Nano World Journal

https://doi.org/10.17756/nwj.2022-s1-027

Review Article

Open Access

Biogenic Synthesis of Metallic Nanomaterials and its Antimicrobial and Cytotoxic Potential: A Review

Rakhi Giri, Deepika Sharma, and Lalita Ledwani*

Manipal University Jaipur, Rajasthan, India

***Correspondence to:**
Lalita Ledwani
Manipal University Jaipur, Rajasthan, India
E-mail: lalita.ledwani@jaipur.manipal.edu; lalitaledwani@gmail.com

Received: August 23, 2022
Accepted: November 04, 2022
Published: November 06, 2022

Citation: Giri R, Sharma D, Ledwani L. 2022. Biogenic Synthesis of Metallic Nanomaterials and its Antimicrobial and Cytotoxic Potential: A Review. *Nano World J* 8(S1): S168-S175.

Copyright: © 2022. Giri et al. This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY) (http:// creativecommons.org/licenses/by/4.0/) which permits commercial use, including reproduction, adaptation, anddistribution of the article provided the original author and source are credited.

Published by United Scientific Group

Abstract

Nanotechnology is a speedily rising domain. Nanotechnology and biomedical sciences empower an assorted scope of biological study issues and medical applications at the molecular and cellular levels. The synthesis of bio-inspired nanoparticles (NPs) has expanded the fame in the biomedical field in recent years due to numerous benefits, including easiness, cost-viability, stability, less time requirement, non-toxic by-products, eco-friendliness, and the potential to scale up for large-scale synthesis. As a result, bio-inspired synthesis is seen as a significant tool to diminish the disastrous impacts of conventional approaches for synthesizing NPs, which are regularly used in research centers and industry. Synthesis of bio-inspired NPs using microorganisms and plant extract has been thoroughly studied involving fungi, bacteria, and algae. Bio-inspired metal and metal oxide nanoparticles (MNPs and MONPs) have been used for tumor detection, angiogenesis, diagnosis of genetic disease and genetic disorders, photo imaging and photothermal therapy, cancer therapy, hyperthermia, drug delivery, tissue repair, etc. They have also been used for antimicrobial functions along with its anti-cancer, anti-inflammatory, and wound therapy applications. This review was focused on an overview of bio-inspired NPs, synthesis, type of bio-inspired NPs and application of antimicrobial, antifungal, anticancer, antibiotic, anti-allergic and antioxidant, and advantages of bio-inspired nanoparticles.

Keywords

Antimicrobial, Biomedical, Microorganisms

Introduction

Nanotechnology is one of the most rapidly developing fields, with applications in a wide range of biomedical sciences. The NPs act as building blocks, which can assume a significant function in nanotechnology due to their distinct properties when compared with their bulk properties. Nanotechnology has been used to make various forms of nanomaterials, including tubes, wires, and particles used in different fields [1]. Top-down and bottom-up approaches are generally used to create NPs with dimensions less than 100 nm. In "top-down" production, the bulk material is fractured down into nanoscale structures or particles. "Bottom-up" refers to the formation of a nanomaterial through self-assembly in atomic form, molecule by molecule or group by group [2]. Figure 1 below illustrates the various methods of NPs synthesis. There are number of physicochemical and biological methods used in earlier studies to create different types of nanoparticles with different morphology, size, and shape. These procedures are usually expensive and involve hazardous chemicals, these toxins are absorbed on the surface of NPs due to undesirable properties.

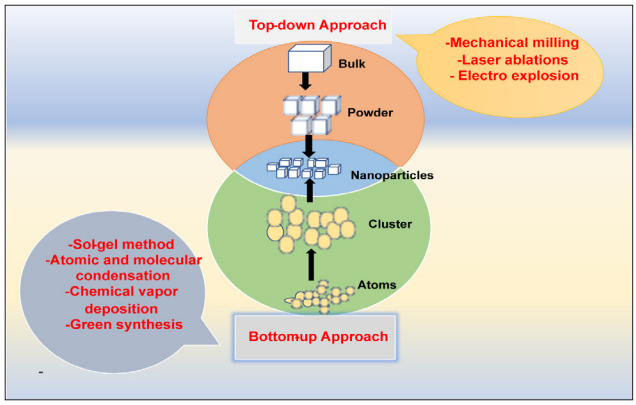

Figure 1: Different nanoparticles synthesis approaches.

These processes utilize high temperatures, apply radiations, incorporate poisonous synthetic compounds, including the age of risky side-effects, and need a specific device, and consumption. By these issues, biological systems have arisen as a viable alternative because of its cost-effective, green biocompatibility, and environmental-friendly approaches. Interestingly, the characteristics of NPs synthesized in various ways were discovered to be significantly diverse, making these routes even more powerful. Their synthesis has been discovered to be very simple and inexpensive[3,4]. These do not necessitate the technical skills of laboratory personnel with modern equipment. Furthermore, these are considerably faster in terms of output and can be done even at grass-roots levels, ranging from the vegetables we consume to the plants we grow to the microorganisms we appreciate for their genetic diversity. The advantage of bioinspired nanoparticles was shown in Figure 2[5]. MNPs, MONPs, and magnetic NPs are the three main types of NPs. In recent years, there has been an increasing attention in using these nanostructures in specialized biomedical applications such as focused drug administration hyperthermia, photoablation treatment, bioimaging, and biosensors [6,7]. This review was focused on an overview of bio-inspired NPs, synthesis, type of bio-inspired NPs and application of antimicrobial, antifungal, anticancer, antibiotic, anti-allergic and antioxidant, and advantages of bio-inspired NPs.

