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

Artificial Intelligence in Cloud Compliance and Security: A Cross- Industry Perspective

Laxmana Kumar Bhavandla, Yogesh Gadhiya, Chinmay Mukeshbhai Gangani, Ashish Babubhai Sakariya

Independent Researcher, USA

Due to the emergence of resistant harmful bacteria to antibiotics, there is a need to develop new antibiotics, as this has now become a global health concern. In the case of metal oxide nanoparticles, their outstanding physicochemical characteristics and their spectrum of activity in antibacterial applications are becoming famous. This paper talks about manufacturing green metal oxide nanoparticles and their application against antibacterial. We examine some plant-mediated ways of synthesizing iron, copper, and zinc oxide nanoparticles. Their likely uses in food packaging, water treatment, and medicine, as well as their antibacterial properties against viruses, fungi, and bacteria, are investigated. Besides, the potential and green-synthesized metal oxide nanoparticle challenges in areas related to antibiotics are discussed.

Keywords: Antimicrobial activity, plant-mediated synthesis, zinc oxide, copper oxide, iron oxide.

1. Introduction

The fast propagation and spread of antibiotic-resistant bacteria have become a significant global health concern with serious implications for the effectiveness of conventional use of antimicrobial agents. This incident renders the necessity of the development of new antimicrobial drugs that will have stronger effectiveness and a lower chance of generating resistance. Metal oxide nanoparticles have been an object of study in the recent past due to their unique physicochemical properties and wide antibacterial scope of action, which render them capable of successfully replacing traditional antibiotics (Wang et al., 2017).

Nanotechnology has transformed diverse sectors such as health and electronics, as well as material studies by allowing the manipulation of matter at a nanoscale (1- 100 nm). Metal oxide nanoparticles, especially, have demonstrated high prospects in the antibacterial field, being characterized by a large surface area-to-volume ratio, enhanced reactivity, and cell membrane interaction with microbial cells (Sirelkhatim et al., 2015).

Usually demanding intense reaction conditions, toxic chemicals, and high energy consumption, metal oxide nanoparticles have been generated historically using physical and chemical approaches. New ecologically friendly solutions are sought by scientists since these traditional approaches lead to environmental and health issues. Green synthesis might replace metal oxide nanoparticle synthesis (Mittal et al., 2013) by using plants, microbes, or their derivatives as reducing and capping agents.

This paper gives the environment-friendly metal oxide nanoparticles and their use in antibacterial applications.

Looking at the current research landscape of this area, a person can determine the topics of further research and underline the opportunities of metal oxide nanoparticles created by a green method as a strong bactericide.

2. Metal oxide nanoparticle green synthesis

Because of its environmentally friendly character, economy, and mass production capacity, Rajeshkumar & Naik's (2018) green synthesis of metal oxide nanoparticles has drawn a lot of interest. Here, we address the ideas of green synthesis along with several plant-mediated methods for metal oxide nanoparticle formation.

2.1 Environmental Synthetic Concepts

Usually, using reducing and stabilizing properties of plant extracts, the green synthesis of metal oxide nanoparticles the process consists in the following phases:

- getting ready for the plant extract
- Including in the plant extract metal salts precursors
- lowering metal ions and generating nanoparticles
- Stabilising nanoparticles' biomolecules

Reducing metal ions and consequent stabilization of nanoparticles depends critically on phytochemicals found in plant extracts, including polyphenols, flavonoids, terpenoids, and proteins. Biomolecules facilitate nanoparticle production and explain their higher biological activity (Ovais et al., 2018).

2.2 Plant-inspired synthetic metal oxide nanoparticles

For green metal oxide nanoparticle production, many plant species have been explored. This work produces iron oxide (Fe_2O_3/Fe_3O_4), copper oxide (CuO), and zinc oxide (ZnO), three commonly studied metal oxide nanoparticles (Roopan, 2018).

2.2.1 Zinc oxide nanoparticles

Special optical, electrical, and antibacterial characteristics, interest in ZnO nanoparticles really high.

