intracellularly in the nanophase form. What's even more intriguing is the recent discovery that this bacterium can also accumulate gold at the nanoscale. Microbial species like Bacillus subtilis 168 have been seen to play a role in reducing gold from a trivalent to a zero-valent state. They can accumulate gold intracellularly in the form of NPs, ranging in size from 5-25 nm, exhibiting an octahedral morphology inside the bacterial cell walls15. Other microorganismal species, such as sulfate-reducing bacteria, have been explored for their capability to synthesize various types of metallic NPs. When exposed to gold salts in gold mines, these bacteria can produce metallic gold from the gold-thiosulfate complex in a 10 nm size, with hydrogen sulfide (H2S) released as the end product of their metabolic process. Recently, Escherichia coli DH5α has also been observed to biochemically reduce gold from aurochloric acid to gold NPs.

Fungal Mediated NP Synthesis: Fungi have demonstrated notable efficiency in the synthesis of metal and metal oxide NPs. This is attributed to their possession of a range of intracellular enzymes, reducing agents, and proteins, providing them with a distinct advantage compared to other organisms.

The likely mechanism for the formation of metal NPs in fungi involves enzymatic reduction, particularly by reductase enzymes located in the cell wall or within the

fungal cell. This method stands out for its simplicity when scaling up, with fungal organisms, especially through techniques like thin solid substrate fermentation, allowing for the production of monodisperse NPs with desired shapes. Unlike extracts from plants and bacteria, fungal mycelia can endure variations in culturing conditions during the scale-up process in a bioreactor.

Furthermore, fungal species exhibit a meticulous growth nature crucial for the formation of NPs. This characteristic facilitates the release of essential enzymes and proteins in concentrations sufficient for the bio-reduction of corresponding metal salts, resulting in the formation of biochemically reduced metallic ions as zero-valent NPs.

Fungi also overcome the challenges associated with downstream processing in NP synthesis, as they proficiently secrete extracellular enzymes, streamlining large-scale enzyme production. Additional benefits of employing fungi in the "green" synthesis of metal NPs include economic viability and straightforward biomass handling. However, a notable drawback in utilizing these biological processes for NP synthesis is the complexity of genetic manipulation in eukaryotes compared to prokaryotes16.

Generally, NPs synthesized intracellularly tend to be smaller and more specific to application requirements. Nonetheless, these approaches involve typical downstream processing, and the extraction procedures are challenging, leading to the drawback of low yields. Conversely, extracellular NPs can be easily isolated with greater simplicity, and the subsequent processing is considerably streamlined. As they are synthesized outside the cells, either on the cell surface or at the periphery, these NPs can be readily accessed for various applications without the need for distinct and complex extraction methods.

Table 3: Fungal strains for NP synthesis intracellularly [17, 18]

Fungal species	Type of NP	Size range (in nm)
Verticillium sp.	Gold	25-30
Aspergillus flavus	Silver	8-10
Trichothecium sp.	Gold	Not determined
Verticillium sp.	Silver	25-35

Table 4: Fungal strains for NP synthesis extracellularly [19,20]

Fungal species	Type of NP	Morphology & Size (in nm)
Fusarium oxysporum	Gold	Spherical, 20-40
Colletotrichum sp.	Gold	Spherical, 20-40
Aspergillus niger	Silver	Spherical, 20
Volvariella volvacea	Silver and Gold	Spherical and hexagonal, 20-150
Penicillium fellutanum	Silver	Spherical, 5-25
Fusarium oxysporum	Cadmium selenide	Spherical, 9-15
Fusarium oxysporum	Magnetite	Quasi-spherical, 20-50

Table 3 displays prominent fungal species capable of synthesizing NPs as intracellular metabolites, while Table 4 enumerates key fungal species employed in the extracellular synthesis of metal-based NPs. It is noteworthy that the size and shape of the generated NPs vary based on the species, ultimately influencing their potential applications. Furthermore, the extracellular synthesis of NP is favored for its simplicity in recovering metabolites, presenting fewer complications in the process.

Viral Mediated NP Synthesis: It is extremely challenging to culture viruses in vivo, but they can still be utilized in NP synthesis. They generally have applications in electronics and semiconductors due to their ability of cathodoluminescence and surface plasmon resonance.