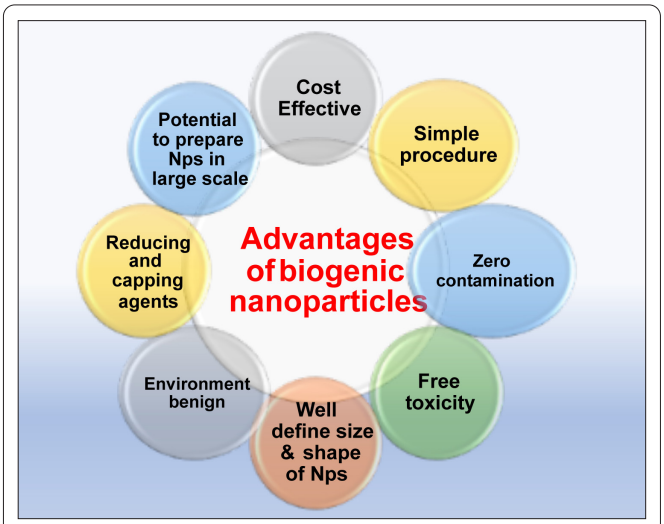

Figure 2: Advantages of bioinspired nanoparticles.

Synthesis of Bio-inspired Nanoparticles

Nanoparticles Synthesis by Plants

Green NPs are synthesized in a single-step biosynthesis process. Use of plants in the synthesis of NPs is more interested than the conventional process because plant sources are free from toxicants, contain natural capping agents, and also allow a higher yield of products with better-defined characteristics. Numerous plant parts such as leaves, roots, stems, flowers, etc. are used for the preparation of NPs. Extract from a plant may act as both capping and reducing agents. It has been achieved that plants and bioactive compounds from their extract, for example, polyphones, phenolic acids or proteins, sugars, terpenoids, and alkaloids act as reducing and capping agents in the synthesis of nanoparticles [5,8]. Properties of phytochemicals present in plants can influence the size, morphology, and shape of NPs. Following three-phases are integrated for nanomaterials synthesis using plants: (1) the biocompatible and nontoxic dissolvable medium, (2) environmentally benign reducing agents, and (3) non-harmful substances for adjustment of the NPs. In the formation of NPs using plant extracts, the extract is mixed at continuous stirring with a solution of metal solution; the NPs were obtained within a time. It depends on various parameters such as the relative concentrations of plant extract, nature of plant extract, pH, temperature, and time of reaction, as well as the rate of mixing of plant extract and metal salt(s).[6]

Bio-inspired synthesis of NPs is useful because of its reduced environmental impact in comparison to other physicochemical techniques, in addition it tends to be utilized to deliver huge amounts of nanoparticles that are free of adulteration and have a clear size and morphology (Figure 3).

Nanoparticles Synthesis by Microorganisms

The use of microorganisms as nano factories has received much attention recently because of their eco-friendliness and affordability. During their metabolic reactions, microbes go through a wide range of processes to metabolize nutrients, grow, and release energy. Several microorganisms including bacteria, fungi, yeast, and algae have been extensively researched to synthesize NPs on both extracellular and intracellular ways. NPs are synthesized using extracellular methods since they can avoid the downstream processing steps typically involved in intracellular techniques such as sonication to break down the cell wall and centrifugation As reducing agents, a variety of other factors, such as metal-resistant genes, proteins, peptides, enzymes, reducing cofactors, and organic materials, also play a significant role.

The process of extracellular synthesis involves culturing the microorganisms in a rotating shaker under optimum growth conditions, followed by centrifugation to obtain the biomass. The supernatant from centrifugation is then mixed with a metal salt solution to synthesize NPs of metal ions. An apparent color change in the reaction mixture is the first qualitative sign of NPs formation. By high-speed centrifugation,

