Journal of Advances in Biology & Biotechnology

Volume 27, Issue 7, Page 1054-1069, 2024; Article no.JABB.118690
ISSN: 2394-1081

Green Synthesis: An Alternative Sustainable Route for Nanotechology

Mannem Niveditha [a++*], Vijay R Shelar [b#] and Bhalerao B.M. [c†]

[a] *Seed Science and Technology, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahmednagar (Maharashtra), India.*
[b] *Seed Technology Research Unit, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahmednagar (Maharashtra), India.*
[c] *Department of Biochemistry, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahmednagar (Maharashtra), India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jabb/2024/v27i71065

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/118690

Review Article

Received: 18/04/2024
Accepted: 20/06/2024
Published: 26/06/2024

ABSTRACT

With the advancements and technological innovation in the past few decades, there has been an exponential increase in the nanotechnology industry. It has come to become one of the most exciting forefront fields in the 21st century. Nanotechnology is the science that deals with particulate matter at nanoscale (1-100 nm). Nanomaterials at nanoscale tend to exhibit unique properties than their bulk counterparts. The rising demand for nanoparticles and nano based products also brings in huge concerns, as the chemical and physical methods for synthesis of nanoparticles require a lot of investment and also involve toxic agents, which result it some serious after effects hazardous to

[++] *PhD Scholar;*
[#] *Seed Research Officer;*
[†] *Assistant Professor;*
**Corresponding author: E-mail: nivedithamannem45@gmail.com;*

Cite as: *Niveditha, Mannem, Vijay R Shelar, and Bhalerao B.M. 2024. "Green Synthesis: An Alternative Sustainable Route for Nanotechology". Journal of Advances in Biology & Biotechnology 27 (7):1054-69. https://doi.org/10.9734/jabb/2024/v27i71065.*

both environment and the living entities. This is when green chemistry comes into the picture, green synthesis approach was found to counter the problems posed by the previous synthesis methods. The mechanism involved in green synthesis, factors affecting the synthesis and the popular techniques used in characterization of the synthesized nanoparticles are discussed in this review paper. Green synthesis has the potential to be an effective approach in minimizing the risks encountered in the traditional methods of synthesis, yet the field is new and more is to be explored and continuous research with follow up is required to adopt green synthesis at a commercial level.

Keywords: Nanoparticles; green synthesis; nanotechnology; eco-friendly; characterization.

1. INTRODUCTION

Nanotechnology is the branch of science that deals with matter at nanoscale (1-100 nm). The nanoparticles exhibit unique properties at nanoscale that are not exhibited by their bulk counterparts. Through means of various physical and chemical processes nanoparticles with specific envisioned properties are synthesized [1]. The study of nanoparticles (NPs) involves a lengthy history of observation and inquiry. The evolution and growth of nanotechnology is described briefly in Table 1 [2].

A study on the nanotechnology-based-products in the market by Vance et al. [3] revealed that about 1814 products containing nano-sized materials were present in the global market, introduced by approximately 622 companies. At present there exists to be a huge demand for nano-sized materials which adds to be near about 300,000 to 1.6 million tonnes worldwide. The Asia-Pacific region holds the largest market share of about 34 per cent, which is followed by North America (31%) and Europe (30%).

On the other hand, with the rise of nanotechnology huge concerns are also on the rise related to their impact on the environment and toxicity of the nanoparticles on the living entities [4]. Furthermore their possible influence on the global economics, along with a hypothetical doomsday theories. Hence due the concerns on rise, it has led to the debate among advocacy groups and governments on if special regulations on nanotechnology are obligatory.

Table 1. History of nanotechnology

Year	Scientist	Contribution
1925	Richard Zsigmondy (Nobel Laureate in Chemistry)	Pioneered the theory of a nanometer Coined the term nanometer in the process of evaluating the size of gold colloids
1959	Richard Feynman (Father of modern nanotechnology, Nobel Laureate in Physics)	At a Caltech meeting, stated “There is plenty of room at the bottom”, which opened up many new horizons, encouraging more research
1986	Norio Taniguchi	Coined the term “ Nanotechnology”
Early 2000’s	-	Extensive research and development in the field of nanotechnology, increased number of applications in daily life
2003	-	Concerns about nanoparticles effect on human health and environment arise
2006	-	Offshoot of green chemistry, green nanotechnology came into the picture

2. SYNTHESIS OF NANOPARTICLES

Nanoparticles are synthesized by two distinguishing approaches. One is the “top-down approach” and the other is the “bottom-up approach” [5]. In top-down approach, solid bulk matter is broken down into smaller particles and further reduced to nano-sized particles using mechanical forces such as ball milling, laser ablation, etc which help in breaking down the particles to nano-size and later the nanoparticles are stabilized to required size [6,7]. But, it is difficult to breakdown to achieve the required nano-size using top-down approach. And the bottom-up approach starts with matter at atomic level, where they use chemical (hydrothermal method, sol-gel method, gas phase method, thermolysis, and hydrolysis) and biological routes to assemble the atoms to initiate new nuclei, thereby fabricating the particles to grow to the required nanosize at the end of the synthesis [8].

Top-down approaches demand huge capital involving high costs, high amount of energy and is time consuming, even after which there is no guarantee of achieving the desired nano-size at the end of the synthesis. And though some top-down approaches involving UV irradiation, laser ablation, aerosol technologies and photochemical reduction processes produce nanoparticles, they also release some harmful byproducts during the synthesis. And further the there is no control over the surface chemistry, size, and structure of the nanoparticles in top-down approaches. Therefore bottom-up approaches are often preferred for synthesis which begin with simple molecules that are later grown into nanoparticles and also allows a greater control upon the shape and size of the nanoparticles to be synthesized. Even though chemical synthesis has certain advantages that include less time consumption, low cost equipment, low space and temperature requirements, the chemicals used for the synthesis lead to generation of harmful and toxic by-products that affect the environment and living beings [1].

In order to counter these limitations, since the past decade a new era of green synthesis has gained great interest among the researchers [9]. The traditional methods (physical and chemical) of synthesis of nano-sized materials demanded sophisticated equipment under extreme harsh conditions. But it contrast, the green route of synthesis of nano-sized materials is carried out under ambient temperature and pressure, which suggests simplicity, energy and money saving. Essentially, green synthesis of nanoparticles fabricated by proper regulation, control, clean up and remediation process directs its efforts towards environmental friendliness.