Table 5: Viral species for NP synthesis [21]

Viral species	NP	Morphology
Tobacco mosaic virusM13 Bacteriophage	Lead sulfide, Silicon dioxideZinc sulfide, Cadmium sulfide	Nanotubes on surfaceNanowires, Quantum dots

Yeast Mediated NP Synthesis: Yeasts are unicellular fungi that inhabit eukaryotic microorganisms, with over 1,500 identified species. They are utilized for the production of countless metal NPs along with the synthesis of heterogeneous NP.

Table 6: Major yeast strains involved in NP synthesis

Yeast strains	NPs	Morphology & size (in nm)
C. glabrata	Cadmium sulphide	Spherical, 20A
S. pombe	Cadmium sulphide	Hexagonal, 1-1.5
Torulopsis sp.	Lead sulphide	Spherical, 2-5
Yeast strain MKY3	Silver	Hexagonal, 2-5

Synthesis of Nanoparticles From Plants

Plants have the capability to accumulate heavy metals in various parts such as leaves, roots, and fruits. This characteristic has led to a growing interest in utilizing plant extracts as a straightforward, efficient, cost-effective, and viable approach for NP synthesis. Among the diverse sources available for NP synthesis, plant biodiversity stands out as the most intriguing and effective.

Plants with high genetic diversity contain a wealth of fascinating biomolecules, including coenzymes, vitamin-based intermediates, and others, capable of reducing metal ions to NPs in a single step. These methods can be easily implemented under ambient temperature and pressure conditions, without the need for advanced and rapid technical requirements. Additionally, plant-based NP synthesis approaches are environmentally friendly, easy to scale up, and traditionally favored. Phenomenal reducing agents found in plant metabolites, such as phenolic compounds, alkaloids, and sterols, contribute to the success of plant-mediated NP synthesis.

Most studies in this field have primarily focused on silver and gold NPs, gaining considerable attention due to the widespread applications in nanomedicine-based innovations. A notable advantage of plant-mediated NP synthesis lies in its simplicity and cost--effectiveness compared to microorganisms. The ease of the procedural and result-based advantages, along with relatively quicker applicational administrations, positions plants as a preferred choice. In recent years, plant extract-based NP synthesis has experienced significant growth with advancements, developments, and increasing NP requirements22.

Plant extracts are anticipated to act as both reducing and stabilizing agents in NP synthesis. The nature of the plant extract plays a crucial role in determining the morphology of the synthesized NPs, as different plant extracts contain varying concentrations of biochemical reducing agents. The NP production process involves mixing the plant extract with a solution of metal salt at room temperature, with the reaction completing within minutes. The metals undergo a biochemical reduction, transitioning from their mono or divalent oxidation states to zero-valent states, resulting in NP production. This is visually indicated by the observed color change in the culture medium vessel. Successfully applied to synthesizing gold, silver, and other metal-based methods has proven to be effective.