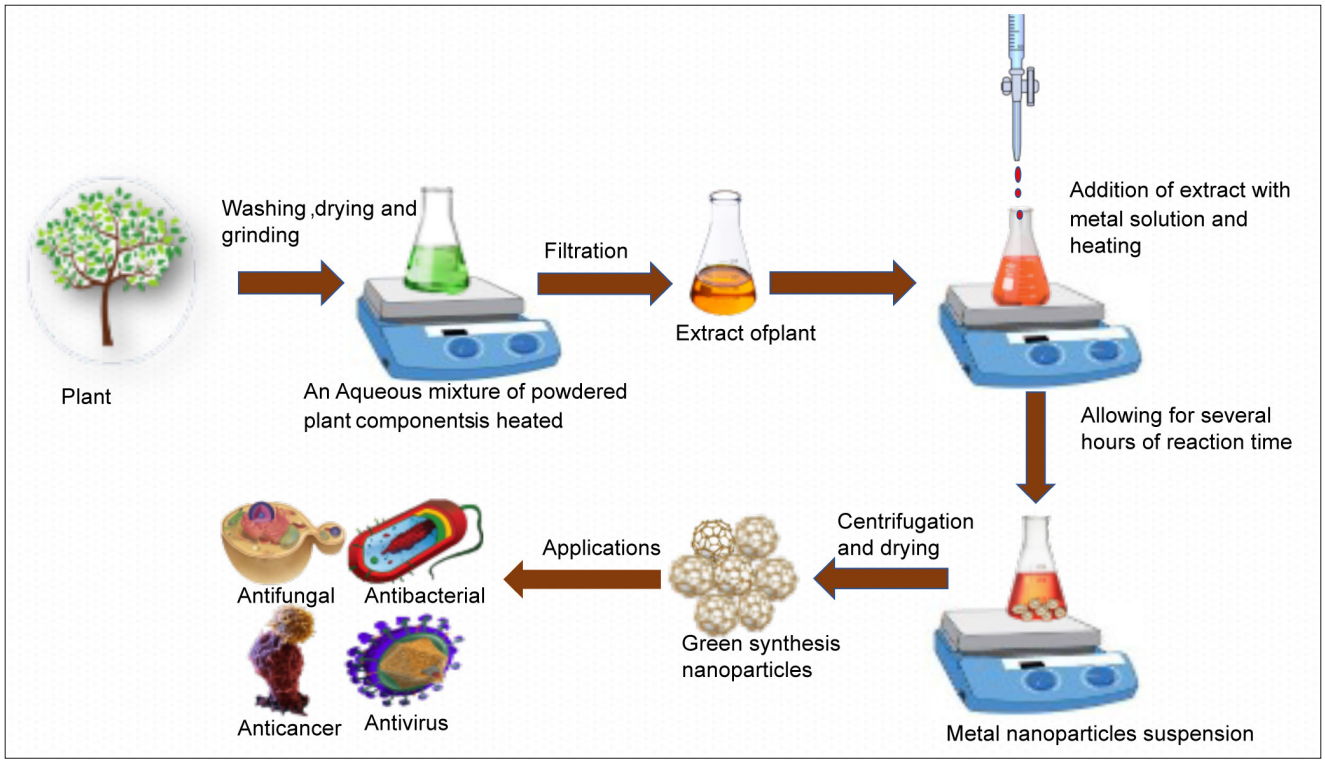

Figure 3: Nanoparticles synthesis by plants.

the NPs are separated from the colloid, washed thoroughly in water/solvent (ethanol/methanol), and then collected as bottom pellets: Figure 4 shows the NPs synthesize by extracellular.

For the intracellular synthesis of NPs, the microbes must be cultivated under optimal growth conditions before the biomass can be harvested. After thorough washing the biomass with sterile water, it is incubated with a metal ion solution. Once NPs are formed, a color change is visible. Following the incubation phase, the biomass is treated with ultrasonication, washing, and centrifugation, which releases the NPs once the cell wall has been broken down. A final step involves washing, centrifuging, and collecting the released NPs. Figure 5 shows the details process of synthesis of NPs by intracellular.

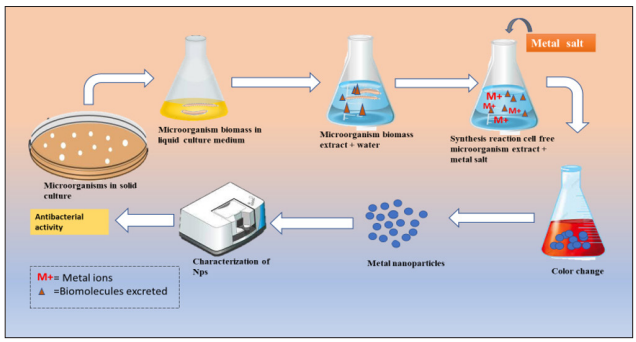

Figure 4: Extracellular synthesis of nanoparticles.

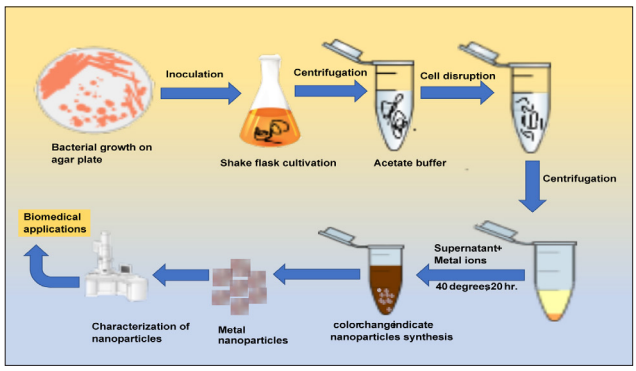

Figure 5: Intracellular synthesis of nanoparticles.

Type of Bio-inspired Nanoparticles and their Biomedical Applications

This section aims to classify NPs according to their nano systems. Figure 6 illustrates the three different types of NPs: MNPs, MONPs, and magnetic NPs. MNPs such as gold (Au), silver (Ag), iron (Fe), titanium (Ti), copper (Cu), and zinc (Zn) are commonly used in biomedical applications. MNPs are of various types and have novel properties that can be effectively changed. Depending on the electronic structure, the metal

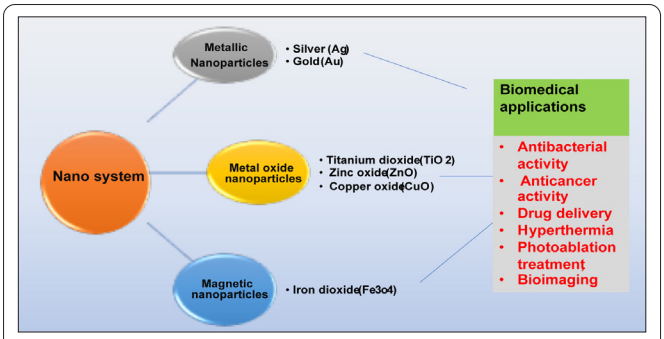

Figure 6: Type of bioinspired nanoparticles and their biomedical application.

Table 1: Plant mediated Nanomaterials and their biomedical applications.

