Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

The Impact of Metal/Metal Oxide Nanoparticle Formation Through Green Synthesis from Plants and Microbes: A Thorough Analysis

Praseetha P K[1], G. Sakthivel[1], Nirmal Kumar Devarajan[2], Shyni M[3], Surya Prakash D V[4], T. Mohammad Munawar[5*]

[1]Department of Nanotechnology, Noorul Islam Centre for Higher Education, India
[2]Department of Prosthodontics, Ayder comprehensive specialized hospital, Mekelle University, Ethiopia.
[3]Inbiotic's, 47A-Asambu Road, Vadsery, Nagercoil, Tamilnadu, India
[4]Department of Biotechnology, Meerut Institute of Engineering and Technology, India.
[5]Department of Biological and Chemical Engineering, Mekelle Institute of Technology, Mekelle University, Ethiopia.
Email: munna686@gmail.com

The control of an atom and molecules, and its manipulations, gave rise to concept of nanotechnology domain. The formation of metal and metal oxide nanoparticles via green synthesis methods using plants and microbial systems, emphasizing their synthesis techniques and potential applications. The environmental and economic advantages of biogenic reduction processes, which leverage microbial enzymes, fungi, and plant extracts to produce nanoparticles, as opposed to traditional chemical and physical synthesis methods. The current comprehensive review focuses mainly on the green synthesis of metal and metal oxide nanoparticles using plants and microbes, from the synthesis process and parameters to their latest applications in industrial and biomedical fields. Microbe-mediated synthesis utilizes various bacteria and fungi, such as Pseudomonas aeruginosa, Aspergillus niger, and Fusarium oxysporum, to produce nanoparticles like Ag, Au, and ZnO with specific biomedical applications. Similarly, plant-based synthesis involves phytochemicals from plants generate nanoparticles for antimicrobial and anticancer purposes. Microwave-assisted green synthesis, highlighting its efficiency in enhancing reaction kinetics and controlling nanoparticle characteristics. The applications of green-synthesized nanoparticles are vast, including their use in medical diagnostics, drug delivery systems, antimicrobial coatings, and environmental remediation. Meanwhile, limitations of green synthesis, includes challenges in resource availability, uniformity of nanoparticle properties, reproducibility, scalability, and potential toxicity need to focus. Yet, there are a number of obstacles that seriously restrict the use of green synthesis techniques, including the availability of resources, consistency of nanoparticle characteristics, repeatability, scalability, and possible toxicity. Addressing these obstacles and optimising the advantages will advance the safe and sustainable use of green-synthesised nanoparticles in both scientific and industrial fields.

Keywords: Nanoparticle; Green synthesis; Silver nanoparticle; Gold nanoparticle; Metal oxide nanoparticle.

1. Introduction

The current lively hood is trying to bring miniaturization everywhere which give rise to “Nano era.” Every spheres of technology has benefited due to nano science in varying form. The nanotechnology was used in ancient time without proper subject knowledge. Anyhow, the silver (AgNp) or gold (AuNp) nanoparticle (Np) aesthetic beauty is evidenced by Lycurgus cup back in fourth century AD [1]. In 1676 industrial applications of colloidal particle was reported, the colloidal gold application can be noted from 1718 [2]. In 1959, Prof. Richard Feynman entitled the famous coats on a conference “There is Plenty of Room at Bottom” that develop into nano science concept [3]. Nanotechnology is the sophisticated technological advancement of the twenty-first century when it comes to the scientific community's understanding of the molecular properties of atoms and their assembly at the nanoscale dimension range from 1-100nm [4]. The recent advances in this field have let scientists change the nanoparticles' physical, chemical, and biological properties [5]. A comprehensive inventory of all the possible uses for nanotechnology is too big and varied to get into here, but one of its most significant contributions will surely be the creation of novel and efficient medical therapies (nano-medicine) [6-8]. Nanoparticles can now be used in a wide range of fields, including drug delivery, image contrast agents, diagnostic applications, and dental implant material alloys [9–10].

The nanoparticles differ in size, shape, and internal structure. It can be spherical, cylindrical, tubular, conical, hollow core, spiral, flat, etc., and its diameters vary from 1 nm to 100 nm. The surface could have a consistent shape or show variations. Certain kinds of nanoparticles are made up of one or more loose or clumped crystal solids. These can be crystalline or amorphous [11–12]. In an effort to increase quality and lower manufacturing costs, a multitude of synthesis techniques are being created or refined. In order to enhance the optical, mechanical, physical, and chemical properties of nanoparticles, certain techniques are altered to produce specialised nanoparticles. Better nanoparticle characterization and subsequent applications are the result of significant advancements in instrumentation.

There are several physico and chemical approaches are being used for synthesising the nanoparticles. However, the method applied to produce nanoparticles by means of biogenic reduction of the metal precursors should be eco-friendly, less expensive as the same time the purity of the nanoparticles is a highly important concern as free from chemical contamination for several medical applications [13-14]. Biological approaches to synthesising nanoparticles employing microbes, enzymes, fungi, and plant extracts are environmentally benign alternatives to chemical and physical methods [15–16] (Figure 1).In this review, which concentrates on the advancements and outlines the green synthesis of nanoparticle processes that involve using plant extracts and other natural products and are therefore comparatively more environmentally friendly ways to synthesise nanoparticle.

2. Green synthesis- development timeline

In 1990 "Green Chemistry in Emerald" by Cathcartin was 1st report about "Green" effort in synthetic chemistry field [17]. In ancient time, the biologically prepared nanoparticle like Ayurvedic bhasmas was there in ancient time, these can be prepared in nanometer scale by two ways, the Putapaka and Kupipakwa technique which are the earliest examples of nanoparticle in the application of medical field [18]. Ayurveda nanoparticle preparation follows two routes; initially is in the form of chemical synthesis involving organic and inorganic chemical along with solvents, strong reagent, and reducing agents. The other one is green synthesis routers which involving an environmental friendly and safe synthesis manner [19–20]. Green synthesis methods in nanoparticles preferred due to its cost effective and eco-friendly nature which is always lucrative for biomedical and pharmaceutical application. Green chemistry has different advantages like safe reagent/solvent use for synthesis purpose, process of energy-efficient conversions, nanoparticles synthesis by biological process, Synthesis of nanoparticle that is eco-friendly and safer for future application [20, 21]. Synthetic method incorporates all material used in the process in to final product that has less or no toxic nature to humans and environments. Chemical product designed to preserves the efficiency of functions which will reduce toxicity.

Substance in chemical processes should be chosen to decrease the potential for chemical accident, which includes release, explosion, and fire [22]. Some of nanoparticle by green synthesis is given below which is better than nanoparticles produced by normal root by its special effect. Magnetic nanoparticle based on Fe3O4 (Iron (II, III) oxide) made by One-pot solvo-thermal process using reducing agent ethylene glycol where synthesis time is 30 minutes [23]. Facile reduction leads to airstable nanoparticle formation, Co Reductions of p-nitrophenol -p-aminophenol by sodium borohydride catalyst; surfactant used is cobalt sulfate using tetrabutyl ammonium bromide and reductant as sodium borohydride [24]. AuNp and AgNp nanoparticle prepared by Calcium alginate gel bead using a stabilizer and reductant ,Green photochemical method is useful for biopolymer-based solid phase, catalyst used are efficient, ease of preparation, environmental-friendly, cost-effective and stable [25]. Ag nanoparticles by using cow milk as reductant. Protein in cow milk reduces Ag+ ion; it is efficient phyto-pathogen inhibitor; simple, fast , easily available and less expensive [26]. AuNp synthesised by reducing agent as Amine and stabilizer Control the formation of structures during synthesis [27].