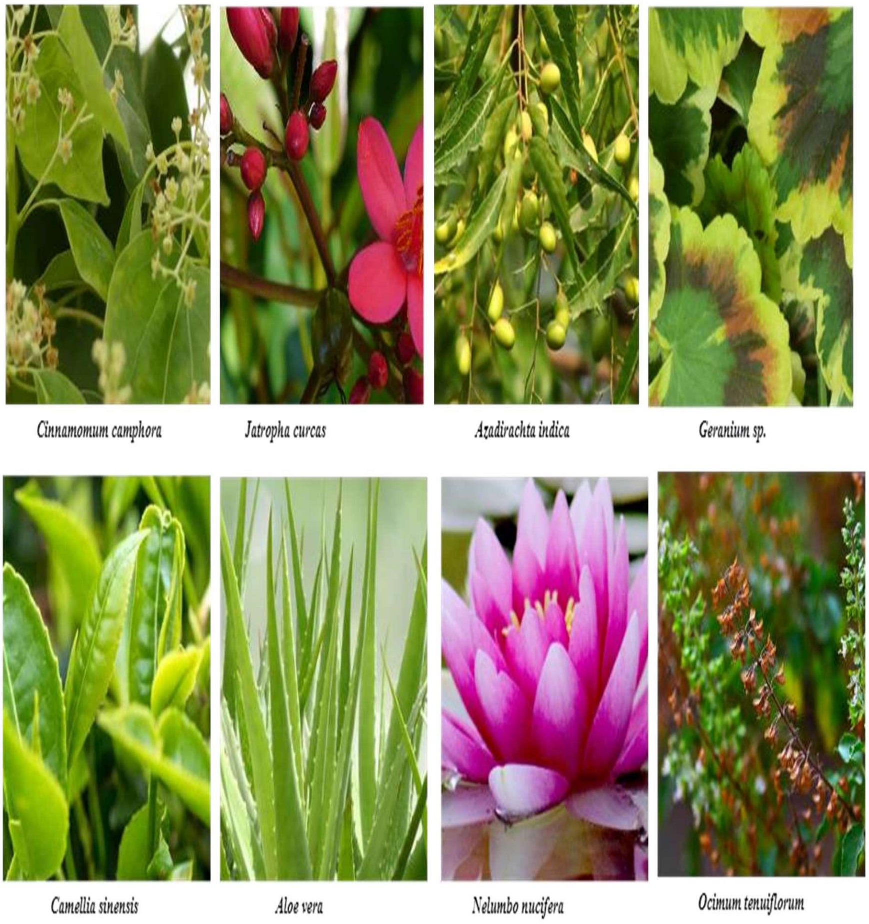

Figure 5: Some plant species used in NP synthesis

Biologically active compounds, such as phytochemicals found in plants, have functional groups that enable them to reduce metal ions more efficiently. They also affect the stability and rate of NP formation. Certain essential phytochemicals accountable for the bio-reduction of NPs comprise amides, carboxylic acids, aldehydes, ketones, sugars, terpenoids, and flavones. Additionally, factors like temperature, pH, and metal salt concentration can also impact the formation of NPs.

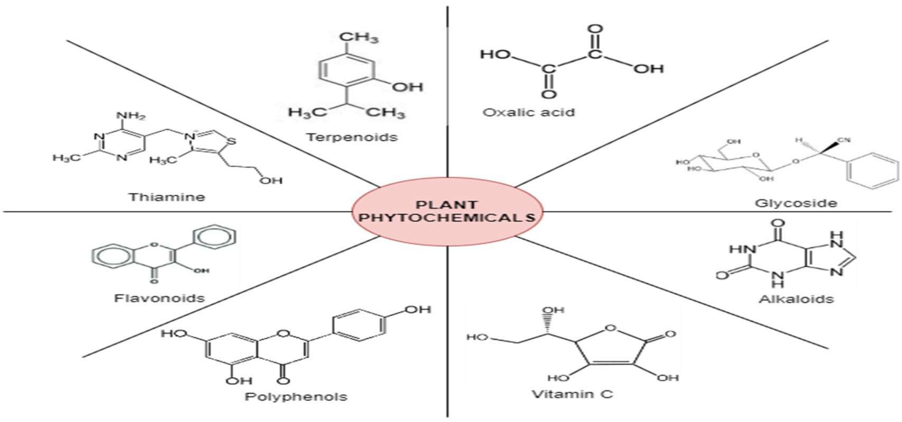

Figure 6: Phytochemicals present in plants

General Mechanism Involved in Plant-Mediated NP Synthesis:

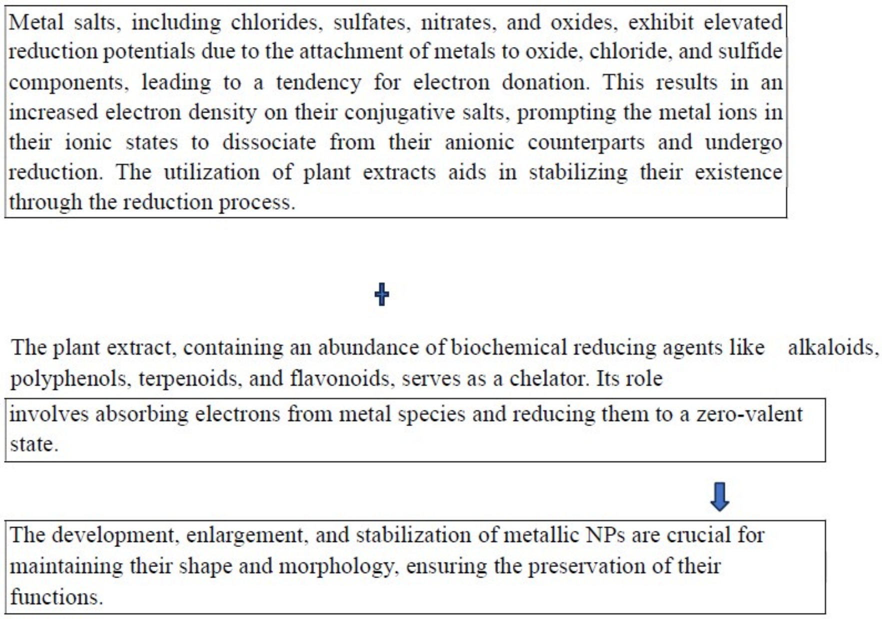

Figure 7: Mechanism of plant-mediated NP synthesis

Figure 7 offers an overview of diverse methods for synthesizing NPs using plant species. It resembles Figure 4 but concentrates specifically on synthesis facilitated by plants. The plant extract comprises a variety of compounds, including flavonoids, phenolic, and terpenoid intermediates, playing a role in the bio-reduction of salts of metal solutions in the cultivation process.

Table 7: Plant species utilized in NP synthesis [18,23,24]

Plant involved	NP	Morphology and size range(nm)
Acalypha indica	Silver	Spherical, 20-30
Azadirachta indica	Silver/Gold	50-100
Cinnamomum camphora	Gold	Cubic hexagonal,3.2-20
Datura metel	Silver	Quasilinear, 16-40
Geranium leaf	Gold	16-40
Jatropha curcas	Lead	10-12.5
Nelumbo nucifera	Silver	Spherical, 25-80

The reduction of silver ions into the required NP form in this study was attributed to the presence of hydroxyl ions, NAD+, and ascorbic acid in the extract. Kesharwani and colleagues successfully obtained high-quality NPs from the leaf extract of Datura metel, characterized by a stable size ranging from 16 to 40 nanometers and distinctive morphology. The leaf extracts harbored various bioactive compounds, including alkaloids, amino acids, alcoholic compounds, and chelating proteins, all contributing to the bio-reduction of silver ions. Furthermore, the conversion of silver ions into their zero-valent form and their subsequent stabilization as formed products were facilitated by alcoholic intermediates such as quinol and chlorophyll pigments23. Table 7 presents an elaborate overview of major plant species utilized for NP synthesis, revealing that many plants were employed in the synthesis of gold and silver NPs. Plantmediated synthesis demonstrates superior control compared to other biological methods for NP synthesis. For instance, specific conditions such as temperature, pH, and salt concentrations were carefully regulated when using plants like Jatropha, Geranium, and common lotus for NP synthesis. However, the process of plant cell culture is more challenging compared to microbial cultures, making the plant-derived NP synthesis route less popular. In certain instances, the development of callus is necessary, adding complexity to the overall procedure.

Methods for Obtaining Plant Extracts

Regarding the isolation of plant metabolites, several commonly employed extraction methods exist. These methods encompass solvent-based extraction, microwave-assisted extraction, and maceration extraction. Every method has its

advantages and disadvantages, but the optimal extraction technique should be economical, uncomplicated, time-efficient, and suitable for implementation in any laboratory environment. Choosing an appropriate technique will depend on the specific needs of the experiment or study being conducted.

1. Extraction Using Solvent

A method exists that combines a solvent-based extraction with the integration of soluble components in solid materials for mass transfer. As the concentration of the soluble compound in the solvent increases, the mass transfer ratio decreases. Recently, environmentally friendly solvents have garnered attention across various disciplines due to their perception as safe, biologically compatible, and eco-friendly alternatives to traditional solvents. Moreover, they are easier to formulate and more cost-efficient. Some innovations in green solvent technologies include deep eutectic solvents (DESs), natural deep eutectic solvents (NDESs), ionic liquids (ILs), surfactants, and bio-derived solvents [25].

2. Extraction Using Microwave Energy

Microwave energy is utilized in this method to retrieve analytes from the sample, the process involves rapidly elevating the temperature of the materials to the required energy level, aligning with the dielectric susceptibility of both the solvent and the raw plant material. This results in a reduction in the time of extraction and volume of solvent compared to other methods, making it a more environment-friendly option. Additionally, it has been shown to improve the recovery of analytes and their reproducibility. However, two important aspects need to be considered; firstly, the thermal degradation of samples must be avoided, and secondly, it is important to note that, this type of extraction is restricted to phenolic compounds of small molecular size [26].

3. Extraction by Maceration

The method of extracting plant compounds can be done in three basic steps. First, the plant should be properly ground into small pieces. Second, the appropriate solvent should be added to a closed vessel to confirm the category of compound intended for extraction from the sample. Third, the liquid phase should be filtered for separation[27]. Although considered simple, concise, and easy, this method produces large amounts of organic waste due to the solvents used. Therefore, efficient chemical waste management processes should be taken into consideration to handle the waste.