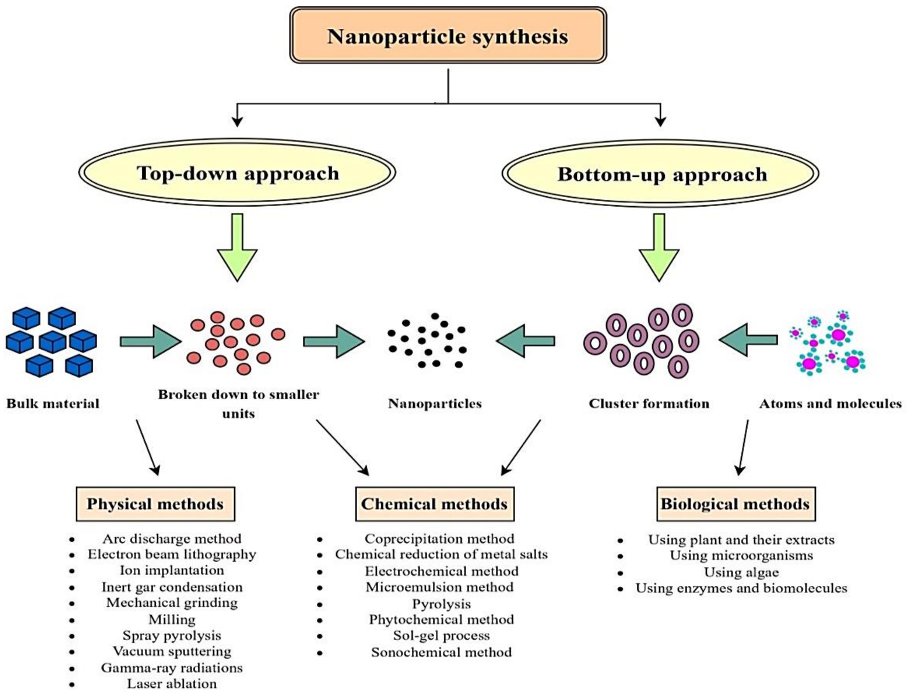

Fig. 1. Top-down and Bottom-up approaches for nanoparticle synthesis

3. GREEN SYNTHESIS

Scientists can no longer assume green science or green route to be just an option, but the most preferred option. With the increasing synthesis of nanoparticles, so is the need for new approaches for the synthesis so as to cause less harm to the biosphere. In the early 2000 Anastas and Warner in their book "Green Chemistry" established the basis of green chemistry, which consists of 12 basic principles [10]. They include:

1. Prevention – Steps should be devised to prevent or minimize waste production.
2. Atom Economy - Too carry of the synthesis with as much as minimum materials.
3. Less Hazardous Chemical Synthesis - Prioritization of methods that result in minimal or no toxicity.
4. Designing Safer Chemicals - Chemicals should be designed such that they show limited or no toxicity.
5. Safer Solvents - The use of solvents and auxiliary chemicals needs to be avoided or minimized wherever feasible.
6. Design for Energy Efficiency - Efficient energy utilization and saving methods need to be adopted.
7. Use of Renewable Feedstocks - renewable feedstock and depletion should be avoided whenever possible.
8. Reduce Derivatives – Additional wastes generated through derivatives such as blocking agents and protecting/deprotecting groups need to be avoided whenever possible.
9. Catalysis - Catalysis agents are desirable than the stoichiometric agents.
10. Design for Degradation - Chemicals should be designed in such a way that at the end of synthesis, they break down into non-toxic derivatives.
11. Real-time Analysis for Pollution Prevention - Synthesis should be monitored in realtime to check for toxic chemical production.
12. Inherently Safer Chemistry for Accident Prevention - Selection of agents in synthesis should be such that the possibility of hazardous accidents is nill or reduced to the maximum extent possible.

These 12 principles are taken into consideration in green chemistry whenever feasible, in order to contain the release of hazardous chemicals into the environment and limit the human exposure to those chemicals [10]. Galuszka et al., in 2012, expanded these 12 principles in their review paper review of green analytical chemistry and also proposed the mnemonic "SIGNIFICANCE" as an easy means to memorize the 12 Principles of Green Chemistry.

- S - Select direct analytical technique
- I - Integrate analytical processes and operations
- G - Generate as little waste as possible and treat it properly
- N - Never waste energy
- F -Implement automation and miniaturization of methods
- I - Increase safety of operator
- C - Carry out in-situ measurements
- A - Avoid derivatization
- N - Note the sample number and size should be minimal
- C - Choose multi-analyte or multi-parameter methods
- E - Eliminate or replace toxic reagents

The scientists were well aware of the fact that the biological entities possessed the ability of reducing the metal precursors in the late nineteenth century itself, yet its mechanisms were vaguely explored during that time. Eventually later with positive research progress of the green synthesis they were able to harness the power of renewable sources like plants and microbes, which could act as reducing agents thereby stabilizing and capping the nanoparticles, [11,12] rather than the use of toxic, expensive chemicals and techniques that involve high energy consumption, the researchers were more attracted towards the biological methods [13,14,15,9]. Conventional methods for the synthesis of nanoparticles are more in practice at industrial scale past many years, but the green route has been proven to be quite effective for synthesis of the nanoparticles owing to its low cost, ease of characterization and less chance of failure [16,17].

Green synthesis offer several advantages over the traditional methods [18,19,20]:

1. It is pollution free [21]
2. It is cost effective and economical [22].
3. It is environment friendly.
4. Feasibility of huge amount of synthesis with advancing technologies.
5. No necessity of sophisticated equipment or need of toxic materials [23].
6. More sustainable [24].

Accordingly green synthesis of nanoparticle emphases on three key aspects [25]:

Table 2. Different biological agents involved for biosynthesis of nanoparticles

Biological source	Factors that aid in synthesis	Advantages	Disadvantages
Plant	Secondary metabolites act as capping and stabilizing agents	Minimal cost, eco-friendly, no sophisticated equipment required, low energy consumption, lack of toxic precursors, biocompatibility, no extra efforts for culture or colony maintenance	Not fully explored yet the after effects or harmful effects, the low yields of secreted proteins generated by plants decrease the rate of synthesis
Fungi	Reducing enzymes and biomimetic mineralization	Large scale NP fabrication, low cost, eco-friendly, low energy demand, increased metal accumulation, enhanced wall-binding capacity, simple biomass handling	Low reproducibility, problematic genetic manipulation, other solvents required for obtaining pure NPs, particle size distribution is broader
Algae	Polysaccharides act as capping and stabilizing agents	No toxic byproducts, biocompatible, can grow under diverse conditions, cost effective, easy handling, no cellular maintenance required	Algal culture demands more time, more work on reproducibility needed, size control is limited, Up-scaling fabrication is limited, not all species can be used in NPs synthesis
Bacteria	Nitrate-dependent reductase or NADPH-dependent reductase enzymes in bacteria reduces metal ions	Non-toxic, cost effective, energy saving	Tedious procedures isolation, sampling, storage and culturing involved, morphology of NPs is difficult to control

- A green solvent
- An eco-friendly benign reducing agent
- A nontoxic material as a stabilizer

The extracts from leaves [26,27,28,23], flowers [29,30,31], roots, peelings [32], fruits [33], and seeds [34,35] of various plants or microorganisms (bacteria, fungi and algae) [36,37,38] are being used at present for the synthesis of the nanoparticles through the green route as shown in Table 2 [39]. For green synthesis of nano-sized components both microbes and plant mediated approaches are in practice. In the synthesis involving microbes, the in-built sophisticated biochemical mechanisms are put into action for reducing of the ions into nano-sized particles, it often leads to well-defined nanoparticles varying in compositions, shapes and sizes accordingly [40]. But when a large scale production is in question, the synthesis involving microbial preparations is challenging. But this could easily be tackled by using plant based extracts for synthesis, where the production rate could be significantly amplified.