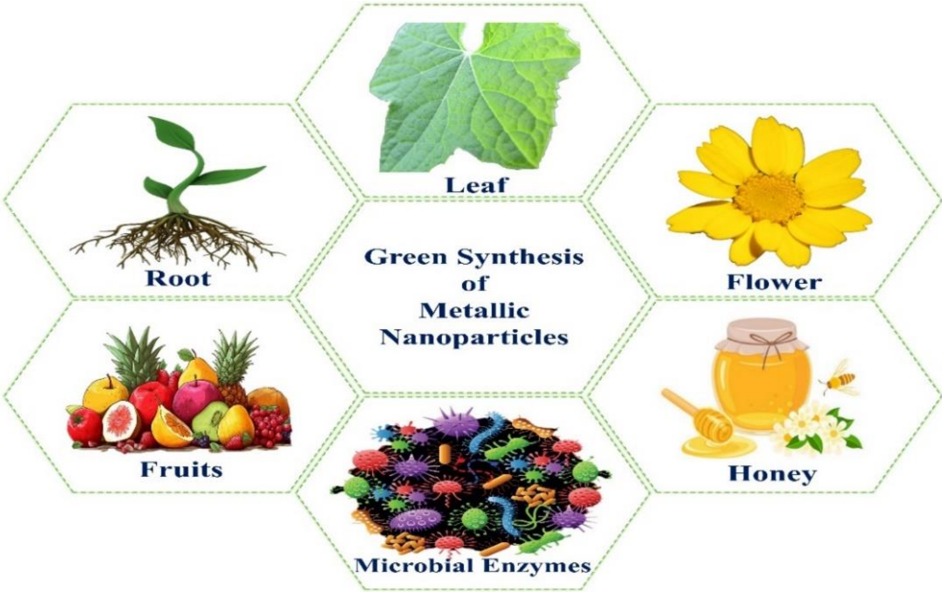

Figure 1 Sources of metallic/Metal oxide nanoparticle for green synthesis process

3. Different roots of green synthesis

3.1. Microbe-mediated Green Synthesis

Microbes are the first life forms on Earth, and they are the source of all other kinds of life. They remained the most common type of life on Earth for billions of years, long before any plants or animals existed [28, 29]. Because of their genetic diversities, presence of ubiquitous, easiness of availability, screening, cultivation and maintenance, and tailoring the functional and structural property nanoparticles microbes were consider as the fair choice for green synthesis of nanoparticles [20]. Since the diverse biocatalyst presence in microbe has made the method most appropriate and selective. Inorganic materials are generated either extra or intra cellular by unicellular and multicellular microorganisms [30]. In the attempt to create novel materials, microbes such as fungus and bacteria that possess the capacity to regulate the creation of metallic nanoparticles [15].The use of microbial resources in nanoparticle synthesis is comparatively favourable because the proteins released by microbes improve the stability of the nanoparticles. Moreover, the vital enzyme and protein were present in microbes as a large amount as reducing agent influences the fast bio-reduction for nanoparticle synthesis [31, 32].

Microbes possess multiple reductase enzymes that transform metal salts into metal nanoparticles through processes of accumulation and detoxification [33]. Recent studies have demonstrated the ability of bacteria to produce AgNp and AuNp nanoparticles. These bacteria include Pseudomonas deptenis, Visella oriza, Bacillus methylotrophicus, Bhargavaea indica, and Brevibacterium frigoritolerans. Microorganisms of other different genera, including Lactobacillus, Bacillus, Pseudomonas, Streptomyces, Klebsiella, Enterobacter, Escherichia, Aeromonas, Corynebacterium, Weissella, Rhodobacter, Rhodococcus, Brevibacterium, Trichoderma, Desulfovibrio, Sargassum, Shewanella, Plectonemaboryanum, Pyrobaculum, and Rhodopseudomonas have also been known to synthesise metal nanoparticles [34, 35]. The microbe mediated nanoparticle's details are given in Table 1.

Table 1 Microbe mediated metal/metal oxide nanoparticle's green Synthesis

Species	Microbial Source	Nanoparticle	Application	References
Fungi	Fusarium oxysporum	AgNp	–	[36]
	Aspergillus niger	AgNp	Antibacterial activity	[37]
	Fusarium solani	AgNp	Antimicrobial agent	[38]
	Verticillium luteoalbum	AuNp	–	[39]
	Fusarium oxysporum	ZrNp	Space application as quantum dots	[40]
	Trichoderma viride	AgNp	Antibacterial activity	[41]
	Aspergillus fumigates	ZnONp (Zinc Oxide)	Industrial, medical and agricultural sectors	[42]
	Rhizopus oryzae	MgONp (Magnesium oxide)	Agricultural pesticides	[43]
	Rhizopus stolonifer	AgNp	Antifungal	[44, 45]
	Penicillium fellutanum	AgNp	Antibacterial	[46]
	Coriolus versicolor	AgNp	–	[47]
	Phaenerochaete chrysosporium	AgNp	–	[48]
	Fusarium oxysporum	AgNp	Antibacterial, Antitumor	[49]
Yeast	Schizosaccharomyces pombe	CdSNp (Cadmium sulphide)	–	[50]
	Pichia jadinii	AuNp	–	[51]
	Yarrowia lipolytica	AuNp, AgNp	Antibacterial	[52, 53]
	Saccharomycetes. cerevisiae	AgNp	–	[54]
Bacteria	Pseudomonas aeruginosa	AuNp	Bioremediation	[50]
	Bacillus subtilis	AgNp& AuNp	Antimicrobial against clinical pathogens isolated	[55, 56]
	Escherichia coli	CdSNp	Antimicrobail	[57]
	Bacillus cereus	AgNp	Antibacterial activity	[58]
	Pseudomonas stutzeri	AgNp, AuNp	Antimicrobail	[59, 60]
	Rhodobacter sphaeroides	AgNp	–	[61]
	Streptomyces aizuneusis	AgNp	Antifungal, Anti-larval	[62]
Virus	Tobacco mosaic virus	AgNp, AuNp	-	[63, 64]
	Bacteriophage	AgNp, AuNp	Anti-biofilm	[65, 66]
Algae	Chlorella vulgaris	AuNp	Antimicrobial	[67]
	Scenedesmus sp.	AgNp	–	[68]
	Spirulina platensis	AuNp, AgNp	Anti micorbial and Anti oral pathogen	[69, 70]
	Sargassum wightii	AuNp, AgNp	Antibacterial, Anticancer	[71, 72]

3.2. Plant Based Green Synthesis

A usual approach in green synthesis of nanoparticles is use phytochemical from plant extract, carbohydrate, and biomolecule as capping or reducing agent for nanoparticle's preparation [73]. Among all common bio-reductant, plant extract seems to be more useful than other biology resource. Plant-based method is a simple technique where plant extract is mixed with a metal salt, and reactions finish in minute to a few hours at room temperature (Figure 2). A solution of metal salt is reduced into its nanoparticle [74]. By using plant extracts, growth of size of nanoparticles can be controlled by changing conditions of the synthesis like reducing agents pH, concentrations, reactant mixing ratio and temperature [75].

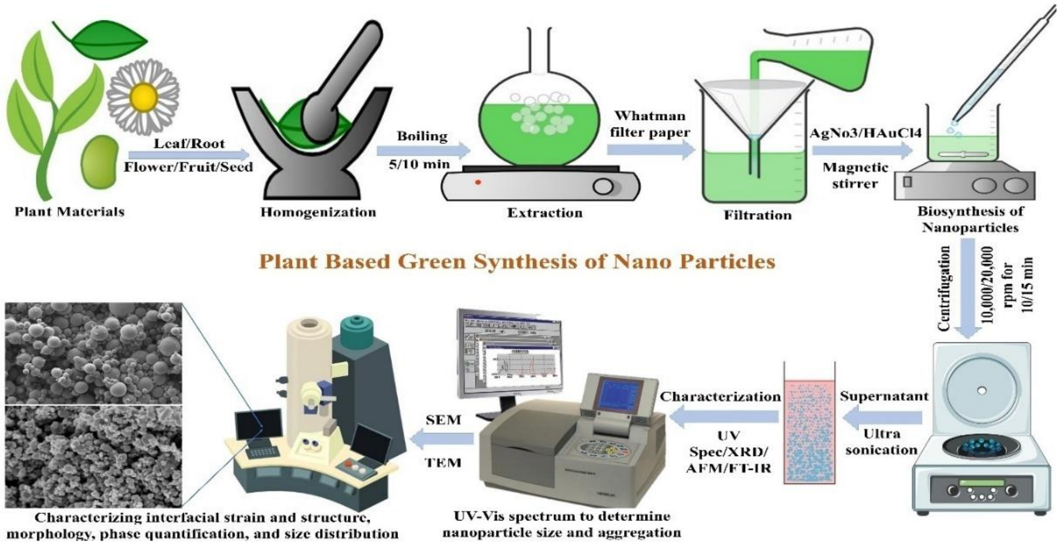

Figure 2 Plant based Green synthesis of nanoparticle general concept

Apart from their exceptional efficacy in green synthesis, plant-based nanoparticles also have a significant impact on other fields. They act as catalyzed processes that break down harmful contaminants in the aquatic environment for water treatment [76, 77]. Green synthesised nanoparticles are also scientifically important for their medicinal uses, including antibacterial, antifungal, anti-cancer, and illness treatment. Nanoparticles have demonstrated significant value in diagnostics and drug delivery to treat cancer and other major diseases [78–80]. The development of biomedical technologies and environmental cleanup is significantly aided by biosynthesized nanoparticles. Few of plant mediated green synthesis of nanoparticle details in Table 2.