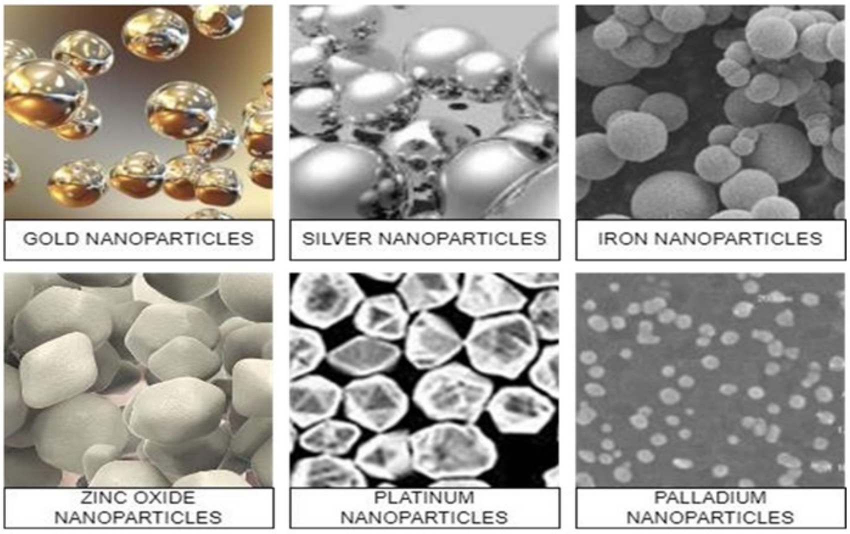

Figure 8: Applications of Various Nanoparticles

Gold Nanoparticles

In the realm of cancer treatment, gold nanoparticles play a crucial role in photothermal therapy. These nanoparticles can be directed toward cancer cells and, upon exposure to light, generate heat, effectively eliminating the cancer cells. Furthermore, they are employed in drug delivery systems to enable targeted and controlled release.

Concerning antimicrobial applications, gold nanoparticles showcase properties that make them valuable in wound healing and as coatings for medical devices, serving to prevent infections.

Silver Nanoparticles

In cancer therapy, silver nanoparticles exhibit promising outcomes by triggering apoptosis, or programmed cell death, in cancer cells. They also find utility as carriers for cancer treatments.

Silver nanoparticles, renowned for their potent antimicrobial and antiviral properties, are instrumental in wound dressings, water purification, and the development of antiviral coatings on surfaces.

Iron Nanoparticles

For anticancer applications, iron oxide nanoparticles are utilized in magnetic hyperthermia, a method for treating cancer. These nanoparticles can be guided to tumors through external magnetic fields, generating heat that effectively destroys cancer cells. Additionally, iron oxide nanoparticles function as contrast agents in magnetic resonance imaging (MRI) for cancer diagnosis.

In the realm of molecular diagnostics, iron nanoparticles play a crucial role in biosensors, detecting specific biomarkers and aiding in the early diagnosis of diseases.

Functioning as bio-reducing agents, iron nanoparticles contribute to environmental remediation by converting toxic metals into less harmful forms.

Zinc Oxide Nanoparticles

Zinc oxide nanoparticles are integral to the cosmetic industry, finding application in sunscreens and cosmetics due to their ability to absorb and scatter UV radiation, providing protection against sun damage.

In various coating applications, zinc oxide nanoparticles, with their antimicrobial properties, contribute to the development of self--cleaning surfaces and antibacterial coatings.

Platinum and Palladium Nanoparticles

Exploring anticancer applications, platinum nanoparticles are under investigation for their potential in drug delivery systems. Palladium nanoparticles are employed in cancer treatment through photothermal therapy.

In the realm of biocatalytic applications, platinum and palladium nanoparticles serve as catalysts in diverse processes, including the production of pharmaceuticals and biofuels.

These instances underscore the diverse and advancing applications of nanoparticles across medicine, industry, and environmental science. Ongoing research endeavors continue to uncover new uses, underscoring the versatility and potential impact of nanotechnology in various fields.