The plant extracts are rich in compounds that possess the ability to reduce complex metal ions into simple ions. In fact the idea of the plant extracts for the metal ions reduction to nano-sized materials was inspired by the accumulation of metallic ions in plant cells and tissues [41]. The production rates are proficient in case of plant extracts mediated synthesis when compared to the microbes mediated synthesis. The plant extracts have been proven to be able to reduce the metal-ions at a faster rate that the microbial entities, and are also known to produce nanoparticles that are very much stable [42,3]. Though there are relatively diverse methods followed during green synthesis, the chief function that happens is that the biological agents utilized in the synthesis reacts with different metal salts in the reaction mixture, thereby reducing them to nanoparticles, which are later used for various purposes but only after characterization [43,44]. The compounds like alkaloids, falvonoids, phenols, tannins etc., present in the plant extracts have shown the ability to reduce the metal ions to nanoparticles with good stability [45,46]. While in case of microbes mediated synthesis the important enzymes present in them serve as a reducing as well as stabilizing agents during the nanoparticle synthesis [47].

The green raw materials containing different enzymes/proteins, polysaccharides, vitamins amino acids, poly- phenols, etc., [48], have the potential to act as both reducing agents where they reduce the metal ions to a stable state from the excited state and capping agents thereby replacing the chemical reagents in nanoparticles synthesis (Collera-Zúñiga et al., 2005), [49]. With proper favorable conditions (temperature, concentration, ambient air and others) green synthesis successfully yields nanoparticles and also surpasses the nanoparticles synthesized through chemical methods.

4. MECHANISM OF SYNTHESIS OF NANOPARTICLES

Even though the key aspects that draw our attention towards green synthesis are its cost effectiveness and environment friendly nature, it is the stability of the green synthesized nanoparticles that has grabbed the interest of the researchers [50]. It was reported that at high extract concentrations, the biomolecules that act as reducing agents, also cover the nanoparticle surfaces, thereby preventing them from aggregation and increasing their stability [51]. Though the synthesis of nanoparticles through the green route is now practiced widely, yet the mechanism of their synthesis poses as a challenge for the scientists [52].

The formation of nanoparticles is completed in primarily three phases:

- Ion reduction
- Cluster formation
- Growth of nanoparticles

In technical terms the synthesis of nanoparticles from plant extracts happens in three phases:

- Activation phase
- Growth phase
- Process termination phase

The activation phase of the synthesis is the phase where the reduction of the metal ions takes place, which further leads to formation of new structures through nucleation (self-organization) of the reduced metal atoms. Further in the growth phase (second phase) the newly formed structures grow, with additional metal ions reduction along with increased thermodynamic stability of the formed nanoparticles. In the final stage, which is the process termination phase, the final shape of the nanoparticles is attained and the shape of the nanoparticles formed affects their stability [1].

For instance when we talk about synthesis of nanoparticles from plant extracts, a standardized method involving systemic approach is followed. Careful selection of the specific plant along with its taxonomical identification is done, after which plant extract from the desired plant part is extracted using appropriate solvent/s, which is followed by some purification techniques like filtration/chromatography/centrifugation to get rid of any impurities. At the same time the required metal salt solution is prepared which acts as the nanoparticle precursor and the earlier plant extract prepared is added to this metal salt solution, during which the optimum temperature and pH for the reaction to happen are maintained accordingly, that would help in initiation of the reaction leading to the formation of the nanoparticles [53]. Among the several methods studied, better results were obtained when there was continuous stirring of the reaction mixture, which resulted in formation of uniform-sized nanoparticles that is indicated visually by a noticeable colour change. Additionally ultrasonic treatment application helps in ensuring uniform dispersion of the synthesized nanoparticles in the solution. After which the synthesized nanoparticles are separated from the solution through centrifugation, where subsequently they are washed to get rid of any remaining impurities. As per preference the nanoparticle precipitate obtained can be further dried using hot air oven or with 70 % ethanol at room temperature to eliminate any additional impurities [54].

5. FACTORS AFFECTING SYNTHESIS OF THE NANOPARTICLES

The features like shape, size and quality of the biosynthesized nanoparticles depend on wide range of aspects such as the plant extract concentration used, metal ion solution concentration, composition and pH, also the temperature at which the reaction takes place [55,56,57]. The factors affecting the synthesis of nanoparticles are described below in Table 3.

The prime factors responsible for size variations among the synthesized nanoparticles could usually be:

- Polyphenols concentration [58,59], as they play a crucial role as reducing and capping agents in synthesis.
- pH of the reaction mixture, it is because acidic and alkaline pH can cause agglomeration among the nanoparticles due to over nucleation (at low pH)

and instability of nanoparticles (at high pH).

The size and shape of the nanoparticles during synthesis can be easily regulated by monitoring the parameters like pH and temperature of the initial reaction mixture. The pH variation strongly influences the nucleation process. Across various studies it has been reported that when synthesis of nanoparticle was carried under acidic pH conditions, it usually resulted in formation of nanoparticles with poor stability. But in case of alkaline pH conditions the synthesis process happened at a faster rate along with production of nanoparticles with good stability. In acidic (low pH) conditions, the growth of the nanoparticles is known to be in the form of clusters which would eventually agglomerate, while in case of higher pH (alkaline) conditions, many pearl-like nanoparticles formation was reported along with some large diameter nanoparticles during the synthesis [60]. And in case of temperature, faster growth dynamics was observed at higher temperatures (more than normal room temperature) but at the same time, when the reaction rate is faster defects were observed thereby affecting the crystalline structure and quality of the synthesized nanoparticles. The nucleation time is also critical in controlling the size and size distribution of the nanoparticles, smaller nucleation time usually provides a better control over the size of the nanoparticles synthesized.