Table 2 Plant green synthesis of metal/metal oxide nanoparticles

S.No	Plant	Nanoparticles	Application	References
1	C. pumilio	AgNp	Anti-aging	[81]
2	A. hispidum (Bristly starbur)	CuONp (Copper oxide)	Antibacterial	[82]
3	A. vulgaris (Mugwort)	AgNp	Antifungal	[83]
4	P. undulata (False feabane)	AuNp, AgNp	Antimicrobial, Antioxidant, and Cytotoxic Activities	[84][51]
6	A. hispidum (Bristly starbur)	CuONp,AgNp	Antibacterial	[82][85]
7	Averrhoa bilimbi	AuNp, AgNp	Antioxidant	[86, 87]
8	C. intybus (Chicory)	AgNp	Antimicrobial, Anticancer	[88]
9	Aristolochia bracteolata lam	AgNp, ZnONp	Antimicrobial	[89, 90]
10	Leucas aspera	AgNp	Antimicrobial	[91]
11	Azadirachta indica (the neem tree)	CuONp, AgNp	Antimicrobial	[92, 93]
12	Moringa oleifera	AgNp	Antibacterial	[94]
13	Cinnamomum zeylanisum	AgNp and AuNp	Antibacterial	[95]
14	Olive leaf's	AgNp	Antibacterial	[96]

15	Jatropha Latex	AgNp, TiO2Np (Titanium dioxide)		[97, 98]
16	Tabernaemontana divaricate	ZnONp, AgNp	Antimicrobial	[99, 100]
17	Azadirachta indica	AgNp	Antimicrobial	[101]
18	Mangifera indica	AgNp, AuNp	Antimicrobial, Anticancer	[102, 103]
19	Alpinia katsumadai	AgNp	Antibacterial, Antioxidant	[104]
20	Budleja globosa	AgNp	-	[105]
21	Citrus sinensis	AgNp, AuNp	Anticancer, Antioxidant	[106,107]
22	Crocus sativus L.	AgNp, AuNp	Antibacterial, Antitumor	[108, 109]
23	Citrus limon	AgNp	Antimicrobial, Anti-bacterial	[110, 111]
24	Citrus limetta	AgNp	Antibacterial	[112]
25	Daucus carota (Carrot)	AgNp	Antibacterial	[113]
26	Malus Pumila (Red apple)	AgNp	Antibacterial	[114]
27	Amaranthus Tricolor L.	AgNp	Antibacterial	[115]
28	Lycopersicon esculentum	AgNp, AuNp	Anticancer	[116]
29	Hibiscus rosa sinensis	AgNp, AuNp, ZnONp	-	[117, 118]
30	Zingiber officinale	AgNp, AuNp	Antioxidant	[119, 120]

3.3. Microwave- assisted Green Synthesis

Green chemistry can decrease reaction's time and temperature. Compared to traditional heating methods, microwave heating has several advantages since it increases reaction kinetics and heats up quickly, which in turn leads to faster reaction rates and cleaner, higher-yielding products [121]. Microwave heating is crucial to the synthesis of nanoparticles because it improves the nucleation process, which is the first step in the creation of nanoparticles, by maintaining a regulated high temperature [122, 123]. As opposed to conventional heating, microwave heating has already been shown to manufacture nanoparticles with a greater degree of crystallinity and to provide producers with more control over the morphology and size of the nanostructures they create (Figure 3) [124, 125].

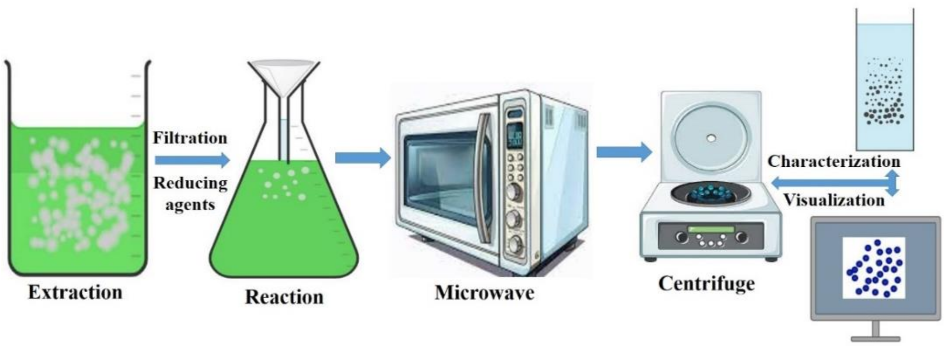

Figure 3 Microwave based green synthesis of nanoparticle illustration

Microwaves use an electromagnetic wave type that is pure energy radiating in forms of a wave propagating at light speed. Microwave propagations happen at low speed within condensed matter, than in the air/vacuum, where there is lower light speed [126, 127]. Microwave assisted nanoparticle synthesis dependents on time and power, which have to be adjusted. Microwave can also assist with hydrothermal synthesis tools. The commonly used microwave frequencies in nanoparticle's preparation range from 2 to 45 GHz, in which dielectric parameter dependent on temperature strongly [128]. The transfer of energy between microwave and matter is much complicated. The efficient parameter includes dielectric loss (current loss), dielectric polarization, magnetic loss (induction /eddy currents), magnetic heating, and 2nd order of effect [129]. Microwave mediated nanoparticles examples are given below:

i. AuNp by Psidium guajava Treatments of leaf extracts in gold chloride solutions followed by microwave-assisted route for suppressing enzyme actions [130].

ii. AgNp nanoparticles by Streptomyces pigment-mediated microwaves assisted synthesis [131].

iii. ZnONp nanoparticles by Chemical-mediated Microwave-assisted hydrothermal method [132].

iv. CuONPs synthesized by the microwave combustion method using Moringa oleifera and Punica grantum[133].

v. Green synthesis of silver nanoparticles from Fraxinus excelsior leaf extract using microwave [134].

vi. A microwave-assisted green synthesis approach was applied to create the AgNp, Ag2ONp, and Ag2O3Np combination [135].

4. Applications of green synthesised nanoparticles

Green-synthesized nanoparticle such as AgNp, CuNp, AuNp and magnetite nanoparticle can be used in wastewater treatment in heavy metal polluted industrial area. Usually, they implemented in removing heavy metals from wastewater and are also used in optoelectronic, electronic, energy catalytic, magnetic, and structural application [136, 137]. In automotive industries, nanoparticles were implemented in lightweight constructions, paintings and coating for windscreen and car body[138]. In textile, nonwoven industry, and fabric, nanoparticle is used in surface-processed textile and smart clothing’s., nanoparticles are used in food areas for package of material, storage life sensor, additive, and fruit juice’s clarifications [139, 140]. In construction industry, nanoparticle are used as flame retardant, thermal insulating agent, and as surface-functionalized building material for floor tile, wood, and roof tile, groove mortar and facade coating[20][143]. In household, nanoparticle is used as ceramic coating for odor catalyst, irons, and glass cleaner, floor, ceramic, and window [144–146].

5. Biomedical field / diagnostics field

The nanoparticles application in medicines and diagnostic areas are large , and this include use as marker for biology screening test (e.g., gold /semiconductors particle), contrast agent for MRI, and antimicrobial coating and composite material for antibacterial surface and medical device. They are made used in preparations of sunscreen, as antimicrobial agent, thermal sprays coating prostheses, in cancer therapies, and implant. They are found also in cosmetic industry, lipstick, skin cream, and toothpaste. Example of nanoparticle in medical field is Liposome PEG-stabilized liposomal system which are used as antifungal, anticancer, antibiotic drug, anesthetic and anti-inflammatory drug along with gene medicine delivery

[147, 148]. Metal nanoparticle because of their ideal physicochemical & optical property, are used largely for interactions with biological and chemical material [14]. Example Plant-mediated synthesised Ag nanoparticle used for detecting interaction between biotin and streptavidin. AgNpare used in Optical and chemo biosensors. Most importantly, nanoparticle shows anti-oxidant and antimicrobial applications such as ZnONp defence against pathogenic fungi (Penicillium expansum and Botrytis cinerea) [149, 150]. Fe_2O_3, Al_2O_3, CeO_2, MgO, and ZrO_2Npagainst UTI pathogen, namely, Enterobacter sp., Pseudomonas sp., Klebsiella sp., Proteus morganii, E.coli, andS. Aureus [151]. Au nanoparticles were used in DPPH assay, nitric oxide radical scavenging, superoxide radical scavenging, and hydrogen peroxide scavenging studies are done with Lemna minor-mediated nanoparticles [152]

6. Limitations

6.1. Resource availability

The reductant and stabilizer which used don't meet sometimes the demand- supply ratios, that is, the interactions of solvent or media for growth of microbes or for plant extracts extraction. So, possibly particular combinations of these 2 inputs may not give the needed yield [153].

6.2. Uniformity

Similar kind of plants or microbial source, or non-biological source, which are used for nanoparticle synthesis shows deviation in shape, size, and other characteristics. Relying on that alternative ways for long-term applications is not fully guaranteed as a fair good way since alternative synthesis route may not always been justified [154, 155].