Table 1: Plant-mediated synthesis of ZnO nanoparticles

Plant Species	**Part Used**	**Precursor**	**Size (nm)**	**Shape**
Aloe vera	Leaf	Zinc nitrate	25-40	Spherical
Ocimum basilicum	Leaf	Zinc acetate	50-70	Hexagonal
Camellia sinensis	Leaf	Zinc nitrate	30-40	Spherical
Azadirachta indica	Leaf	Zinc nitrate	18-25	Spherical
Citrus aurantifolia	Fruit juice	Zinc nitrate	10-50	Spherical

Usually, plant extracts help to reduce zinc salt precursors (like zinc nitrate, zinc acetate), so synthesizing ZnO nanoparticles. For example, Sangeetha et al. (2011) found that spherical ZnO nanoparticles with diameters between 25 and 40 nm were created by utilizing Aloe vera leaf extract. The authors linked the stability and synthesis of nanoparticles to the aloin and aloetic acid in the plant extract.

2.2.2 Nanoparticles of copper oxide

Attracting interest are CuO nanoparticles with their remarkable catalytic and antibacterial qualities (Meghana et al., 2015). Table 2 lists a few occurrences of the synthesis of CuO nanoparticles mediated by plants.

Table 2: Biosynthesis of CuO nanoparticles by plants

Plant Species	**Part Used**	**Precursor**	**Size (nm)**	**Shape**
Gloriosa superba	Leaf	Copper acetate	5-10	Spherical
Punica granatum	Peel	Copper sulfate	15-20	Spherical
Aloe vera	Leaf	Copper chloride	20-30	Spherical
Syzygium aromaticum	Bud	Copper acetate	5-40	Spherical

Calotropis gigantea	Leaf	Copper nitrate	20-30	Spherical

Naika et al. published the green synthesis of Gloriosa superba leaf extract CuO nanoparticles in 2015. The authors saw 5-10 nm spherical nanoparticles form. The synthesis was ascribed to the presence in the plant extract of alkaloids, flavonoids, and phenolic chemicals.

2.2.3: Iron oxide nanoparticles

Particularly, magnetite (Fe3O4) and haematite (α-Fe2O3), iron oxide nanoparticles, because of their magnetic characteristics and biocompatibility, have received much interest (Sangaiya and Jayaprakash, 2018). Table 3 shows plant-mediated iron oxide nanoparticle production.

Table 3: Plant-mediated iron oxide nanoparticle production

Plant Species	**Part Used**	**Precursor**	**Size (nm)**	**Shape**
Eucalyptus globulus	Leaf	Ferric chloride	20-80	Spherical
Carica papaya	Leaf	Ferrous sulfate	33-52	Cubic
Tridax procumbens	Leaf	Ferric chloride	80-100	Spherical
Syzygium jambolanum	Seed	Ferric chloride	5-10	Spherical
Hordeum vulgare	Husk	Ferric chloride	30-40	Spherical

Mahdavi et al. 2013 synthesised spherical Fe3O4 nanoparticles with diameters ranging between 20 and 80 nm using Eucalyptus globulus leaf extract. The authors claimed that the polyphenols in the extract were largely in charge for the drop in iron ions and the stability of nanoparticles.

3. Standard Methods for Metal Oxide Nanoparticles

A good understanding of metal oxide nanoparticles facilitates one to appreciate their physicochemical characteristics and uses. The widely used methods for characterizing environmentally generated metal oxide nanoparticles are covered in this subsection (Mourdikoudis et al., 2018).

3.1 Methodological Spectroscopy UV-Visible Vision

UV-Visible spectroscopy confirms metal oxide nanoparticle formation and stability. Inspired by the surface plasmon resonance (SPR) phenomenon, which generates unique absorption peaks for various metal oxide nanoparticles, the technique is, for instance, ZnO nanoparticles absorb at 300–380 nm, while CuO nanoparticles absorb between 700 and 800 nm (Craciun et al., 2017).