Plant Name	Common name	Plant part used	Size (nm)	Morphology	Biomedical Application	References
Silver Nanoparticles (AgNps)						
Allium cepa	Garden onion	Onion (bulb)	33.6	Spherical	Antifungal	[12]
Allium sativum	Garlic	Leaf	4 - 22	Spherical	Antimicrobial	[13]
Alstonia scholaris	Blackboard tree	Bark	50	Spherical	Antibacterial	[14]
Andrographis paniculata	Green Chiretta	Leaf	67 - 58	Spherical	Hepatocurial activity	[15]
Musa paradisiaca	Banana	Peel	23.7	Spherical	Antibacterial	[16]
Ficus benghalens	Indian Banyan	Leaf	16	Spherical	Antibacterial	[17]
Gelsemium sempervirens		Whole plant	112	Spherical	Cytotoxicity	[18]
Hemidesmus indicus	Anantmool	Root	20 - 30	Cubic, and hexagonal	Antimicrobial	[19]
Lycopersicon esculentum	Tomato	Fruit	13 - 20	Triangular, and Hexagonal	Antioxidant	[20]
Memecylon edule	Kaayam	Leaf	10 - I 2.5	Spheres	Antibacterial	[21]
Mentha piperita	Peppermint	blower	2 - 10	Triangular, and Hexagonal	Antimicrobial	[22]
Momordica cymbalaria	Kakrol	Fruit	30 - 35	Cubic, Hexagonal, and Crystalline	Cytotoxicity, Antioxidant, and Antimicrobial	[23]
Nelumbo nucifera	Lotus	Whole plant	20	Triangular,Circular, and Hexagonal	Antioxidant	[24]
Plukenetia volubilis	Sacha inchi,	Leaf	30 - 50	Spherical	Antimicrobial	[24]
Potentilla fulgens	Himalayan Cinquefoil	Root		Spherical	Anticancer	[25]
Rheum emodi	Amlavetasa	Root	27 - 30	Spherical	Antimicrobial, and Anticancer	[26, 27]
Rosa indica	Cyme Rose	Petals	25 - 40	Spherical	Antimicrobial, Anticancer, and Antiinlammatory	[28]
Sinapis arvensis	Charlock mustard	Seed	10 - 20	Spherical	Antioxidant	[29]
Swietenia mahogani	Cuban mahogany	Leaf	5 - 20	Spherical	Antimicrobial	[30]
Thuja occidentalis	Northern white-cedar	Whole plant	15 - 70	Spherical	Antimicrobial	[18]
Gold Nanoparticles (AuNPs)						
Acorus calamic	Sweet Flag	Roots	15 - 20	Spherical	Antibacterial and UV blocking	[31]
Allium cepa	Onion	Fruit	100	Spherical and Cubic	Anticancer	[32]
Annona muricata	Custard Apple	Leaf	25.5	Spherical	Antimicrobial	[33]
Chrysan themum	Indian Chrysanthemum	Whole plant	20 - 100	Spherical	Antioxidant	[34]
Cinnamomum zeylanicum	Cinnamon	Leaf	7 - 20	Spherical	Antimicrobial	[35]
Crinum latifolium	Milk and wine lily	Leaf	17.6 nm	Spherical	Antimicrobial	[36]
Galaxaura elongata	Red algae	Leaf	3.85 - 77.13	Rod, Triangular, and Hexagonal	Antibacterial	[37]
Garcinia mangos tana	Mangosteen	Fruit	32.96 ± 5.25	Spherical, Hexagonal, and Triangular	Biomedical	[38]
Gymnocladus assamicus	Coffee tree	Leaf	4 - 22	Triangular, and Pentagonal, Hexagonal	Catalytic	[39]
Lansium domesticum	Langsat	Fruit	<100	Spherical	Antimicrobial	[40]
Magnolia kobus	Kobus magnolia,	Leaf	20 - 60	Face Centred Cubic	Catalytic	[41]
Mirabilis jalapa	Four o'clock flowe	Flower	100	Spherical	Antibacterical	[42]
Morinda citrifolia	Indian mulberry	Root	5 - 10	Spherical	Antimicrobial	[43]
Moringa oleifera	Drumstick tree	Leaf	10 - 40	Spherical	Antimicrobial	[44]
Musa paradisiaca	Banana	Peel	50	Spherical, triangular	Antibacterial and Anticancer	[45]
Nepenthes khasiana	Pitcher plant	Leaf	50 - 80	Triangular and Spherical	Antimicrobial	[46]
Salix alba	White willow	Leaves	50 - 80	Spherical	Antifungal	[47]
Terminalia arjuna	Argun kahua	Leaf	15 - 30	Spherical	Antimicrobial	[48]

Magnetic Nanoparticles						
Lawsonia inermis	Heena	Leaf	21 - 32	Shattered rock like	Antibacterial	[49]
Mangifera indica	Aam	Leaf	50 - 100	Spherical	Antibacterial	[50]
Platanus orientalis	Oriental Plane	Leaf	~34	Spherical	Antibacterial	[51]
Rheum emodi	Amlavetasa	Roots	~12	Spherical	Antibacterial, and Anticancerous	[52]
Copper Oxide Nanoparticles (CuO NPs)						
Gloriosa superba	-	Leaf	5 - 10	Spherical	Antibacterial	[53]
Gum karaya	-	Gum	4.8 - 7.8	Spherical	Antibacterial	[54]
Nerium oleander	-	Leaf	10 - 90	Spherical	Antibacterial	[55]
Tridax procumbens	Coatbuttons	Leaf	12 - 18	Spherical	Antimicrobial	[56]
Zinc Oxide Nanoparticles (ZnO NPs)						
Aloe Barbadensis	Aloe Vera	Latex	5 - 50	Spherical	Antimicrobial	[57]
Artocarpus gomezianus	Sampang'	Fruit	20 - 40	Spherical	Anti-larvicidal	[58]
Physalis alkekengi	Bladder cherry	Leaf	12 - 15	Spheres	Antimicrobial	[59]
Ruta graveolens	Herb-of-grace	Stem	28	Spherical	Antibacterial, and Antioxidant	[60]
Solanum nigrum	Blackberry nightshade	Leaf	4 - 10	Spherical	Catalytic	[61]
Titanium Dioxide Nanoparticles (TiO_2 NPs)						
Azadirachta indica	Neem	Leaf	124	Spherical	Photocatalytic	[62]
Psidium guajava	Lemon guava	Leaf	12 - 15	Spherical	Antibacterial, and Antioxidant	[63]
Rheum emodi	Amlavetasa	Roots	45	Spherical	Cytotoxic	[64]

can form into the metallic, semiconductor, and insulators. MONPs are composed of titanium dioxide (TiO_2), silicon dioxide (SiO_2), and zinc oxide (ZnO) Among the components, magnetic NPs are Fe_xO_y, in addition to their unique properties, these nanoparticles are the most studied since they have many potential applications in biomedical.