6.3. Reproducibility

There is a limitation on getting consistency of similar nanoparticle's property by giving the same resource. When employing biological source for nanoparticles synthesis, attainment of targeted property is non controllable, but chemical method can control such areas [156, 157].

6.4. Large-scale production

Pilot-scale nanoparticle's synthesis faces the large scale applicability challenge. Even innovative technique like sol-gel, combustion, sonochemistry, coprecipitation method, hydrothermal, and microwave-assisted methods meet with qualitative drawback in material formed in terms of crystalline quality and physical property, which are not encountered often in large scale study[20][158].

6.5. Toxicity

Even if there are different methods for eco-friendly green synthesis of nanoparticle that is stable for a long time period, a complete toxic-free nanoparticle which is on the environment and human safer side is a long distant dream. Reports states that many nanoparticle have toxicity against microbe (fungi and bacteria), which indicate their effects on single cell [159]. Enough data of study of exposures of such nanoparticle in high animal and on humans is still pending. The eco-toxicological view is also addressed seldomly. Thus, most of experiments and nanoparticles research data have to get more focus on to this context.

7. Conclusion

In order to maximize the benefits that green synthesis technologies offer to society and individuals, it is imperative to strike a balance between their applications and restrictions. Although the nanoparticles generated by this method exhibit stability and economy, they also offer promising advantages, such as environmental safety and easy integration into biological systems. The use of renewable raw materials increases the potential for creating these green-synthesised nanoparticles in a variety of disciplines. Despite recent developments, there are still obstacles to overcome such as the availability of resources, consistency of nanoparticle characteristics, repeatability, scalability, and potential toxicity issues. In order to fully utilise green-synthesised nanoparticles in a variety of scientific and industrial applications, it is imperative to address these obstacles. Green synthesis has the potential to become a more scientifically recognized and sustainable solution for future uses if it finds the right balance.

References

[1] Deshmukh, K. (2019). Nanotechnology in ancient era. Biotechnology products in everyday life, 3-14

[2] Mehmood, U., Yasmeen, S., Nazar, R., & Tiwari, S. K. (2023). Metallic nanoparticles: status and prospect. In Nanoparticles Reinforced Metal Nanocomposites: Mechanical Performance and Durability (pp. 127-159). Singapore: Springer Nature Singapore

[3] Kousar, R., Khan, Z. U. H., Sabahat, S., Sun, J., Muhammad, N., Shah, N. S.,& Salam, M. A. (2024). Synergetic comparative study: Photocatalytic and biological investigations of green-synthesized metal oxide nanoparticles. Nano-Structures & Nano-Objects, 38, 101184

[4] Manou, L., Spyrtou, A., Hatzikraniotis, E., & Kariotoglou, P. (2022). What does "Nanoscience–Nanotechnology" mean to primary school teachers?. International Journal of Science and Mathematics Education, 20(6), 1269-1290

[5] Roco, M. C. (1999). Nanoparticles and nanotechnology research. Journal of nanoparticle research, 1(1), 1

[6] Yohan, D., & Chithrani, B. D. (2014). Applications of nanoparticles in nanomedicine. Journal of Biomedical Nanotechnology, 10(9), 2371-2392

[7] Wu, K., Su, D., Liu, J., Saha, R., & Wang, J. P. (2019). Magnetic nanoparticles in nanomedicine: a review of recent advances. Nanotechnology, 30(50), 502003

[8] Mohammadzadeh, V., Barani, M., Amiri, M. S., Yazdi, M. E. T., Hassanisaadi, M., Rahdar, A., & Varma, R. S. (2022). Applications of plant-based nanoparticles in nanomedicine: A review. Sustainable Chemistry and Pharmacy, 25, 100606

[9] McNamara, K., & Tofail, S. A. (2017). Nanoparticles in biomedical applications. Advances in Physics: X, 2(1), 54-88

[10] Priyadarsini, S., Mukherjee, S., Bag, J., Nayak, N., & Mishra, M. (2019). Application of nanoparticles in dentistry: Current trends. In Nanoparticles in Medicine (pp. 55-98). Singapore: Springer Singapore

[11] Kumari, S., & Sarkar, L. (2021). A review on nanoparticles: structure, classification, synthesis & applications. Journal of Scientific Research, 65(8), 42-46

[12] Khan, Y., Sadia, H., Ali Shah, S. Z., Khan, M. N., Shah, A. A., Ullah, N., ... & Khan, M. I. (2022). Classification, synthetic, and characterization approaches to nanoparticles, and their applications in various fields of nanotechnology: A review. Catalysts, 12(11), 1386

[13] Samuel, M. S., Ravikumar, M., John J, A., Selvarajan, E., Patel, H., Chander, P. S., & Chandrasekar, N. (2022). A review on green synthesis of nanoparticles and their diverse

biomedical and environmental applications. Catalysts, 12(5), 459
[14] Nair, G. M., Sajini, T., & Mathew, B. (2022). Advanced green approaches for metal and metal oxide nanoparticles synthesis and their environmental applications. Talanta Open, 5, 100080
[15] Ovais, M., Khalil, A. T., Ayaz, M., Ahmad, I., Nethi, S. K., & Mukherjee, S. (2018). Biosynthesis of metal nanoparticles via microbial enzymes: a mechanistic approach. International journal of molecular sciences, 19(12), 4100
[16] Yadav, K. K., Singh, J. K., Gupta, N., & Kumar, V. J. J. M. E. S. (2017). A review of nanobioremediation technologies for environmental cleanup: a novel biological approach. J Mater Environ Sci, 8(2), 740-757
[17] Ciriminna, R., Formenti, M., Della Pina, C., Luque, R., & Pagliaro, M. (2024). Green chemistry in Italy and Spain (1999–2019): Research policy lessons. Sustainable Chemistry and Pharmacy, 39, 101520
[18] Roopashree, S., Anitha, J., & Rashmi, S. (2021). Advent of nanomaterial in modern health science and ayurveda. Materials Today: Proceedings, 46, 9096-9101
[19] Kurian, J. T., Chandran, P., & Sebastian, J. K. (2023). Synthesis of inorganic nanoparticles using traditionally used indian medicinal plants. Journal of Cluster Science, 34(5), 2229-2255
[20] Das, M., & Chatterjee, S. (2019). Green synthesis of metal/metal oxide nanoparticles toward biomedical applications: Boon or bane. In Green synthesis, characterization and applications of nanoparticles (pp. 265-301). Elsevier
[21] Soni, V., Raizada, P., Singh, P., Cuong, H. N., Rangabhashiyam, S., Saini, A., ...& Nguyen, V. H. (2021). Sustainable and green trends in using plant extracts for the synthesis of biogenic metal nanoparticles toward environmental and pharmaceutical advances: A review. Environmental Research, 202, 111622
[22] Ramiro, J. S., & Aisa, P. B. (2012). Risk analysis and reduction in the chemical process industry. Springer Science & Business Media
[23] Kuritka I, Kozakova Z, Kazantseva NE, Babayan V, Pastorek M, Bazant MP, Saha P. The formation mechanism of iron oxide nanoparticles within the microwave-assisted solvothermal synthesis and its correlation with the structural and magnetic properties. Dalton Trans 2015;https://doi.org/10.1039/c5dt03518j
[24] Mondal A, Mondal A, Adhikary B, Mukherjee DK. Cobalt nanoparticles as reusable catalysts for reduction of 4-nitrophenol under mild conditions. Bull Mater Sci 2017;40(2):321–8. https://doi.org/10.1007/s12034-017-1367-3
[25] Saha S, Pal A, Kundu S, Basu S, Basu S, Pal T. Photochemical green synthesis of calcium-alginate-stabilized Ag and Au nanoparticles and their catalytic application to 4-nitrophenol reduction. Langmuir 2010;26(4):2885–93
[26] Lee KJ, Park SH, Govarthanan M, Hwang PH, Seo YS, Cho M, Lee WH, Lee JH, SK K, Oh BT. Synthesis of silver nanoparticles using cow milk and their antifungal activity against phytopathogens. Mater Lett 2013;105:128–31
[27] Blanchard GJ. Newman JDS, Formation of gold nanoparticles using amine reducing agents. Langmuir 2006;22(13):5882–7. https://doi.org/10.1021/la060045z
[28] Staley, J. T. (1997). Biodiversity: are microbial species threatened?. Current Opinion in Biotechnology, 8(3), 340-345
[29] Anton, T. (2017). Planet of Microbes: The Perils and Potential of Earth's Essential Life Forms. University of Chicago Press
[30] Bansal, V., Bharde, A., Ramanathan, R., & Bhargava, S. K. (2012). Inorganic materials using 'unusual'microorganisms. Advances in Colloid and Interface Science, 179, 150-168
[31] Saravanan, A., Kumar, P. S., Karishma, S., Vo, D. V. N., Jeevanantham, S., Yaashikaa, P. R., & George, C. S. (2021). A review on biosynthesis of metal nanoparticles and its environmental applications. Chemosphere, 264, 128580
[32] Tsekhmistrenko, S. I., Bityutskyy, V. S., Tsekhmistrenko, O. S., Horalskyi, L. P., Tymoshok, N.