Table 3. Factors affecting the size and shape of the nanoparticles during synthesis

Sr. No.	Factor (s)	Effect on NPs synthesis
1	**Technique or Method**	The nanoparticles can be synthesized in numerous ways using physical, chemical and biological means. The green route of synthesis being economical, non-toxic and eco-friendly is more advantageous over the traditional methods [61,62].
2	**pH**	Nanoparticles tend to show aggregation and are less stable in pH (acidic) conditions ranging from 3 to 6, while in case of pH lower than 3,the nanoparticles are more stable as the protonated forces of all the molecules work against electrostatic interactions. Likewise, in conditions with pH above 7 due to deprotonation, the repulsion of aggregated molecules is seen.
3	**Temperature**	The physical approaches demand high range of temperature more than 350^{o}C, and it is not that higher in case of chemical approaches. But in contrast to these methods, slightly higher temperatures (but below 100^{o}C) than the normal room temperature is sufficient to carry out the synthesis by green route. The nature and size of the synthesized nanoparticles can be regulated by the reaction temperature [63].
4	**Pressure**	Pressure is one of the important factors during the synthesis. At ambient pressure, in green synthesis the metal ions are reduced at a faster rate [64].
5	**Time**	Time is another significant factor that affects the rate of synthesis of nanoparticles through green synthesis [65,66]. Shrinking and enlargement of the nanoparticles could happen within the synthesized nanoparticles when stored for a prolonged period of time, ultimately affecting their functional properties. The aggregation among the nanoparticles is also influenced by the synthesis process and the storage conditions [65,67,68,69].
6	**Particle shape and size**	The size and shape of the nanoparticles greatly influence the synthesis and the functionality of the nanoparticles. Usually the size reduction of the nanoparticles also brings down the melting point of the synthesized nanoparticles [68].
7	**Pore Size**	Nanoparticles quality and its applications are both affected by the porosity of the formed nanoparticles. Generally this factor is exploited for drug delivery, where the desired molecules of biological origin are bound to the surface of the nanoparticles for specified objective [70].

Optimization of the solvent ratio, reaction time, temperature, pH and the ratio of the plant extract to the metal solution (reaction mixture) are all the crucial aspects that needs to addressed during green synthesis of the nanoparticles. Yet, still because of the involvement of various biomolecules that act as reducing, stabilizing and capping agents the interaction between the polyphenols and nanoparticles is not very clear. The surface charge of the nanoparticles is one another important parameter for its characterization. The nature and intensity of the surface charge influence the interaction between the nanoparticles and the biological environment (the bioactive compounds from plants, algae, fungi, and bacteria).

The stability of the nanoparticles is one of the vital requirements as the synthesized nanoparticles later have a vast range of applications.

6. CHARACTERIZATION OF THE NANOPARTICLES

In the end using diverse analytical techniques the synthesized nanoparticles are characterized in order to estimate their composition and physiochemical properties. They provide essential insights with respect to the properties and behavior of the synthesized nanoparticles. For instance to configuration of shape, size and structure of the synthesized nanoparticles Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM) are employed, while the optical properties are assessed using UV-Vis spectrophotometry and to identify the functional groups present on the surface of the nanoparticles FTIR spectroscopy is used. Furthermore Dynamic Light Scattering (DLS) and Zeta Potential measurements are employed to estimate the size and surface charge of the nanoparticles [71,72,73]. Many other techniques and instruments used for characterization of the nanoparticles are described in Table 4.

Table 4. Techniques and instruments used for characterization of nanoparticles

Objective	Instrument/ Technique	Purpose	References
Formation of Nanoparticles	UV (Ultraviolet-visible) spectrophotometry	To estimate size, structure, stability of nanoparticles including their aggregation	[61] [74] [75] [76] [77]
Size and morphology of NPs	TEM (Transmission electron microscopy)	To evaluate the morphology (size and shape) along with the structural allography of NPs	[63] [78] [79] [80]
	High TEM (Transmission electron Microscopy)	For determining atom’s arrangement and local microstructures	[65] [66] [81] [82]
	SEM (Scanning electron microscopy)	Morphology examination of the nanoparticles	[67] [83] [68] [84] [85]
	AFM (Atomic force microscopy)	To estimate the size, morphology or surface texture	[70] [78] [86] [26]
	DLS (Dynamic Light Scattering)	Evaluation of the particle size distribution	[70] [63] [87] [85]
Surface study or Charge on the surface of	Zeta potential	Determination of the charge on the surface and stability of the NPs	[88] [61]

Objective	Instrument/ Technique	Purpose	References
NPs	FT-IR (Fourier-transform infrared-spectroscopy)	Characterization of the functional groups present on the surface of the nanoparticles	[61] [65] [89] [90] [58]
	XPS (X-ray photoelectron spectroscopy)	Characterization of the bonds involved and determination of the mechanism of the reactions occurring in the nanoparticles surface	[65] [67]
	Thermal gravimetric analysis	To estimate the binding efficiency of the coating on the nanoparticles surface	[65] [67]
Crystallinity	XRD (X-ray diffraction)	To determine the crystalline structure of the nanoparticles	[70] [74] [63] [91] [92]
Magnetic properties	VSM (Vibrating sample magnetometry)	To determine the magnetization of the magnetic nanoparticles	[65] [67]
	Superconducting-quantum-interface device magnetometry	Confirmation of the magnetic properties of nanoparticles	[65] [67]
	Field flow flotation	Separation of nanoparticles based on their magnetic susceptibility	[93] [66]
Others	Chromatography	Separation based on mobility/ affinity of nanoparticles	[94] [63] [95] [96]
	X-ray spectra (Energy dispersive)	To evaluate the elemental composition of the nanoparticles	[61] Lal et al., 2011
	Centrifugation	Separation of nanoparticles based on their density	[97] Balnois et al., 2007; [98]
	Laser-induced breakdown detection	To estimate the size and colloidal conentration	[99,100]
	Mass Spectroscopy	To determine size and charge state, depth profiling in fluorescent labelled nanoparticles	[101] [87]
	X-ray fluorescence spectroscopy	Quantification of elemental concentrations in powdered/liquid nanoscale samples	[102] [96]
	Small angle X-ray scattering	Determine the structural characteristics of nanoparticles	[102] [96]
	Energy dispersive X-ray spectra	Evaluation of the elemental composition of the nanoparticles	[103] [62]
	Hyperspectral imaging	Assessing nanoparticles type, estimation of the fate and transformation of the nanoparticles in the water samples and also determining the surface chemistry along with functional groups added to the nanoparticles	[104], [105-108]

7. CONCLUSION

Possessing the unique qualities that the nanoparticles possess, they have a varied range of applications. And so is the field and application of nanomaterials is escalating, therefore extensive research is now thus focused towards studying about the synthesis, their characteristics, behavior and the wide range of applications and ultimately their effect in the environment.

The traditional methods of synthesis pose a huge threat to the environment because their high energy requirements and the toxic reagents involved. Carrying on with the traditional methods of synthesis even further in the future indicates both our negligence and ignorance of the distressing after effects towards the environment. And hence demands for a more conscious approach.