MNPs adaptability may be customised based on their size, shape, and purpose. The synthesis of MNPs and MONPs with different chemical functional groups permits them to be formed with antibodies, ligands, and drugs of interest and consequently opens a wide scope of possible applications in biotechnology, magnetic separation pre-concentration of target investigations, targeted drug delivery, and vehicles for gene and drug delivery and more importantly diagnostic imaging[3,9]. The antibacterial estimation of MNPs and MONPs has been performed against different strains of Gram-positive and Gram-negative organisms. The antibacterial activity depends on the pH, size, distribution, and accumulation of NPs and displays dose- and time-dependent effectiveness. Detail of some of the prominent biosynthesised MNPs and MONPs was as follows:

AgNPs exhibit distinctive physical, chemical, and biological properties, in contrast to Ag macroparticles. Prominent properties of AgNPs have been of great interest in diverse areas such as biological and biomedical applications. Along with high electrical conductance, thermal conductance, chemically stability, and catalytical activity; AgNPs exhibit antibacterial, antifungal, antiviral, and anti-inflammatory properties. Among the other metals, AuNps have mostly been studied for their astonishing biocompatibility and exceptional properties. These properties have been widely utilized in different applications for e.g. drug conveyance, and mostly in antimicrobial activity. Based on super magnetic and high properties, the FeNPs are represented as special class of metal oxides. Their shape, size, and magnetic nature enable them to reduce both the Gram-negative and Gram-positive bacteria colonization. Utilization of magnetic field, bringing about an expansion of the restorative antimicrobial properties, particularly when compare with traditional antimicrobial compounds.

In MONPs includes Zn, Cu, magnesium (Mg), TiO_2. MONPs have been widely utilized in against different bacterial microorganisms. Favourable position of MONPs, for example, high dependability, simple assembly of the ideal size, shape and porosity, no expanding varieties, simple consolidation into hydrophobic and hydrophilic frameworks, and simple functionalization by different particles due to the negative charge of the surface, all of which make them a promising apparatus for biomedical application.[10] Synthesis of ZnO NPs by plant extract is used in many catalytic procedures due to the greater surface area and high catalytic activity. Optoelectronics, nanolayers, solar cells, gas sensors, coatings, and paints and health related applications are various applications of ZNPs [11]. Depending on the size and presence of light, ZNPs have wide scope in antibacterial activity. TiO_2NPs is another inorganic metal oxide that is extensively used in biomedical applications, due to its antimicrobial, photo catalytic properties. It

is widely used in cosmetics, solar cells, electrochemical, pollution control, and antibacterial coatings [10]. CuO NPs are related to Cu salt family and exhibit a variety of potentially beneficial physical features such as electron correlation effects, spin dynamics, and high temperature superconductivity.

Table 1 summarises a sizable number of research studies addressing the production of MNPs employing plants. The table lists the key results in relation to the plant's name, size, form, and pharmacological uses.

Conclusion

The metal-based bio-inspired NPs are being substantially used in biomedical applications. In the current manuscript, the overview of bio-inspired, synthesis process advantage of bio-inspired NPs and main features of metal and metal oxide are used pharmaceutical applications e.g. as antibacterial, antifungal, antiviral, antimicrobial, anti-cancer, and anti-inflammatory agents is presented. These NPs have been widely considered as alternative over conventional antibiotics to overcome bacterial resistance because of their distinct antimicrobial activity against Gram-positive and Gram-negative bacteria. NPs work differently from the traditional way of treatments; they not only develop antibiotic resistance, but also weakened multiple biomolecules which affect the resistant strains.