Future Perspectives

The objectives of green chemistry and sustainability involve substituting fossil resources like oil, coal, and natural gas with biomass as the primary feedstock. The emphasis on utilizing biomass for sustainable fuels and chemicals has gained global and political attention. The transition from non-renewable fossil fuels to renewable biomass as a feedstock for liquid fuels and commodity chemicals presents a range of economic, environmental, and social benefits. These advantages encompass an enhanced, stable, and secure supply of feedstocks, a reduction in the carbon footprint of chemicals and liquid fuels, and a more resilient and profitable agricultural economy. Importantly, these three fundamental characteristics of the bio-based economy correspond with the three pillars of sustainability: profitability, planet, and people. Additionally, numerous existing products can be substituted with alternatives that are inherently safer and have a diminished environmental impact, such as biocompatible and biodegradable plastics.

Efficient cancer diagnosis and treatment necessitate novel approaches for early cell detection. In-vivo fluorescent tumor imaging stands out as a critical strategy for visualizing and identifying cancer cells in their initial stages. These approaches also bring the advantage of biodegradability and clearance, playing a crucial role in treatments based on nanomedicine.

To advance the integration of principles from "green" chemistry, it is possible to establish various chemical associations, organizations, and institutes. Their mission would involve researching cleaner reactions, products, and processes. Encouraging the adoption of "green" chemistry within universities and research laboratories can contribute to the creation of economically sustainable technologies for cleaner production. The introduction of "green" synthesis methods in industrial enterprises, the training of future scientists to tackle environmental issues with a focus on eco-friendly processes, and the enforcement of legislation for environmental protection are additional strategies to foster sustainable practices. Ultimately, adopting innovative alternative methods that minimize the generation of undesirable chemicals, including the use of renewable raw materials, less hazardous reagents, alternative solvents such as ionic liquids and water, "green" catalysts, and decreased energy consumption, becomes imperative to safeguard human health and mitigate adverse effects on the environment at each stage of the industrial process.

Conclusion

The synthesis of NPs utilizing eco-friendly methods has become increasingly important in the fields of inorganic chemistry, applied chemistry, and biochemistry. The advancement of nanotechnology, emphasizing green chemistry, has necessitated the exploration of environmentally friendly approaches to produce biocompatible and non-toxic NPs. These considerations hold significant importance within the realm of nanoscience. The use of green chemistry-based synthetic approaches has become increasingly popular for producing NPs, using various sources such as plant extracts and microorganisms. This has led to large-scale manufacturing with minimal environmental impact. The production of NPs from natural extracts is gaining popularity due to the availability, simplicity of handling, and broad range of metabolites found in plant extracts. According to business experts, the global nanotechnology market has a promising future. It is important to note that non-conventional methods of synthesis are not only cost-effective but also less complicated. It is remarkable to note that silver NPs can be synthesized using onion leaf extract within a mere two hours, providing a noteworthy advantage for researchers. It is important to recognize that future research endeavors may shift towards optimizing reaction conditions and genetically engineering organisms to produce significant quantities of proteins, enzymes, and biomolecules crucial for NP synthesis and stabilization. A thorough comprehension of the biochemical processes, pathways, and cycles associated with heavy metal detoxification, accumulation, and resistance in plants is essential for progressing NP production. The potential approach to boost the efficacy of these organisms in NP synthesis includes genetically modifying plants to enhance their tolerance and capacity for accumulating metals. The article provides a valuable overview of green synthesis methods for NPs, highlighting the role of biological components.

References

1. SLY Tang, RL Smith and M Poliakoff, Green Chem. (2005) 7, 761

2. Reiss, Gunter; Hutten, Andreas (2010) "Magnetic NPs". In Sattler, Klaus D. Handbook of Nanophysics: NPs and Quantum Dots. CRC Press. 2-1.

3. Beilby, G.T, "The Effects of Heat and of Solvents on Thin Films of Metal". Proceedings of the Royal Society A 1903, 72: 226–35.

4. Turner, T, "Transparent Silver and Other Metallic Films". Proceedings of the Royal Society A (Transparent silver and other metallic films 1908,|format= requires |url= (help) 81: 548.

5. Huang, H.; Jiang, S.; Cheng, S 301–310. Bibcode:1908RSPSA..81..301T. 6. K. Bogunia-Kubik and M Sugisaka (2002) BioSystems, 65: 123–38.