The green route for the synthesis of nanoparticles is a simple process which is cost effective and eco-friendly too, that requires not much effort or time. And most importantly it causes minimal or no harm to the environment or the living entities. At the same time, green synthesis has its own set of drawbacks, while nanotechnology has already raised the stakes for human health, the limited studies on the bioaccumulation and toxicity of the nanoparticles in the environment is a huge concern that is mounting upon. Due to their small size, nanoparticles pose a constant threat, as they are prone to cause inhalation problems and many other fatal diseases. And at commercial level green synthesis of the nanoparticles has yet not been explored and is long due.

So addressing the huge potential applications of the nanoparticles in various fields, according to feasibility of cost and techniques green mode of synthesis can be adopted. Furthermore, a clear understanding of the different biochemical pathways that take place during the synthesis would allow for the adaptation and evolution of the sustainable green routes for the synthesis of nanoparticles at a larger scale. And it is also important to note that the pros and cons of green synthesis can vary depending on the specific method, reaction and desired outcome. Therefore continuous research and disclosure of the developments and findings in this field is a must to augment the applicability and effectiveness of green route for synthesis of nanomaterials.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Chella Purushothaman Devatha, Arun K Thalla. Green Synthesis of Nanomaterials. In Bhagyaraj S, Oluwafemi OS, Kalarikkal N, Thomas S. (Eds.), Synthesis of inorganic nanomaterials: Advances and key technologies (169-184) Cambridge, MA: Woodhead Publishing; 2018.
2. Bayda S, Adeel M, Tuccinardi T, Cordani M, Rizzolio F. The history of nanoscience and nanotechnology: From chemical–physical applications to nanomedicine. Molecules. 2019;25(1):112.
3. Vance ME, Kuiken T, Vejerano EP, McGinnis SP, Hochella Jr MF, Rejeski D, Hull MS. Nanotechnology in the real world: Redeveloping the nanomaterial consumer products inventory. Beilstein Journal of Nanotechnology. 2015;6(1):1769-1780.
4. Buzea C, Pacheco II, Robbie K. Nanomaterials and nanoparticles: Sources and toxicity. Biointerphases. 2007;2(4): MR17-MR71.
5. Iqbal P, Preece JA, Mendes PM. Nanotechnology: The “top-down” and “bottom-up” approaches. Supramolecular chemistry: From molecules to nanomaterials; 2012s.
6. Lu J, Guo J, Song S, Yu G, Liu H, Yang X, Lu Z. Preparation of Ag nanoparticles by spark ablation in gas as catalysts for electrocatalytic hydrogen production. RSC Advances. 2020;10(63):38583-38587.
7. Unal IS, Demirbas A, Onal I, Ildiz N, Ocsoy I. One step preparation of stable gold nanoparticle using red cabbage extracts under UV light and its catalytic activity. Journal of Photochemistry and Photobiology B: Biology. 2020;204: 111800.
8. Varadan VK, Pillai AS, Mukherji D, Dwivedi M, Chen L. Nanoscience and nanotechnology in engineering. World Scientific Publishing Company; 2010.

9. Santo-Orihuela PL, Desimone MF, Catalano PN. Green synthesis: A land of complex nanostructures. Current Pharmaceutical Biotechnology. 2023;24(1): 3-22.
10. Anastas PT, Warner JC. Green chemistry: Theory and practice. Oxford University Press; 2000.
11. Bandeira M, Possan AL, Pavin SS, Raota CS, Vebber MC, Giovanela M, Crespo JS. Mechanism of formation, characterization and cytotoxicity of green synthesized zinc oxide nanoparticles obtained from *Ilex paraguariensis* leaves extract. Nano-Structures and Nano-Objects. 2020;24: 100532.
12. Galdopórpora JM, Ibar A, Tuttolomondo MV, Desimone MF. Dual-effect core–shell polyphenol coated silver nanoparticles for tissue engineering. Nano-Structures and Nano-Objects. 2021;26:100716.
13. Luangpipat T, Beattie IR, Chisti Y, Haverkamp RG. Gold nanoparticles produced in a microalga. Journal of Nanoparticle Research. 2011;13:6439-6445.
14. Dhillon GS, Brar SK, Kaur S, Vermab M. Green approach for nanoparticle biosynthesis by fungi: Current trends and applications. Critical Reviews in Biotechnology. 2012;32(1):49-73.
15. Arumugam A, Karthikeyan C, Hameed ASH, Gopinath K, Gowri S, Karthika V. Synthesis of cerium oxide nanoparticles using *Gloriosa superba* L. leaf extract and their structural, optical and antibacterial properties. Materials Science and Engineering: C. 2015;49:408-415.
16. Bhalerao BM, Borkar PA. Plant as a natural source for synthesis of silver nanoparticles: A review. International Journal of Chemical Studies. 2017;5(6):98-104.
17. Abdelghany TM, Al-Rajhi AM, Al Abboud MA, Alawlaqi MM, Ganash Magdah A, Helmy EA, Mabrouk AS. Recent advances in green synthesis of silver nanoparticles and their applications: About future directions. A review. Bio Nano Science. 2018;8:5-16.
18. Moosa AA, Ridha AM, Al-Kaser M. Process parameters for green synthesis of silver nanoparticles using leaves extract of Aloe vera plant. Int J Multi Curr Res. 2015; 3:966-975.
19. Koul A, Kumar A, Singh VK, Tripathi DK, Mallubhotla S. Exploring plant-mediated copper, iron, titanium, and cerium oxide nanoparticles and their impacts. In Nanomaterials in plants, algae, and microorganisms. Academic Press. 2018; 175-194.
20. Singh K, Singh J, Rawat M. Green synthesis of zinc oxide nanoparticles using *Punica Granatum* leaf extract and its application towards photocatalytic degradation of Coomassie brilliant blue R-250 dye. SN Applied Sciences. 2019;1:1-8.
21. Alsammarraie FK, Wang W, Zhou P, Mustapha A, Lin M. Green synthesis of silver nanoparticles using turmeric extracts and investigation of their antibacterial activities. Colloids and Surfaces B: Biointerfaces. 2018;171:398-405.
22. Kataria N, Garg VK. Green synthesis of Fe_3O_4 nanoparticles loaded sawdust carbon for cadmium (II) removal from water: Regeneration and mechanism. Chemosphere. 2018;208:818-828.
23. Devi HS, Boda MA, Shah MA, Parveen S, Wani AH. Green synthesis of iron oxide nanoparticles using *Platanus orientalis* leaf extract for antifungal activity. Green Processing and Synthesis. 2019;8(1):38-45.
24. Nasrollahzadeh M, Sajadi SM. Pd nanoparticles synthesized in situ with the use of *Euphorbia granulate* leaf extract: Catalytic properties of the resulting particles. Journal of Colloid and Interface Science. 2016;462:243-251.
25. Mohan S, Oluwafemi OS, George SC, Jayachandran VP, Lewu FB, Songca SP, Thomas S. Completely green synthesis of dextrose reduced silver nanoparticles, its antimicrobial and sensing properties. Carbohydrate Polymers. 2014;106:469-474.
26. Logeswari P, Silambarasan S, Abraham J. Synthesis of silver nanoparticles using plants extract and analysis of their antimicrobial property. Journal of Saudi Chemical Society. 2015;19(3):311-317.
27. Chahardoli A, Karimi N, Fattahi A. *Nigella arvensis* leaf extract mediated green synthesis of silver nanoparticles: Their characteristic properties and biological efficacy. Advanced Powder Technology. 2018;29(1):202-210.
28. Leili M, Fazlzadeh M, Bhatnagar A. Green synthesis of nano-zero-valent iron from Nettle and Thyme leaf extracts and their application for the removal of cephalexin antibiotic from aqueous solutions.