References

1. Huang J, Lin L, Sun D, Chen H, Yang D, et al. 2015. Bio-inspired synthesis of metal nanomaterials and applications. *Chem Soc Rev* 44(17): 6330-6374. https://doi.org/10.1039/C5CS00133A
2. Khezerlou A, Alizadeh-Sani M, Azizi-Lalabadi M, Ehsani A. 2018. Nanoparticles and their antimicrobial properties against pathogens including bacteria, fungi, parasites and viruses. *Microb Pathog* 123: 505-526. https://doi.org/10.1016/j.micpath.2018.08.008
3. Kuppusamy P, Yusoff MM, Maniam GP, Govindan N. 2016. Biosynthesis of metallic nanoparticles using plant derivatives and their new avenues in pharmacological applications – an updated report. *Saudi Pharm J* 24(4): 473-484. https://doi.org/10.1016/j.jsps.2014.11.013
4. Mudshinge SR, Deore AB, Patil S, Bhalgat CM. 2011. Nanoparticles: emerging carriers for drug delivery. *Saudi Pharm J* 19(3): 129-141. https://doi.org/10.1016/j.jsps.2011.04.001
5. Ramesh P, Kokila T, Geetha D. 2015. Plant mediated green synthesis and antibacterial activity of silver nanoparticles using *Emblica officinalis* fruit extract. *Spectrochim Acta A Mol Biomol Spectrosc* 142: 339-343. https://doi.org/10.1016/j.saa.2015.01.062
6. Anderson SD, Gwenin VV, Gwenin CD. 2019. Magnetic functionalized nanoparticles for biomedical, drug delivery and imaging applications. *Nanoscale Res Lett* 14(1): 188. https://doi.org/10.1186/s11671-019-3019-6
7. Patra JK, Das G, Fraceto LF, Campos EVR, Rodriguez-Torres MDP, et al. 2018. Nano based drug delivery systems: recent developments and future prospects. *J Nanobiotechnology* 16: 71. https://doi.org/10.1186/s12951-018-0392-8
8. Chikkanna MM, Neelagund SE, Rajashekarappa KK. 2019. Green synthesis of zinc oxide nanoparticles (ZnO NPs) and their biological activity. *SN Appl Sci* 1(1): 1-10. https://doi.org/10.1007/s42452-018-0095-7
9. Seabra AB. 2017. Iron oxide magnetic nanoparticles in photodynamic therapy: a promising approach against tumor cells. In: Rai, M, Shegokar R (eds). Metal nanoparticles in pharma. Springer, Cham, pp 3-20. https://doi.org/10.1007/978-3-319-63790-7_1
10. Arya A, Kumar S, Suryavanshi A, Kain D, Vandana. 2019. Biosynthesis of metallic nanoparticles from medicinal plants: a review. *J Nanosci Tech* 5(5): 827-831. https://doi.org/10.30799/jnst.277.19050502
11. Kumar JS, Kumar SV, Rajeshkumar S. 2017. Synthesis of zinc oxide nanoparticles using plant leaf extract against urinary tract infection pathogen. *Resource-Efficient Technologies* 3(4): 459-465. https://doi.org/10.1016/j.reffit.2017.05.001
12. Saxena A, Tripathi RM, Singh RP. 2010. Biological synthesis of silver nanoparticles by using onion (*Allium cepa*) extract and their antibacterial activity. *Dig J Nanomater Biostruct* 5(2): 427-432.
13. Rastogi L, Arunachalam J. 2011. Sunlight based irradiation strategy for rapid green synthesis of highly stable silver nanoparticles using aqueous garlic *(Allium sativum)* extract and their antibacterial potential. *Mater Chem Phys* 129(1-2): 558-563. https://doi.org/10.1016/j.matchemphys.2011.04.068
14. Shetty P, Supraja N, Garud M, Prasad TNVK. 2014. Synthesis, characterization and antimicrobial activity of *Alstonia scholaris* bark-extract-mediated silver nanoparticles. *J Nanostruct Chem* 4(4): 161-170. https://doi.org/10.1007/s40097-014-0132-z
15. Panneerselvam C, Ponarulselvam S, Murugan K. 2011. Potential anti-plasmodial activity of synthesized silver nanoparticle using *Andrographis paniculata* Nees (Acanthaceae). *Arch Appl Sci Res* 3(6): 208-217.
16. Ibrahim HMM. 2015. Green synthesis and characterization of silver nanoparticles using banana peel extract and their antimicrobial activity against representative microorganisms. *J Radiat Res Appl Sci* 8(3): 265-275. https://doi.org/10.1016/j.jrras.2015.01.007
17. Saxena A, Tripathi RM, Zafar F, Singh P. 2012. Green synthesis of silver nanoparticles using aqueous solution of *Ficus benghalensis* leaf extract and characterization of their antibacterial activity. *Mater Lett* 67(1): 91-94. https://doi.org/10.1016/j.matlet.2011.09.038
18. Das S, Das J, Samadder A, Bhattacharyya SS, Das D, et al. 2012. Biosynthesized silver nanoparticles by ethanolic extracts of *Phytolacca decandra, Gelsemium sempervirens*, *Hydrastis canadensis* and *Thuja occidentalis* induce differential cytotoxicity through G2/M arrest in A375 cells. *Colloids Surf B Biointerfaces* 101: 325-336. https://doi.org/10.1016/j.colsurfb.2012.07.008
19. Latha M, Sumathi M, Manikandan R, Arumugam A, Prabhu NM. 2015. Biocatalytic and antibacterial visualization of green synthesized silver nanoparticles using *Hemidesmus indicus. Microb Pathog* 82: 43-49. https://doi.org/10.1016/j.micpath.2015.03.008
20. Maiti S, Krishnan D, Barman G, Ghosh SK, Laha JK. 2014. Antimicrobial activities of silver nanoparticles synthesized from *Lycopersicon esculentum* extract. *J Anal Sci Technol* 5(1): 40. https://doi.org/10.1186/s40543-014-0040-3
21. Elavazhagan T, Arunachalam KD. 2011. *Memecylon edule* leaf extract mediated green synthjesis of silver and gold nanoparticles. *Int J Nanomedicine* 6: 1265-1278. https://doi.org/10.2147/IJN.S18347
22. Robles-Martínez M, Patiño-Herrera R, Pérez-Vázquez FJ, Montejano-Carrizales JM, González JFC, et al. 2020. *Mentha piperita* as a natural support for silver nanoparticles: a new Anti-*Candida albicans* treatment. *Colloid Interface Sci Commun* 35: 100253. https://doi.org/10.1016/j.colcom.2020.100253
23. Swamy MK, Akhtar MS, Mohanty SK, Sinniah UR. 2015. Synthesis and characterization of silver nanoparticles using fruit extract of *Momordica cymbalaria* and assessment of their *in vitro* antimicrobial, antioxidant and cytotoxicity activities. *Spectrochim Acta A Mol Biomol Spectrosc* 151: 939-944. https://doi.org/10.1016/j.saa.2015.07.009
24. Kumar B, Smita K, Cumbal L, Debut A. 2014. Synthesis of silver nanoparticles using Sacha inchi (*Plukenetia volubilis* L.) leaf extracts. *Saudi J Biol Sci* 21(6): 605-609. https://doi.org/10.1016/j.sjbs.2014.07.004

25. Mittal AK, Tripathy D, Choudhary A, Aili PK, Chatterjee A, et al. 2015. Bio-synthesis of silver nanoparticles using *Potentilla fulgens* Wall. ex Hook. and its therapeutic evaluation as anticancer and antimicrobial agent. *Mater Sci Eng C Mater Biol Appl* 53: 120-127. https://doi.org/10.1016/j.msec.2015.04.038

26. Sharma D, Kumar N, Devki, Tiwari S, Mehrotra T, et al. 2021. Cytotoxic potential of *Rheum emodi* capped silver nanoparticles and *In silico* study of human CDK-4/6 proteins with hydroxyanthraquinones. *Journal of the Indian Chemical Society* 98(9): 100136. https://doi.org/10.1016/j.jics.2021.100136

27. Sharma D, Ledwani L, Bhatnagar N. 2015. Antimicrobial and cytotoxic potential of silver nanoparticles synthesized using *Rheum emodi* roots extract. *New Front Chem* 24(2): 121-135.