O., & Spivak, M. Y. (2020). Bacterial synthesis of nanoparticles: A green approach. Biosystems Diversity, 28(1), 9-17
[33] Gahlawat, G., & Choudhury, A. R. (2019). A review on the biosynthesis of metal and metal salt nanoparticles by microbes. RSC advances, 9(23), 12944-12967
[34] Patil-Patankar, V., & Sanghvi, G. (2022). Nanoherbicides: A sustainable option for field applications. In Relationship Between Microbes and the Environment for Sustainable Ecosystem Services, Volume 1 (pp. 335-355). Elsevier
[35] Choudhary, A., Musheer, N., Ashraf, S., & Saeed, S. (2024). Microbe-mediated nanoparticles: Potential nanobiofungicides. In Nanofungicides (pp. 65-84). Elsevier
[36] Ahmad, A., Mukherjee, P., Senapati, S., Mandal, D., Khan, M. I., Kumar, R., & Sastry, M. (2003). Extracellular biosynthesis of silver nanoparticles using the fungus Fusarium oxysporum. Colloids and surfaces B: Biointerfaces, 28(4), 313-318
[37] Sagar, G., & Ashok, B. (2012). Green synthesis of silver nanoparticles using Aspergillus niger and its efficacy against human pathogens. European Journal of Experimental Biology, 2(5), 1654-1658
[38] El Sayed, M. T., & El-Sayed, A. S. (2020). Biocidal activity of metal nanoparticles synthesized by Fusarium solani against multidrug-resistant bacteria and mycotoxigenic fungi. Journal of Microbiology and Biotechnology, 30(2), 226
[39] Nasrollahzadeh, M., Sajadi, S. M., Issaabadi, Z., & Sajjadi, M. (2019). Biological sources used in green nanotechnology. In Interface science and technology (Vol. 28, pp. 81-111). Elsevier
[40] Tran, T. V., Nguyen, D. T. C., Kumar, P. S., Din, A. T. M., Jalil, A. A., & Vo, D. V. N. (2022). Green synthesis of ZrO 2 nanoparticles and nanocomposites for biomedical and environmental applications: a review. Environmental Chemistry Letters, 1-23
[41] Elgorban, A. M., Al-Rahmah, A. N., Sayed, S. R., Hirad, A., Mostafa, A. A. F., & Bahkali, A. H. (2016). Antimicrobial activity and green synthesis of silver nanoparticles using Trichoderma viride. Biotechnology & Biotechnological Equipment, 30(2), 299-304
[42] Rajan, A., Cherian, E., & Baskar, G. (2016). Biosynthesis of zinc oxide nanoparticles using Aspergillus fumigatus JCF and its antibacterial activity. Int. J. Mod. Sci. Technol, 1(2), 52-57
[43] Hassan, S. E. D., Fouda, A., Saied, E., Farag, M. M., Eid, A. M., Barghoth, M. G., ...& Awad, M. F. (2021). Rhizopus Oryzae-mediated green synthesis of magnesium oxide nanoparticles (MgO-NPs): A promising tool for antimicrobial, mosquitocidal action, and tanning effluent treatment. Journal of Fungi, 7(5), 372
[44] AbdelRahim, K., Mahmoud, S. Y., Ali, A. M., Almaary, K. S., Mustafa, A. E. Z. M., & Husseiny, S. M. (2017). Extracellular biosynthesis of silver nanoparticles using Rhizopus stolonifer. Saudi journal of biological sciences, 24(1), 208-216
[45] Moreno-Vargas, J. M., Echeverry-Cardona, L. M., Moreno-Montoya, L. E., & Restrepo-Parra, E. (2023). Evaluation of antifungal activity of Ag nanoparticles synthetized by green chemistry against Fusarium solani and Rhizopus stolonifera. Nanomaterials, 13(3), 548
[46] Khan, N. T., Jameel, J., & Rehman, S. A. (2016). Biogenesis of silver nanoparticles using Penicillium fellutanum and determination of its antibacterial activity. Biochem Anal Biochem, 5(305), 2161-1009
[47] Deniz, F., Adıgüzel, A. O., & Mazmancı, M. A. (2019). The biosynthesis of silver nanoparticles by cytoplasmic fluid of coriolus versicolor. Turkish Journal of Engineering, 3(2), 92-96
[48] Vigneshwaran, N., Kathe, A. A., Varadarajan, P. V., Nachane, R. P., & Balasubramanya, R. H. (2006). Biomimetics of silver nanoparticles by white rot fungus, Phaenerochaete chrysosporium. Colloids and Surfaces B: Biointerfaces, 53(1), 55-59
[49] Husseiny, S. M., Salah, T. A., & Anter, H. A. (2015). Biosynthesis of size controlled silver nanoparticles by Fusarium oxysporum, their antibacterial and antitumor activities. Beni-Suef University Journal of Basic and Applied Sciences, 4(3), 225-231
[50] Husseiny, M. I., Abd El-Aziz, M., Badr, Y., & Mahmoud, M. A. (2007). Biosynthesis of gold

nanoparticles using Pseudomonas aeruginosa. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 67(3-4), 1003-1006

[51] Khan, M., Al-Hamoud, K., Liaqat, Z., Shaik, M. R., Adil, S. F., Kuniyil, M., ...& Tahir, M. N. (2020). Synthesis of au, ag, and au–ag bimetallic nanoparticles using pulicaria undulata extract and their catalytic activity for the reduction of 4-nitrophenol. Nanomaterials, 10(9), 1885

[52] Agnihotri, M., Joshi, S., Kumar, A. R., Zinjarde, S., & Kulkarni, S. (2009). Biosynthesis of gold nanoparticles by the tropical marine yeast Yarrowia lipolytica NCIM 3589. Materials Letters, 63(15), 1231-1234

[53] Bolbanabad, E. M., Ashengroph, M., & Darvishi, F. (2020). Development and evaluation of different strategies for the clean synthesis of silver nanoparticles using Yarrowia lipolytica and their antibacterial activity. Process Biochemistry, 94, 319-328

[54] Korbekandi, H., Mohseni, S., Mardani Jouneghani, R., Pourhossein, M., & Iravani, S. (2016). Biosynthesis of silver nanoparticles using Saccharomyces cerevisiae. Artificial cells, nanomedicine, and biotechnology, 44(1), 235-239

[55] Thirumurugan, A., Ramachandran, S., Tomy, N. A., Jiflin, G. J., & Rajagomathi, G. (2012). Biological synthesis of gold nanoparticles by Bacillus subtilis and evaluation of increased antimicrobial activity against clinical isolates. Korean Journal of Chemical Engineering, 29, 1761-1765

[56] Reddy, A. S., Chen, C. Y., Chen, C. C., Jean, J. S., Chen, H. R., Tseng, M. J., ... & Wang, J. C. (2010). Biological synthesis of gold and silver nanoparticles mediated by the bacteria Bacillus subtilis. Journal of nanoscience and nanotechnology, 10(10), 6567-6574

[57] Shivashankarappa, A., & Sanjay, K. R. (2020). Escherichia coli-based synthesis of cadmium sulfide nanoparticles, characterization, antimicrobial and cytotoxicity studies. Brazilian Journal of Microbiology, 51, 939-948

[58] Alsamhary, K. I. (2020). Eco-friendly synthesis of silver nanoparticles by Bacillus subtilis and their antibacterial activity. Saudi Journal of Biological Sciences, 27(8), 2185-2191

[59] Khan, W., & AS, P. (2016). Extracellular synthesis of gold nano particles from Pseudomonas stutzeri (MTCC 8362) and its antimicrobial activity. International Journal of Innovative Research in Science, Engineering and Technology, 5(9), 16482-16489

[60] Bachii, S. A., & Abd-Al Sahib, W. H. (2021). Preparation and characterization of silver nanoparticles biosynthesis by Pseudomonas stutzeri environmental bacteria isolated from oil fields and their antimicrobial activity

[61] Bai, H. J., Yang, B. S., Chai, C. J., Yang, G. E., Jia, W. L., & Yi, Z. B. (2011). Green synthesis of silver nanoparticles using Rhodobacter sphaeroides. World Journal of Microbiology and Biotechnology, 27, 2723-2728