6. X Liu, Q Dai, L Austin, J Coutts, G Knowles (2008) J. Am. Chem. Soc., 130: 2780–2.

7. K-H Cho, J-E Park, T Osaka, SG (2005) Park, Electrochim. Acta, 51: 956–60.

8. N Dura'n, PD Marcato, S De, I H Gabriel, O L Alves et al. (2007) J. Biomed. Nanotechnol. 3: 203–8.

9. Yadav N (2013). International Journal of Applied Pharmaceutics. Solid Lipid NPs- A Review

10. ravani S. Green synthesis of metal NPs using plants. Green Chemistry 13: 2638-50.

11. N Jain, A Bhargava, S Majumdar, JC Tarafdar, J Panwar (2011) "Extracellular biosynthesis and characterization of silver NPs using Aspergillus flavus NJP08: a mechanism perspective," Nanoscale, 2: 635–641.

12. MF Lengke, ME Fleet, G Southam (2007) "Biosynthesis of silver NPs by filamentous cyanobacteria from a silver(I) nitrate complex," Langmuir, 5: 2694– 9.

13. A Bharde, A Wani, Y Shouche, PA Joy, BLV Prasad et al. (2005) "Bacterial aerobic synthesis of nanocrystalline magnetite," Journal of the American Chemical Society, 26: 9326–27.

14. MI Husseiny, MA El-Aziz, Y Badr, MA Mahmoud (2007) "Biosynthesis of gold NPs using Pseudomonas aeruginosa," Spec-

trochimica Acta A, 67: 1003–6.

15. L Du, H Jiang, X Liu, E Wang (2000) “Biosynthesis of gold NPs assisted by Escherichia coli DH5[illegible] and its application on direct electrochemistry of hemoglobin,” Electrochemistry Communications, 9: 1165–70.

16. V Bansal, D Rautaray, A Bharde et al. (2005) “Fungus-mediated biosynthesis of silica and titania particles,” Journal of Materials Chemistry, 15: 2583–9.

17. N Vigneshwaran, NM Ashtaputre, PV Varadarajan, RP Nachane, KM Paralikar (2007) “Biological synthesis of silver NPs using the fungus Aspergillus flavus,” Materials Letters, 61: 1413–8.

18. P Mukherjee, A Ahmad, D Mandal et al. (2001) “Fungus-mediated synthesis of silver NPs and their immobilization in the mycelial matrix: a novel biological approach to NP synthesis,” Nano Letters, 1: 515–519.

19. K Kathiresan, S Manivannan, MA Nabeel, B Dhivya (2009) “Studies on silver NPs synthesized by a marine fungus, Penicillium fellutanum isolated from coastal mangrove sediment,” Colloids and Surfaces B, 71: 133–7.

20. V Bansal, D Rautaray, A Ahmad, M Sastry (2004) “Biosynthesis of zirconia NPs using the fungus Fusarium oxysporum,” Journal of Materials Chemistry, 14: 3303– 5.

21. CT Dameron, RN Reese, RK Mehra et al. (1989) “Biosynthesis of cadmium sulphide quantum semiconductor crystallites,” Nature, 338: 596–7.

22. Z Lei, L Zhang, X Wei (2008) “One-step synthesis of silver NPs by sonication or heating using amphiphilic block copolymer as templates,” Journal of Colloid and Interface Science, 324: 216–9.

23. HJ Lee, G Lee, NR Jang et al. (2011) “Biological synthesis of copper NPs using plant extract,” Nanotechnology, 1: 371–4.

24. AK Mittal, A Kaler, UC (2012) Banerjee, “Free radical scavenging and antioxidant activity of silver NPs synthesized from flower extract of Rhododendron dauricum,” Nano Biomedicine and Engineering, 4: 118–24.

25. Hashemi B, Zohrabi P, Dehdashtian S (2018) Application of green solvents as sorbent modifiers in sorptive-based extraction techniques for extraction of environmental pollutants. TrAC Trends in Analytical Chemistry, 109: 50-61.

26. Rao SS, Saptami K, Venkatesan J, Rekha PD (2020) Microwave-assisted rapid synthesis of silver NPs using fucoidan: Characterization with assessment of biocompatibility and antimicrobial activity. International Journal of Biological Macromolecules.

27. Trusheva B, Trunkova D, Bankova V (2007) Different extraction methods of biologically active components from propolis: a preliminary study. Chemistry Central Journal 1: 13.

28. He Y, Du Z, Ma S, Liu Y, Li D et al. (2016) Effects of green-synthesized silver NPs on lung cancer cells in vitro and grown as xenograft tumors in vivo. Int. J. Nanomed. 2016, 11: 1879.