28. Manikandan R, Manikandan B, Raman T, Arunagirinathan K, Prabhu N M et al. 2015. Biosynthesis of silver nanoparticles using ethanolic petals extract of *Rosa indica* and characterization of its antibacterial, anticancer and anti-inflammatory activities. *Spectrochim Acta A Mol Biomol Spectrosc* 138: 120-129. https://doi.org/10.1016/j.saa.2014.10.043

29. Khatami M, Pourseyedi S, Khatami M, Hamidi H, Zaeifi M, et al. 2015. Synthesis of silver nanoparticles using seed exudates of *Sinapis arvensis* as a novel bioresource, and evaluation of their antifungal activity. *Bioresour Bioprocess* 2(1): 19. https://doi.org/10.1186/s40643-015-0043-y

30. Mondal S, Roy N, Laskar RA, Sk I, Basu S, et al. 2011. Biogenic synthesis of Ag, Au and bimetallic Au/Ag alloy nanoparticles using aqueous extract of mahogany (*Swietenia mahogani* JACQ.) leaves. *Colloids Surf B Biointerfaces* 82(2): 497-504. https://doi.org/10.1016/j.colsurfb.2010.10.007

31. Ganesan RM, Prabu HG. 2019. Synthesis of gold nanoparticles using herbal *Acorus calamus* rhizome extract and coating on cotton fabric for antibacterial and UV blocking applications. *Arab J Chem* 12(8): 2166-2174. https://doi.org/10.1016/j.arabjc.2014.12.017

32. Parida UK, Bindhani BK, Nayak P. 2011. Green synthesis and characterization of gold nanoparticles using onion (*Allium cepa*) extract. *World Journal of Nano Science and Engineering* 1(4): 93-98. https://doi.org/10.4236/wjnse.2011.14015

33. Folorunso A, Akintelu S, Oyebamiji AK, Ajayi S, Abiola B, et al. 2019. Biosynthesis, characterization and antimicrobial activity of gold nanoparticles from leaf extracts of *Annona muricata*. *J Nanostruct Chem* 9(2): 111-117. https://doi.org/10.1007/s40097-019-0301-1.

34. Liu Q, Liu H, Yuan Z, Wei D, Ye Y. 2012. Evaluation of antioxidant activity of chrysanthemum extracts and tea beverages by gold nanoparticles-based assay. *Colloids Surf B Biointerfaces* 92: 348-352. https://doi.org/10.1016/j.colsurfb.2011.12.007

35. Smitha SL, Philip D, Gopchandran KG. 2009. Green synthesis of gold nanoparticles using *Cinnamomum zeylanicum* leaf broth. *Spectrochim Acta A Mol Biomol Spectrosc* 74(3): 735-739. https://doi.org/10.1016/j.saa.2009.08.007

36. Vo TT, Nguyen TTN, Huynh TTT, Vo TTT, Nguyen TTN, et al. 2019. Biosynthesis of silver and gold nanoparticles using aqueous extract from *Crinum latifolium* leaf and their applications forward antibacterial effect and wastewater treatment. *J Nanomater* 2019: 8385935. https://doi.org/10.1155/2019/8385935

37. Abdel-Raouf N, Al-Enazi NM, Ibraheem IB. 2017. Green biosynthesis of gold nanoparticles using *Galaxaura elongata* and characterization of their antibacterial activity. *Arab J Chem* 10: S3029-S3039. https://doi.org/10.1016/j.arabjc.2013.11.044

38. Lee KX, Shameli K, Miyake M, Kuwano N, Bt Ahmad Khairudin NB, et al. 2016. Green synthesis of gold nanoparticles using aqueous extract of *Garcinia mangostana* fruit peels. *J Nanomater* 2016: 8489094. https://doi.org/10.1155/2016/8489094

39. Tamuly C, Hazarika M, Bordoloi M. 2013. Biosynthesis of Au nanoparticles by *Gymnocladus assamicus* and its catalytic activity. *Mater Lett* 108: 276-279. https://doi.org/10.1016/j.matlet.2013.07.020

40. Shankar S, Jaiswal L, Aparna R, Prasad R. 2014. Synthesis, characterization, in vitro biocompatibility, and antimicrobial activity of gold, silver and gold silver alloy nanoparticles prepared from *Lansium domesticum* fruit peel extract. *Mater Lett* 137: 75-78. https://doi.org/10.1016/j.matlet.2014.08.122

41. Song JY, Jang HK, Kim BS. 2009. Biological synthesis of gold nanoparticles using *Magnolia kobus* and *Diopyros kaki* leaf extracts. *Process Biochemistry* 44(10): 1133-1138. https://doi.org/10.1016/j.procbio.2009.06.005

42. Vankar PS, Bajpai D. 2010. Preparation of gold nanoparticles from *Mirabilis jalapa* flowers. *Indian J Biochem Biophys* 47(3): 157-60.

43. Sundrarajan M, Bama K, Bhavani M, Jegatheeswaran S, Ambika S, et al. 2017. Obtaining titanium dioxide nanoparticles with spherical shape and antimicrobial properties using *M. citrifolia* leaves extract by hydrothermal method. *J Photochem Photobiol B* 171: 117-124. https://doi.org/10.1016/j.jphotobiol.2017.05.003

44. Abay B, Tunç N, Rakap M. 2017. Hydrolysis of hydrazine borane for chemical hydrogen storage by highly efficient poly (N-vinyl-2-pyrrolidone)-protected rhodium nanoparticles. *NanoWorld J* 3(1): 23-28. https://doi.org/10.17756/nwj.2017-041

45. Vijayakumar S, Vaseeharan B, Malaikozhundan B, Gopi N, Ekambaram P, et al . 2017. Therapeutic effects of gold nanoparticles synthesized using *Musa paradisiaca* peel extract against multiple antibiotic resistant *Enterococcus faecalis* biofilms and human lung cancer cells (A549). *Microb Pathog* 102: 173-183. https://doi.org/10.1016/j.micpath.2016.11.029