[62] Abd-Elhady, H. M., Ashor, M. A., Hazem, A., Saleh, F. M., Selim, S., El Nahhas, N., ...& Hassan, E. A. (2021). Biosynthesis and characterization of extracellular silver nanoparticles from Streptomyces aizuneusis: antimicrobial, anti larval, and anticancer activities. Molecules, 27(1), 212

[63] Gubarev, A. S., Lezov, A. A., Mikhailova, M. E., Senchukova, A. S., Mikusheva, N. G., Sobolev, V. Y., ... & Tsvetkov, N. V. (2021). Green Synthesis of Silver Nanoparticles with the Tobacco Mosaic Virus. Reviews and Advances in Chemistry, 11(3), 189-196

[64] Love, A. J., Makarov, V. V., Sinitsyna, O. V., Shaw, J., Yaminsky, I. V., Kalinina, N. O., & Taliansky, M. E. (2015). A genetically modified tobacco mosaic virus that can produce gold nanoparticles from a metal salt precursor. Frontiers in plant science, 6, 984

[65] Abdelsattar, A. S., Gouda, S. M., Hassan, Y. Y., Farouk, W. M., Makky, S., Nasr, A., ...& El-Shibiny, A. (2022). In vitro bacteriophage-mediated synthesis of silver nanoparticles for antibacterial applications and heavy metal detection. Materials Letters, 318, 132184

[66] Ahiwale, S. S., Bankar, A. V., Tagunde, S., & Kapadnis, B. P. (2017). A bacteriophage mediated gold nanoparticles synthesis and their anti-biofilm activity. Indian journal of microbiology, 57,

188-194

[67] Annamalai, J., & Nallamuthu, T. (2015). Characterization of biosynthesized gold nanoparticles from aqueous extract of Chlorella vulgaris and their anti-pathogenic properties. Applied Nanoscience, 5, 603-607

[68] Jena, J., Pradhan, N., Nayak, R. R., Dash, B. P., Sukla, L. B., Panda, P. K., & Mishra, B. K. (2014). Microalga Scenedesmus sp.: a potential low-cost green machine for silver nanoparticle synthesis. Journal of Microbiology and Biotechnology, 24(4), 522-533

[69] Rashad, S., A El-Chaghaby, G., & A Elchaghaby, M. (2019). Antibacterial activity of silver nanoparticles biosynthesized using Spirulina platensis microalgae extract against oral pathogens. Egyptian Journal of Aquatic Biology and Fisheries, 23(5 (Special Issue)), 261-266

[70] Hamza, W. T., Taha, H. M., & Abouelkheir, S. S. (2018). Spirulina platensis synthesized gold nanoparticles (AuNPs) as an antibacterial and antioxidant agent. Egypt Soc Exp Biol, 14, 385-391

[71] Suganya, S., Dhanalakshmi, B., & Kumar, S. D. (2020). Biosynthesis and characterization of silver nanoparticles from Sargassum wightii and its antibacterial activity against multi-resistant human pathogens

[72] Suganya, S., Dhanalakshmi, B., Dinesh Kumar, S., & Santhanam, P. (2020). Cytotoxic effect of silver nanoparticles synthesized from Sargassum wightii on cervical cancer cell line. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 90, 811-818

[73] Jeevanandam, J., Kiew, S. F., Boakye-Ansah, S., Lau, S. Y., Barhoum, A., Danquah, M. K., & Rodrigues, J. (2022). Green approaches for the synthesis of metal and metal oxide nanoparticles using microbial and plant extracts. Nanoscale, 14(7), 2534-2571

[74] Mittal AK, Chisti Y, Banerjee UC. Synthesis of metallic nanoparticles using plant extracts. Biotechnol Adv 2013;31(2):346–56

[75] Khan, M., Shaik, M. R., Adil, S. F., Khan, S. T., Al-Warthan, A., Siddiqui, M. R. H., ...& Tremel, W. (2018). Plant extracts as green reductants for the synthesis of silver nanoparticles: Lessons from chemical synthesis. Dalton Transactions, 47(35), 11988-12010

[76] Nguyen, N. T. T., Nguyen, L. M., Nguyen, T. T. T., Nguyen, T. T., Nguyen, D. T. C., & Tran, T. V. (2022). Formation, antimicrobial activity, and biomedical performance of plant-based nanoparticles: a review. Environmental Chemistry Letters, 20(4), 2531-2571

[77] Malik, A. Q., Mir, T. U. G., Kumar, D., Mir, I. A., Rashid, A., Ayoub, M., & Shukla, S. (2023). A review on the green synthesis of nanoparticles, their biological applications, and photocatalytic efficiency against environmental toxins. Environmental Science and Pollution Research, 30(27), 69796-69823

[78] Jain, N., Jain, P., Rajput, D., & Patil, U. K. (2021). Green synthesized plant-based silver nanoparticles: Therapeutic prospective for anticancer and antiviral activity. Micro and Nano Systems Letters, 9(1), 5

[79] Chandra, H., Kumari, P., Bontempi, E., & Yadav, S. (2020). Medicinal plants: Treasure trove for green synthesis of metallic nanoparticles and their biomedical applications. Biocatalysis and Agricultural Biotechnology, 24, 101518

[80] Dash, S. S., Sen, I. K., & Dash, S. K. (2022). A review on the plant extract mediated green syntheses of gold nanoparticles and its anti-microbial, anti-cancer and catalytic applications. International Nano Letters, 12(1), 47-66

[81] Mostafa, E., Fayed, M. A., Radwan, R. A., & Bakr, R. O. (2019). Centaurea pumilio L. extract and nanoparticles: A candidate for healthy skin. Colloids and Surfaces B: Biointerfaces, 182, 110350

[82] Gowri, M., Latha, N., & Rajan, M. (2019). Copper oxide nanoparticles synthesized using Eupatorium odoratum, Acanthospermum hispidum leaf extracts, and its antibacterial effects against pathogens: a comparative study. BioNanoScience, 9, 545-552

[83] Kumararaja, G., Saneesha, P. N., Kumar, S. S., Parveen, V. V., Rahim, S. F. A., Shamna, K. V., ... & Gayathri, R. (2019). Development and Characterization of Silver nanoparticles (AgNPs) using

Aqueous leaves broth of Artemisia vulgaris L., and its Anti-fungal activity. Research Journal of Pharmacy and Technology, 12(10), 4822-4826
[84] El-Amier, Y. A., Abduljabbar, B. T., El-Zayat, M. M., Sarker, T. C., & Abd-ElGawad, A. M. (2023). Synthesis of Metal Nanoparticles via Pulicaria undulata and an Evaluation of Their Antimicrobial, Antioxidant, and Cytotoxic Activities. Chemistry, 5(4), 2075-2093
[85] Vani, B. K. K. (2014). Biosynthesis and characterization of silver nano particles from Acanthospermum hispidum root extract. J Adv Stud Agric Biol Environ Sci, 1, 247-253
[86] Isaac, R. R., Sakthivel, G., & Murthy, C. H. (2013). Green synthesis of gold and silver nanoparticles using Averrhoa bilimbi fruit extract. Journal of Nanotechnology, 2013(1), 906592
[87] Mendhulkar, V. D., Kharat, S. N., & Mahadik, S. R. (2018). Plant extract mediated AgNPs synthesis in Averrhoa bilimbi and Syzygium cumini leaf extract, their characterization and antioxidant potential assessment. Der Pharma Chem, 10(11), 24-33
[88] Gharari, Z., Hanachi, P., Sadeghinia, H., & Walker, T. R. (2022). Cichorium intybus bio-callus synthesized silver nanoparticles: A promising antioxidant, antibacterial and anticancer compound. International Journal of Pharmaceutics, 625, 122062
[89] Sreeharsha, N., Kathiravan, G., Rajagopal, K., Rajasekar, A., Rajangam, B., Aldhubiab, B. E., ...& Tratrat, C. (2020). Synthesis, characterization, and biological activity of silver nanoparticles synthesized from Aristolochia bracteolata lam. Pharmacognosy Magazine, 16(71)
[90] Priya, D. D., & Prakash, J. T. J. (2020). Green Synthesis and Characterization of Zinc Oxide Nanoparticles using Leaves Extract of Aristolochia Bracteolate and its Antimicrobial Activities. 8(1)
[91] Sivaramakrishnan, M., Jagadeesan Sharavanan, V., Karaiyagowder Govindarajan, D., Meganathan, Y., Devaraj, B. S., Natesan, S., ... & Kandaswamy, K. (2019). Green synthesized silver nanoparticles using aqueous leaf extracts of Leucas aspera exhibits antimicrobial and catalytic dye degradation properties. SN Applied Sciences, 1, 1-8
[92] Hamadneh, I., Alhayek, H., Al-Mobydeen, A., Abu Jaber, A., Albuqain, R., Alsotari, S., & Al Dujaili, A. (2019). Green synthesis and characterization of yttrium oxide, copper oxide and barium carbonate nanoparticles using Azadirachta indica (the neem tree) fruit aqueous extract. Egyptian Journal of Chemistry, 62(4), 573-581
[93] Senthilkumar, P., Rashmitha, S., Veera, P., Ignatious, C. V., SaiPriya, C., & Samrot, A. V. (2018). Antibacterial activity of neem extract and its green synthesized silver nanoparticles against Pseudomonas aeruginosa. J Pure Appl Microbiol, 12(2), 969-974
[94] Haris, Z., & Ahmad, I. (2024). Green synthesis of silver nanoparticles using Moringa oleifera and its efficacy against gram-negative bacteria targeting quorum sensing and biofilms. Journal of Umm Al-Qura University for Applied Sciences, 10(1), 156-167
[95] Nurul Aini, A., Al Farraj, D. A., Endarko, E., Rubiyanto, A., Nur, H., Al Khulaifi, M. M., ...& Syafiuddin, A. (2019). A new green method for the synthesis of silver nanoparticles and their antibacterial activities against gram-positive and gram-negative bacteria. Journal of the Chinese Chemical Society, 66(7), 705-712
[96] Khalil, M. M., Ismail, E. H., El-Baghdady, K. Z., & Mohamed, D. (2014). Green synthesis of silver nanoparticles using olive leaf extract and its antibacterial activity. Arabian Journal of chemistry, 7(6), 1131-1139
[97] Bar, H., Bhui, D. K., Sahoo, G. P., Sarkar, P., De, S. P., & Misra, A. (2009). Green synthesis of silver nanoparticles using latex of Jatropha curcas. Colloids and surfaces A: Physicochemical and engineering aspects, 339(1-3), 134-139
[98] Hudlikar, M., Joglekar, S., Dhaygude, M., & Kodam, K. (2012). Green synthesis of TiO2 nanoparticles by using aqueous extract of Jatropha curcas L. latex. Materials Letters, 75, 196-199
[99] Raja, A., Ashokkumar, S., Marthandam, R. P., Jayachandiran, J., Khatiwada, C. P., Kaviyarasu, K., ...& Swaminathan, M. (2018). Eco-friendly preparation of zinc oxide nanoparticles using