Environmental Technology. 2018;39(9): 1158-1172.

29. Thovhogi N, Park E, Manikandan E, Maaza M, Gurib-Fakim A. Physical properties of CdO nanoparticles synthesized by green chemistry via *Hibiscus Sabdariffa* flower extract. Journal of Alloys and Compounds. 2016;655:314-320.
30. Thovhogi N, Diallo A, Gurib-Fakim A, Maaza M. Nanoparticles green synthesis by *Hibiscus sabdariffa* flower extract: Main physical properties. Journal of Alloys and Compounds. 2015;647:392-396.
31. Sone BT, Diallo A, Fuku XG, Gurib-Fakim A, Maaza M. Biosynthesized CuO nano-platelets: Physical properties and enhanced thermal conductivity nanofluidics. Arabian Journal of Chemistry. 2020;13(1):160-170.
32. Ehrampoush MH, Miria M, Salmani MH, Mahvi AH. Cadmium removal from aqueous solution by green synthesis iron oxide nanoparticles with tangerine peel extract. Journal of Environmental Health Science and Engineering. 2015;13:1-7.
33. Kumar B, Smita K, Cumbal L, Debut A, Angulo Y. Biofabrication of copper oxide nanoparticles using Andean blackberry (*Rubus glaucus* Benth.) fruit and leaf. Journal of Saudi Chemical Society. 2017;21:S475-S480.
34. Dhand V, Soumya L, Bharadwaj S, Chakra S, Bhatt D, Sreedhar B. Green synthesis of silver nanoparticles using *Coffea arabica* seed extract and its antibacterial activity. Materials Science and Engineering: C. 2016;58:36-43.
35. Gao JF, Li HY, Pan KL, Si CY. Green synthesis of nanoscale zero-valent iron using a grape seed extract as a stabilizing agent and the application for quick decolorization of azo and anthraquinone dyes. RSC Advances. 2016;6(27):22526-22537.
36. Subramaniyam V, Subashchandrabose SR, Thavamani P, Megharaj M, Chen Z, Naidu R. *Chlorococcum* sp. MM11—a novel phyco-nanofactory for the synthesis of Iron nanoparticles. Journal of Applied Phycology. 2015;27:1861-1869.
37. Arsiya F, Sayadi MH, Sobhani S. Green synthesis of palladium nanoparticles using Chlorella vulgaris. Materials Letters. 2017; 186:113-115.
38. Saravanan M, Barik SK, Mubarak Ali D, Prakash P, Pugazhendhi A. Synthesis of silver nanoparticles from *Bacillus brevis* (NCIM 2533) and their antibacterial activity against pathogenic bacteria. Microbial Pathogenesis. 2018;116:221-226.
39. Salem SS, Fouda A. Green synthesis of metallic nanoparticles and their prospective biotechnological applications: An overview. Biological Trace Element Research. 2021;199(1):344-370.
40. Antezana PE, Municoy S, Desimone MF. Building nanomaterials with microbial factories. In Biogenic Sustainable Nanotechnology. Elsevier. 2022;1-39.
41. Das SK, Dickinson C, Lafir F, Brougham DF, Marsili E. Synthesis, characterization and catalytic activity of gold nanoparticles biosynthesized with *Rhizopus oryzae* protein extract. Green Chemistry. 2012; 14(5):1322-1334.
42. Ravichandran R. Nanotechnology applications in food and food processing: Innovative green approaches, opportunities and uncertainties for global market. International Journal of Green Nanotechnology: Physics and Chemistry. 2010;1(2):P72-P96.
43. Catalano PN, Chaudhary RG, Desimone MF, Santo-Orihuela PL. A survey on analytical methods for the characterization of green synthesized nanomaterials. Current Pharmaceutical Biotechnology. 2021;22(6):823-847.
44. Kagdi AR, Pullar RC, Meena SS, Carvalho FE, Sandhu CS, Jotania RB, Basak CB. Green synthesis based X-type Ba–Zn hexaferrites: Their structural, hysteresis, mössbauer, dielectric and electrical properties. Materials Chemistry and Physics. 2022;282:125914.
45. Makarov VV, Love AJ, Sinitsyna OV, Makarova SS, Yaminsky IV, Taliansky ME, Kalinina NO. “Green” nanotechnologies: Synthesis of metal nanoparticles using plants. Acta Naturae (English version). 2014;6(1 (20)):35-44.
46. Krestinin AV, Dremova NN, Knerel’Man EI, Blinova LN, Zhigalina VG, Kiselev NA. Characterization of SWCNT products manufactured in Russia and the prospects for their industrial application. Nanotechnologies in Russia. 2015;10:537-548.
47. Ovais M, Khalil AT, Islam NU, Ahmad I, Ayaz M, Saravanan M, Mukherjee S. Role of plant phytochemicals and microbial enzymes in biosynthesis of metallic