46. Bhau BS, Ghosh S, Puri S, Borah B, Sarmah DK, et al. 2015. Green synthesis of gold nanoparticles from the leaf extract of *Nepenthes khasiana* and antimicrobial assay. *Adv Mater Lett* 6(1): 55-58. https://doi.org/10.5185/amlett.2015.5609

47. Islam NU, Jalil K, Shahid M, Rauf A, Muhammad N, et al. 2019. Green synthesis and biological activities of gold nanoparticles functionalized with *Salix alba*. *Arab J Chem* 12(8): 2914-2925. https://doi.org/10.1016/j.arabjc.2015.06.025

48. Dudhane AA, Waghmode SR, Dama LB, Mhaindarkar VP, Sonawane A, et al. 2019. Synthesis and characterization of gold nanoparticles using plant extract of *Terminalia arjuna* with antibacterial activity. *Int J Nanosci Nanotechnol* 15(2): 75-82.

49. Chauhan S, Upadhyay LSB. 2019. Biosynthesis of iron oxide nanoparticles using plant derivatives of *Lawsonia inermis* (Henna) and its surface modification for biomedical application. *Nanotechnol Environ Eng* 4(1): 8. https://doi.org/10.1007/s41204-019-0055-5

50. Dhuper S, Panda D, Nayak P. 2012. Green synthesis and characterization of zero valent iron nanoparticles from the leaf extract of *Mangifera indica*. *Nano Trends: J Nanotech App* 13(2): 16-22.

51. Devi HS, Boda MA, Shah MA, Parvee S, Wani AH. 2019. Green synthesis of iron oxide nanoparticles using *Platanus orientalis* leaf extract for antifungal activity. *Green Processing and Synthesis* 8(1): 38-45. https://doi.org/10.1515/gps-2017-0145

52. Sharma D, Ledwani L, Mehrotra T, Kumar N, Pervaiz N, et al. 2020. Biosynthesis of hematite nanoparticles using *Rheum emodi* and their antimicrobial and anticancerous effects *in vitro*. *J Photochem Photobiol B* 206: 111841. https://doi.org/10.1016/j.jphotobiol.2020.111841

53. Naika HR, Lingaraju K, Manjunath K, Kumar D, Nagaraju G, et al. 2015. Green synthesis of CuO nanoparticles using *Gloriosa superba* L. extract and their antibacterial activity. *J Taibah Univ Sci* 9(1): 7-12. https://doi.org/10.1016/j.jtusci.2014.04.006

54. Padil VVT, Černík M. 2013. Green synthesis of copper oxide nanoparticles using gum karaya as a biotemplate and their antibacterial application. *Int J Nanomedicine* 8: 889-898. https://doi.org/10.2147/IJN.S40599

55. Gopinath M, Subbaiya R, Selvam MM, Suresh D. 2014. Synthesis of copper nanoparticles from *Nerium oleander* leaf aqueous extract and its antibacterial activity. *Int J Curr Microbiol App Sci* 3(9): 814-818.

56. Karthika T, Thirunavukkarasu A, Ramesh S. 2010. Biosorption of cop-

per from aqueous solutions using *Tridax procumbens*. *Recent Research in Science and Technology* 2(3): 86-91.

57. Sangeetha G, Rajeshwari S,Venckatesh R. 2011. Green synthesis of zinc oxide nanoparticles by *aloe barbadensis* miller leaf extract: structure and optical properties. *Mater Res Bull* 46(12): 2560-2566. https://doi.org/10.1016/j.materresbull.2011.07.046
58. Suresh D, Shobharani R, Nethravathi P, Kumar MP, Nagabhushana H, et al. 2015. *Artocarpus gomezianus* aided green synthesis of ZnO nanoparticles: luminescence, photocatalytic and antioxidant properties. *Spectrochim Acta A Mol Biomol Spectrosc* 141: 128-134. https://doi.org/10.1016/j.saa.2015.01.048
59. Qu J, Yuan X, Wang X, Shao P. 2011. Zinc accumulation and synthesis of ZnO nanoparticles using *Physalis alkekengi* L. *Environ Pollut* 159(7): 1783-1788. https://doi.org/10.1016/j.envpol.2011.04.016
60. Lingaraju K, Naika HR, Manjunath K, Basavaraj RB, Nagabhushana H, et al. 2016. Biogenic synthesis of zinc oxide nanoparticles using *Ruta graveolens* (L.) and their antibacterial and antioxidant activities. *Appl Nanosci* 6(5): 703-710. https://doi.org/10.1007/s13204-015-0487-6
61. Ramesh M, Anbuvannan M, Viruthagiri G. 2015. Green synthesis of ZnO nanoparticles using *Solanum nigrum* leaf extract and their antibacterial activity. *Spectrochim Acta A Mol Biomol Spectrosc* 136: 864-870. https://doi.org/10.1016/j.saa.2014.09.105
62. Sankar R, Rizwana K, Shivashangari KS, Ravikumar V. 2015. Ultra-rapid photocatalytic activity of *Azadirachta indica* engineered colloidal titanium dioxide nanoparticles. *Appl Nanosci* 5(6): 731-736. https://doi.org/10.1007/s13204-014-0369-3
63. Kumar TS, Rahuman AA, Jayaseelan C, Rajakumar G, Marimuthu S, et al. 2014. Green synthesis of titanium dioxide nanoparticles using *Psidium guajava* extract and its antibacterial and antioxidant properties. *Asian Pac J Trop Med* 7(12): 968-976. https://doi.org/10.1016/S1995-7645(14)60171-1
64. Sharma D, Parveen K, Oza A, Ledwani L. 2018. Synthesis of anthraquinone-capped TiO_2 nanoparticles using *R. emodi* roots: preparation, characterization and cytotoxic potential. *Rend Fis Acc Lincei* 29(3): 649-658. https://doi.org/10.1007/s12210-018-0696-5