Tabernaemontana divaricata and its photocatalytic and antimicrobial activity. Journal of Photochemistry and Photobiology B: Biology, 181, 53-58
[100] Naidoo, C. M., Naidoo, Y., Dewir, Y. H., Singh, M., Daniels, A. N., & Lin, J. (2023). Biosynthesis of silver nanoparticles using Tabernaemontana ventricosa extracts. Applied Sciences, 13(14), 8395
[101] Roy, P., Das, B., Mohanty, A., & Mohapatra, S. (2017). Green synthesis of silver nanoparticles using Azadirachta indica leaf extract and its antimicrobial study. Applied Nanoscience, 7(8), 843-850
[102] Sarsar, V., Selwal, K. K., & Selwal, M. K. (2013). Green synthesis of silver nanoparticles using leaf extract of Mangifera indica and evaluation of their antimicrobial activity. J Microbiol Biotech Res, 3(5), 27-32
[103] Donga, S., Bhadu, G. R., & Chanda, S. (2020). Antimicrobial, antioxidant and anticancer activities of gold nanoparticles green synthesized using Mangifera indica seed aqueous extract. Artificial cells, nanomedicine, and biotechnology, 48(1), 1315-1325
[104] He, Y., Wei, F., Ma, Z., Zhang, H., Yang, Q., Yao, B., ...& Zhang, Q. (2017). Green synthesis of silver nanoparticles using seed extract of Alpinia katsumadai, and their antioxidant, cytotoxicity, and antibacterial activities. RSC advances, 7(63), 39842-39851
[105] Carmona, E. R., Benito, N., Plaza, T., & Recio-Sánchez, G. (2017). Green synthesis of silver nanoparticles by using leaf extracts from the endemic Buddleja globosa hope. Green Chemistry Letters and Reviews, 10(4), 250-256
[106] Chen, F., Zheng, Q., Li, X., & Xiong, J. (2022). Citrus sinensis leaf aqueous extract green-synthesized silver nanoparticles: Characterization and cytotoxicity, antioxidant, and anti-human lung carcinoma effects. Arabian Journal of Chemistry, 15(6), 103845
[107] Sujitha, M. V., & Kannan, S. (2013). Green synthesis of gold nanoparticles using Citrus fruits (Citrus limon, Citrus reticulata and Citrus sinensis) aqueous extract and its characterization. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 102, 15-23
[108] Bagherzade, G., Tavakoli, M. M., & Namaei, M. H. (2017). Green synthesis of silver nanoparticles using aqueous extract of saffron (Crocus sativus L.) wastages and its antibacterial activity against six bacteria. Asian Pacific Journal of Tropical Biomedicine, 7(3), 227-233
[109] Vijayakumar, R., Devi, V., Adavallan, K., & Saranya, D. (2011). Green synthesis and characterization of gold nanoparticles using extract of anti-tumor potent Crocus sativus. Physica E: Low-Dimensional Systems and Nanostructures, 44(3), 665-671
[110] Khane, Y., Benouis, K., Albukhaty, S., Sulaiman, G. M., Abomughaid, M. M., Al Ali, A., ...& Dizge, N. (2022). Green synthesis of silver nanoparticles using aqueous Citrus limon zest extract: Characterization and evaluation of their antioxidant and antimicrobial properties. Nanomaterials, 12(12), 2013
[111] Alkhulaifi, M. M., Alshehri, J. H., Alwehaibi, M. A., Awad, M. A., Al-Enazi, N. M., Aldosari, N. S., ... & Abdel-Raouf, N. (2020). Green synthesis of silver nanoparticles using Citrus limon peels and evaluation of their antibacterial and cytotoxic properties. Saudi Journal of Biological Sciences, 27(12), 3434-3441
[112] Dutta, T., Ghosh, N. N., Das, M., Adhikary, R., Mandal, V., & Chattopadhyay, A. P. (2020). Green synthesis of antibacterial and antifungal silver nanoparticles using Citrus limetta peel extract: Experimental and theoretical studies. Journal of Environmental Chemical Engineering, 8(4), 104019
[113] Fareed, N., Nisa, S., Bibi, Y., Fareed, A., Ahmed, W., Sabir, M., ...& Qayyum, A. (2023). Green synthesized silver nanoparticles using carrot extract exhibited strong antibacterial activity against multidrug resistant bacteria. Journal of King Saud University-Science, 35(2), 102477
[114] Ali, Z. A., Yahya, R., Sekaran, S. D., & Puteh, R. (2016). Green synthesis of silver nanoparticles using apple extract and its antibacterial properties. Advances in Materials Science and Engineering, 2016(1), 4102196