nanoparticles. Applied Microbiology and Biotechnology. 2018;102:6799-6814.
48. Can M. Green gold nanoparticles from plant-derived materials: An overview of the reaction synthesis types, conditions, and applications. Reviews in Chemical Engineering. 2020;36(7):859-877.
49. Afreen A, Ahmed R, Mehboob S, Tariq M, Alghamdi HA, Zahid AA, Hasan A. Phytochemical-assisted biosynthesis of silver nanoparticles from Ajuga bracteosa for biomedical applications; 2020.
50. Trickler WJ, Lantz SM, Murdock RC, Schrand AM, Robinson BL, Newport GD, Ali SF. Silver nanoparticle induced blood-brain barrier inflammation and increased permeability in primary rat brain microvessel endothelial cells. Toxicological Sciences. 2010;118(1):160-170.
51. Khalil MM, Ismail EH, El-Baghdady KZ, Mohamed D. Green synthesis of silver nanoparticles using olive leaf extract and its antibacterial activity. Arabian Journal of Chemistry. 2014;7(6):1131-1139.
52. Velusamy P, Kumar GV, Jeyanthi V, Das J, Pachaiappan R. Bio-inspired green nanoparticles: Synthesis, mechanism, and antibacterial application. Toxicological Research. 2016;32(2):95-102.
53. Safat S, Buazar F, Albukhaty S, Matroodi S. Enhanced sunlight photocatalytic activity and biosafety of marine-driven synthesized cerium oxide nanoparticles. Scientific Reports. 2021;11(1):14734.
54. Alhujaily M, Albukhaty S, Yusuf M, Mohammed MK, Sulaiman GM, Al-Karagoly H, Al Malki FA. Recent advances in plant-mediated zinc oxide nanoparticles with their significant biomedical properties. Bioengineering. 2022;9(10):541.
55. Mittal AK, Chisti Y, Banerjee UC. Synthesis of metallic nanoparticles using plant extracts. Biotechnology Advances. 2013;31(2):346-356.
56. Shah M, Fawcett D, Sharma S, Tripathy SK, Poinern GEJ. Green synthesis of metallic nanoparticles via biological entities. Materials. 2015;8(11):7278-7308.
57. Rautela A, Rani J. Green synthesis of silver nanoparticles from *Tectona grandis* seeds extract: Characterization and mechanism of antimicrobial action on different microorganisms. Journal of Analytical Science and Technology. 2019; 10(1):1-10.
58. Nadagouda MN, Castle AB, Murdock RC, Hussain SM, Varma RS. *In vitro* biocompatibility of nanoscale zerovalent Iron particles (NZVI) synthesized using tea polyphenols. Green Chemistry. 2010;12(1): 114-122.
59. Huang L, Weng X, Chen Z, Megharaj M, Naidu R. Green synthesis of iron nanoparticles by various tea extracts: Comparative study of the reactivity. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 2014;130:295-301.
60. Shou Q, Guo C, Yang L, Jia L, Liu C, Liu H. Effect of pH on the single-step synthesis of gold nanoparticles using PEO–PPO–PEO triblock copolymers in aqueous media. Journal of Colloid and Interface Science. 2011;363(2):481-489.
61. Otsuka H, Nagasaki Y, Kataoka K. PEGylated nanoparticles for biological and pharmaceutical applications. Advanced Drug Delivery Reviews. 2003;55(3):403-419.
62. Prasad KS, Pathak D, Patel A, Dalwadi P, Prasad R, Patel P, Selvaraj K. Biogenic synthesis of silver nanoparticles using *Nicotiana tobaccum* leaf extract and study of their antibacterial effect. African Journal of Biotechnology. 2011;10(41): 8122.
63. Chauhan RP, Gupta C, Prakash D. Methodological advancements in green nanotechnology and their applications in biological synthesis of herbal nanoparticles. International Journal of Bioassays (IJB); 2012.
64. Pal SL, Jana U, Manna PK, Mohanta GP, Manavalan R. Nanoparticle: An overview of preparation and characterization. Journal of Applied Pharmaceutical Science, (Issue). 2011;228-234.
65. Brice-Profeta S, Arrio MA, Tronc E, Menguy N, Letard I, Dit Moulin CC, Sainctavit P. Magnetic order in γ-Fe_2O_3 nanoparticles: A XMCD study. Journal of Magnetism and Magnetic Materials. 2005; 288:354-365.
66. Kowalczyk B, Lagzi I, Grzybowski BA. Nanoseparations: Strategies for size and/or shape-selective purification of nanoparticles. Current Opinion in Colloid and Interface Science. 2011;16(2):135-148.
67. Faraji M, Yamini Y, Rezaee M. Magnetic nanoparticles: Synthesis, stabilization, functionalization, characterization, and applications. Journal of the Iranian Chemical Society. 2010;7:1-37.

68. Priya MM, Selvi BK, Paul JA. Green synthesis of silver nanoparticles from the leaf extracts of *Euphorbia hirta* and *Nerium indicum*. Digest Journal of Nanomaterials and Biostructures (DJNB). 2011;6(2).
69. Rajeshkumar S. Synthesis of silver nanoparticles using fresh bark of *Pongamia pinnata* and characterization of its antibacterial activity against gram positive and gram negative pathogens. Resource-Efficient Technologies. 2016; 2(1):30-35.
70. Molpeceres J, Aberturas MR, Guzman M. Biodegradable nanoparticles as a delivery system for cyclosporine: Preparation and characterization. Journal of Microencapsulation. 2000;17(5):599-614.
71. Khane Y, Benouis K, Albukhaty S, Sulaiman GM, Abomughaid MM, Al Ali A, Dizge N. Green synthesis of silver nanoparticles using aqueous *Citrus limon* zest extract: Characterization and evaluation of their antioxidant and antimicrobial properties. Nanomaterials. 2022;12(12):2013.
72. Mahmood RI, Kadhim AA, Ibraheem S, Albukhaty S, Mohammed-Salih HS, Abbas RH, Al-Karagoly H. Biosynthesis of copper oxide nanoparticles mediated *Annona muricata* as cytotoxic and apoptosis inducer factor in breast cancer cell lines. Scientific Reports. 2022;12(1): 16165.
73. Alzubaidi AK, Al-Kaabi WJ, Ali AA, Albukhaty S, Al-Karagoly H, Sulaiman GM, Khane Y. Green synthesis and characterization of silver nanoparticles using flaxseed extract and evaluation of their antibacterial and antioxidant activities. Applied Sciences. 2023;13(4):2182.
74. Tiwari DK, Behari J, Sen P. Time and dose-dependent antimicrobial potential of Ag nanoparticles synthesized by top-down approach. Current Science. 2008;647-655.
75. Parida UK, Bindhani BK, Nayak P. Green synthesis and characterization of gold nanoparticles using onion (*Allium cepa*) extract. World J Nano Sci Eng. 2011; 1(04):93.
76. Talam S, Karumuri SR, Gunnam N. Synthesis, characterization, and spectroscopic properties of ZnO nanoparticles. International Scholarly Research Notices; 2012.
77. Chandra S, Kumar A, Tomar PK. Synthesis and characterization of copper nanoparticles by reducing agent. Journal of Saudi Chemical Society. 2014;18(2):149-153.
78. Gupta V, Gupta AR, Kant V. Synthesis, characterization and biomedical application of nanoparticles. Science International. 2013;1(5):167-174.
79. Arakha M, Pal S, Samantarrai D, Panigrahi TK, Mallick BC, Pramanik K, Jha S. Antimicrobial activity of iron oxide nanoparticle upon modulation of nanoparticle-bacteria interface. Scientific Reports. 2015;5(1):14813.
80. Poguberović SS, Krčmar DM, Dalmacija BD, Maletić SP, Tomašević-Pilipović DD, Kerkez DV, Rončević SD. Removal of Ni (II) and Cu (II) from aqueous solutions using 'green'zero-valent iron nanoparticles produced by oak and mulberry leaf extracts. Water Science and Technology. 2016;74(9):2115-2123.
81. Thomas JM, Midgley PA, Ducati C, Leary RK. Nanoscale electron tomography and atomic scale high-resolution electron microscopy of nanoparticles and nanoclusters: A short survey Nanoscale electron tomography and atomic scale high-resolution electron microscopy of nanoparticles and nanoclusters: A short survey retain--. Progress in Natural Science: Materials International. 2013; 23(3):222-234.
82. Choi Y, Choi MJ, Cha SH, Kim YS, Cho S, Park Y. Catechin-capped gold nanoparticles: Green synthesis, characterization, and catalytic activity toward 4-nitrophenol reduction. Nanoscale Research Letters. 2014;9:1-8.
83. Das RK, Borthakur BB, Bora U. Green synthesis of gold nanoparticles using ethanolic leaf extract of *Centella asiatica*. Materials Letters. 2010;64(13):1445-1447.
84. Luo F, Yang D, Chen Z, Megharaj M, Naidu R. One-step green synthesis of bimetallic Fe/Pd nanoparticles used to degrade Orange II. Journal of Hazardous Materials. 2016;303:145-153.
85. Rajeshkumar S, Bharath LV. Mechanism of plant-mediated synthesis of silver nanoparticles–a review on biomolecules involved, characterisation and antibacterial activity. Chemico-Biological Interactions. 2017;273:219-227.
86. Nithya Deva Krupa A, Raghavan V. Biosynthesis of silver nanoparticles using *Aegle marmelos* (Bael) fruit extract and its application to prevent adhesion of bacteria: A strategy to control microfouling.

Bioinorganic Chemistry and Applications; 2014.

87. Salunke GR, Ghosh S, Santosh Kumar RJ, Khade S, Vashisth P, Kale T, Chopade BA. Rapid efficient synthesis and characterization of silver, gold, and bimetallic nanoparticles from the medicinal plant *Plumbago zeylanica* and their application in biofilm control. International Journal of Nanomedicine. 2014;2635-2653.
88. De Jaeger N, Demeyere H, Finsy R, Sneyers R, Vanderdeelen J, Van der Meeren P, Van Laethem M. Particle sizing by photon correlation spectroscopy part I: monodisperse latices: Influence of scattering angle and concentration of dispersed material. Particle and Particle Syst ems Characterization. 1991;8(1-4): 179-186.
89. Janaki AC, Sailatha E, Gunasekaran S. Synthesis, characteristics and antimicrobial activity of ZnO nanoparticles. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 2015;144:17-22.
90. Dobrucka R, Długaszewska J. Biosynthesis and antibacterial activity of ZnO nanoparticles using *Trifolium pratense* flower extract. Saudi Journal of Biological Sciences. 2016;23(4):517-523.
91. Umer A, Naveed S, Ramzan N, Rafique MS, Imran M. A green method for the synthesis of copper nanoparticles using L-ascorbic acid. Matéria (Rio de janeiro). 2014;19:197-203.
92. Wang T, Lin J, Chen Z, Megharaj M, Naidu R. Green synthesized iron nanoparticles by green tea and eucalyptus leaves extracts used for removal of nitrate in aqueous solution. Journal of Cleaner Production. 2014;83:413-419.
93. Vickrey TM, Garcia-Ramirez JA. Magnetic field-flow fractionation: Theoretical basis. Separation Science and Technology. 1980;15(6):1297-1304.
94. Alves PD, Brandão MG, Nunan EA, Vianna-Soares CD. Chromatographic evaluation and antimicrobial activity of Neem (*Azadirachta indica* A. *Juss., Meliaceae*) leaves hydroalcoholic extracts. Revista Brasileira de Farmacognosia. 2009; 19:510-515.
95. Hossain MA, Al-Toubi WA, Weli AM, Al-Riyami QA, Al-Sabahi JN. Identification and characterization of chemical compounds in different crude extracts from leaves of Omani neem. Journal of Taibah University for Science. 2013;7(4):181-188.
96. López-Serrano A, Olivas RM, Landaluze JS, Cámara C. Nanoparticles: A global vision. Characterization, separation, and quantification methods. Potential environmental and health impact. Analytical Methods. 2014;6(1):38-56.
97. Bootz A, Vogel V, Schubert D, Kreuter J. Comparison of scanning electron microscopy, dynamic light scattering and analytical ultracentrifugation for the sizing of poly (Butyl cyanoacrylate) nanoparticles. European Journal of Pharmaceutics and Biopharmaceutics. 2004;57(2):369-375
98. Mavrocordatos D, Perret D, Leppard GG. Strategies and advances in the characterisation of environmental colloids by electron microscopy. Iupac Series on Analytical and Physical Chemistry of Environmental Systems. 2007;10:345.
99. Bundschuh T, Knopp R, Kim JI. Laser-induced breakdown detection (LIBD) of aquatic colloids with different laser systems. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2001;77(1):47-55.
100. Bundschuh T, Yun JI, Knopp R. Determination of size, concentration and elemental composition of colloids with laser-induced breakdown detection/ spectroscopy (LIBD/S). Fresenius' Journal of Analytical Chemistry. 2001;371:1063-1069.
101. Cai Y, Peng WP, Chang HC. Ion trap mass spectrometry of fluorescently labeled nanoparticles. Analytical Chemistry. 2003; 75(8):1805-1811.
102. Tied K, Boxall AB, Tear SP, Lewis J, David H, Hassellöv M. Detection and characterization of engineered nanoparticles in food and the environment. Food Additives and Contaminants. 2008; 25(7):795-821.
103. Nadeau G, Herguth WR. Applying SEM-EDS to Practical Tribology Problems.
104. Badireddy AR, Wiesner MR, Liu J. Detection, characterization, and abundance of engineered nanoparticles in complex waters by hyperspectral imagery with enhanced darkfield microscopy. Environmental Science and Technology. 2012;46(18):10081-10088.
105. Anastas PT, Warner JC. Principles of green chemistry. Green chemistry: Theory and Practice. 1998;29:14821-14842.

106. Gałuszka A, Migaszewski Z, Namieśnik J. The 12 principles of green analytical chemistry and the SIGNIFICANCE mnemonic of green analytical practices. TRAC Trends in Analytical Chemistry. 2013;50:78-84.
107. Lead JR, Wilkinson KJ. Environmental colloids and particles: Current knowledge and future developments. IUPAC series on Analytical and Physical Chemistry of Environmental Systems. 2007;10:1.
108. Turunc E, Binzet R, Gumus I, Binzet G, Arslan H. Green synthesis of silver and palladium nanoparticles using *Lithodora hispidula* (Sm.) Griseb. (Boraginaceae) and application to the electrocatalytic reduction of hydrogen peroxide. Materials Chemistry and Physics. 2017;202:310-319.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/118690