[115] Fatimah, I., & Aftrid, Z. H. V. I. (2019). Characteristics and antibacterial activity of green synthesized silver nanoparticles using red spinach (Amaranthus Tricolor L.) leaf extract. Green Chemistry Letters and Reviews, 12(1), 25-30
[116] Shejawal, K. P., Randive, D. S., Bhinge, S. D., Bhutkar, M. A., Todkar, S. S., Mulla, A. S., & Jadhav, N. R. (2021). Green synthesis of silver, iron and gold nanoparticles of lycopene extracted from tomato: their characterization and cytotoxicity against COLO320DM, HT29 and Hella cell. Journal of Materials Science: Materials in Medicine, 32, 1-12
[117] Philip, D. (2010). Green synthesis of gold and silver nanoparticles using Hibiscus rosa sinensis. Physica E: Low-Dimensional Systems and Nanostructures, 42(5), 1417-1424
[118] Devi, R. S., & Gayathri, R. (2014). Green synthesis of zinc oxide nanoparticles by using Hibiscus rosa-sinensis. Int. J. Curr. Eng. Technol, 4(4), 2444-2446
[119] Yadi, M., Azizi, M., Dianat-Moghadam, H., Akbarzadeh, A., Abyadeh, M., & Milani, M. (2022). Antibacterial activity of green gold and silver nanoparticles using ginger root extract. Bioprocess and Biosystems Engineering, 45(12), 1905-1917
[120] Hu, D., Gao, T., Kong, X., Ma, N., Fu, J., Meng, L., ...& Latif, S. (2022). Ginger (Zingiber officinale) extract mediated green synthesis of silver nanoparticles and evaluation of their antioxidant activity and potential catalytic reduction activities with Direct Blue 15 or Direct Orange 26. Plos one, 17(8), e0271408
[121] Lam, S. S., & Chase, H. A. (2012). A review on waste to energy processes using microwave pyrolysis. Energies, 5(10), 4209-4232
[122] Dahal, N., Garcia, S., Zhou, J., & Humphrey, S. M. (2012). Beneficial effects of microwave-assisted heating versus conventional heating in noble metal nanoparticle synthesis. ACS nano, 6(11), 9433-9446
[123] Gerbec, J. A., Magana, D., Washington, A., & Strouse, G. F. (2005). Microwave-enhanced reaction rates for nanoparticle synthesis. Journal of the American Chemical Society, 127(45), 15791-15800
[124] Nadagouda, M. N., Speth, T. F., & Varma, R. S. (2011). Microwave-assisted green synthesis of silver nanostructures. Accounts of Chemical Research, 44(7), 469-478
[125] Chin, C. D. W., Treadwell, L. J., & Wiley, J. B. (2021). Microwave synthetic routes for shape-controlled catalyst nanoparticles and nanocomposites. Molecules, 26(12), 3647
[126] Horikoshi, S., Schiffmann, R. F., Fukushima, J., & Serpone, N. (2018). Microwave chemical and materials processing. Microwave Chemical and Materials Processing, 33-45
[127] Čáp, I., Čápová, K., Smetana, M., & Borik, Š. (2021). Electromagnetic waves. Electromagnetic and Acoustic Waves in Bioengineering Applications, 97
[128] Schmidt, R., Prado-Gonjal, J., & Morán, E. (2022). Microwave assisted hydrothermal synthesis of nanoparticles. arXiv preprint arXiv:2203.02394
[129] Elmahaishi, M. F., Ismail, I., & Muhammad, F. D. (2022). A review on electromagnetic microwave absorption properties: their materials and performance. Journal of Materials Research and Technology, 20, 2188-2220
[130] Raghunandan D, Basavaraja S, Mahesh B, Balaji S, Manjunath SY, Venkartaraman A. Biosynthesis of stable polyshaped gold nanoparticles from microwave-exposed aqueous extracellular anti-malignant Guava (Psidium guajava) leaf extract. NanoBiotechnology 2009;5:34–41. https://doi.org/10.1007/s12030-009-9030-8
[131] Manikprabhu D, Lingappa K. Microwave assisted rapid and green synthesis of silver nanoparticles using a pigment produced by Streptomyces coelicolor klmp3. BioinorgChem Appl 2013;1–5
[132] Hasanpoor M, Aliofkhazraei M, Delavari H. Microwave-assisted synthesis of zinc oxide nanoparticles. Procedia Mater Sci 2015;11:320–5, http://creativecommons.org/licenses/by-nc-nd/4.0/
[133] Anand, G. T., Sundaram, S. J., Kanimozhi, K., Nithiyavathi, R., & Kaviyarasu, K. (2021).

Microwave assisted green synthesis of CuO nanoparticles for environmental applications. Materials Today: Proceedings, 36, 427-434
[134] Parveen, M., Ahmad, F., Malla, A. M., & Azaz, S. (2016). Microwave-assisted green synthesis of silver nanoparticles from Fraxinus excelsior leaf extract and its antioxidant assay. Applied Nanoscience, 6, 267-276
[135] Korkmaz, N., & Karadağ, A. (2021). Microwave assisted green synthesis of Ag, Ag2O, and Ag2O3 nanoparticles. Journal of the Turkish Chemical Society Section A: Chemistry, 8(2), 585-592
[136] Kumar, B. (2021). Green synthesis of gold, silver, and iron nanoparticles for the degradation of organic pollutants in wastewater. Journal of Composites Science, 5(8), 219
[137] Patel, A. K., Gupta, D., Singh, A., Mishra, V. K., & Sharma, N. K. (2021). Green-synthesized nanoparticles for treatment of wastewater: an environmentally sustainable pollution remediation technology. In Sustainable Environmental Clean-up (pp. 29-70). Elsevier
[138] Virmani, K., Deepak, C., Sharma, S., Chadha, U., & Selvaraj, S. K. (2021). Nanomaterials for automotive outer panel components: a review. The European Physical Journal Plus, 136(9), 921
[139] Mishra, R., Militky, J., Baheti, V., Huang, J., Kale, B., Venkataraman, M., ...& Wang, Y. (2014). The production, characterization and applications of nanoparticles in the textile industry. Textile Progress, 46(2), 133-226
[140] Shah, M. A., Pirzada, B. M., Price, G., Shibiru, A. L., & Qurashi, A. (2022). Applications of nanotechnology in smart textile industry: A critical review. Journal of Advanced Research, 38, 55-75
[141] Cao, Z., & Dobrynin, A. V. (2016). Nanoparticles as adhesives for soft polymeric materials. Macromolecules, 49(9), 3586-3592
[142] Liu, Z., & Yan, F. (2022). Switchable adhesion: on-demand bonding and debonding. Advanced Science, 9(12), 2200264
[143] Bauer, C., Buchgeister, J., Hischier, R., Poganietz, W. R., Schebek, L., & Warsen, J. (2008). Towards a framework for life cycle thinking in the assessment of nanotechnology. Journal of Cleaner Production, 16(8-9), 910-926
[144] Guduru, R. K., Dixit, U., Bhagat, B., & Mukherjee, K. (2024). Nanoceramics: surfaces and coatings for consumer goods. In Industrial Applications of Nanoceramics (pp. 209-246). Elsevier
[145] Radwan, I. M., Potter, P. M., Dionysiou, D. D., & Al-Abed, S. R. (2021). Silver nanoparticle interactions with surfactant-based household surface cleaners. Environmental engineering science, 38(6), 481-488
[146] Fathy, R. M., Salem, M. S. E. D., & Mahfouz, A. Y. (2020). Biogenic synthesis of silver nanoparticles using Gliocladium deliquescens and their application as household sponge disinfectant. Biological trace element research, 196, 662-678
[147] Salata OV. Application of nanoparticles in biology and medicine. J Nanobiotechnol 2004;2:3
[148] Haleem, A., Javaid, M., Singh, R. P., Rab, S., & Suman, R. (2023). Applications of nanotechnology in medical field: a brief review. Global Health Journal, 7(2), 70-77
[149] Haes AJ, Van DRP. A highly sensitive and selective surface-enhanced nanobiosensor. Mater Res Soc Symp Proc 2002;723:1–6
[150] Abbasi E, Milani M, Aval SF, Kouhi M, Akbarzadeh A, Nasrabadi HT, Nikasa P, Joo SW, Hanifehpour Y, Koshki KN, Samiei M. Silver nanoparticles: synthesis methods,bioapplications and properties. Crit Rev Microbiol 2016;42(2):173–80. https://doi. org/10.3109/1040841X.2014.912200
[151] He L, Liu Y, Mustapha A, Lin M. Antifungal activity of zinc oxide nanoparticlesagainst Botrytis cinerea and Penicillium expansum. Microbiol Res 2010;https://doi.org/10.1016/j.micres.2010.03.003
[152] Ravikumar S, Gokulkrishnan R, Boomi P. In vitro antibacterial activity of the metal oxide nanoparticles against urinary tract infectious bacterial pathogens. Asian Pac J TropDis

2012;28:85–9
[153] Ravishankar B, Raghunandan D, Sharanabasava VG, Do SH, Venkataraman A. Photoirradiated biosynthesis of silver nanoparticles using edible mushroom Pleurotus florida and their antibacterial activity studies. Bioinorg Chem Appl 2011;1–7
[154] Baranwal A, Srivastava A, Kumar P, Bajpai VK, Maurya PK, Chandra P. Prospects of nanostructure materials and their composites as antimicrobial agents. Front Microbio 2018;9. https://doi.org/10.3389/fmicb.2018.00422
[155] Nadeem M, Abbasi BH, Younas M, Ahmad W, Khan T. A review of the green syntheses and anti-microbial applications of gold nanoparticles. Green Chem Lett Rev 2017;10(4):216–27. https://doi.org/10.1080/17518253.2017.1349192
[156] Leong, H. S., Butler, K. S., Brinker, C. J., Azzawi, M., Conlan, S., Dufès, C., ...& Pastore, C. (2019). On the issue of transparency and reproducibility in nanomedicine. Nature nanotechnology, 14(7), 629-635
[157] Desai, N. (2012). Challenges in development of nanoparticle-based therapeutics. The AAPS journal, 14(2), 282-295
[158] Stavis, S. M., Fagan, J. A., Stopa, M., & Liddle, J. A. (2018). Nanoparticle manufacturing–heterogeneity through processes to products. ACS Applied Nano Materials, 1(9), 4358-4385
[159] Ameen, F., Alsamhary, K., Alabdullatif, J. A., & ALNadhari, S. (2021). A review on metal-based nanoparticles and their toxicity to beneficial soil bacteria and fungi. Ecotoxicology and Environmental Safety, 213, 112027.