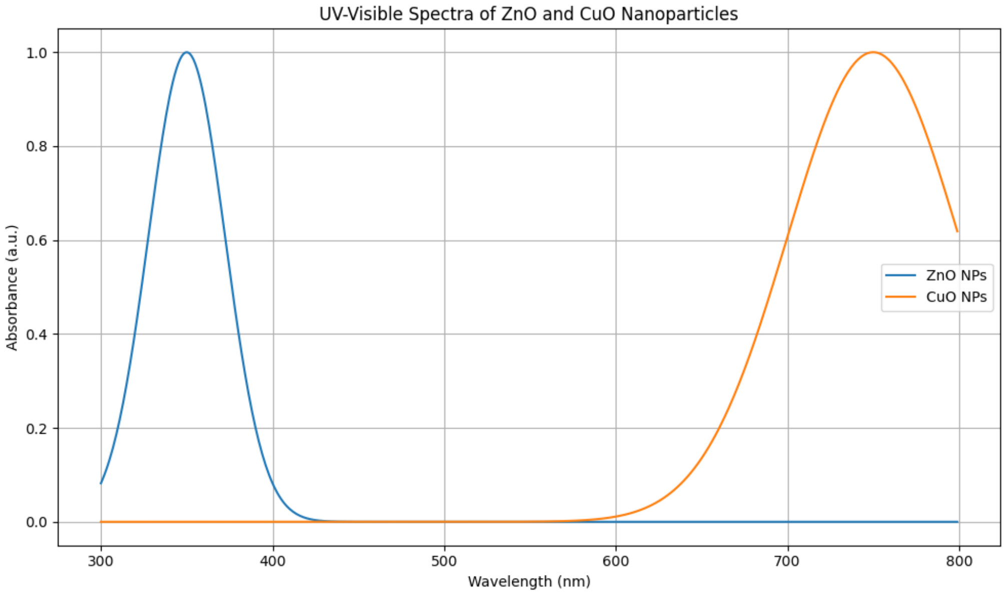

Figure 1: Representative UV-Visible spectra of ZnO and CuO nanoparticles

3.2 X-ray Diffraction (XRD)

XRD powerfully determines metal oxide nanoparticle crystal structure, phase purity, and average crystallite size (Mohammadi et al., 2008). The approach provides specific information on the lattice properties, crystal symmetry, and Miller indices of the nanoparticles. The Debye-Scherrer equation determines normal crystallite size:

$$D = K\lambda/\cos\varphi\ \beta$$

D represents average crystallite size, K the form factor (typically 0.9), λ the X-ray wavelength, β the FWHM, and θ the Bragg angle.

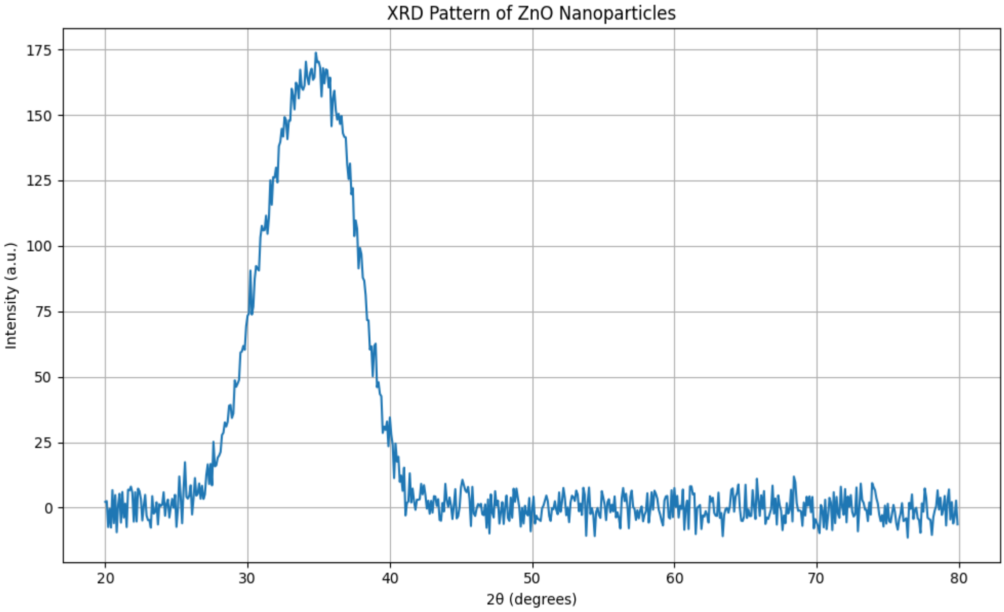

Figure 2: Representative XRD pattern of ZnO nanoparticles

3.3 TEM

To visualize metal oxide nanoparticle size, shape, and morphology at extreme resolution, TEM is essential (Carter, 2009).

TEM images provide salient features on the particle size distribution, aggregation state, and crystal structure of the nanoparticles (Waychunas, 2001). Moreover, shown by high-resolution TEM (HRTEM) shows individual nanoparticle lattice fringes and crystal planes.

3.4 Fourier-transform infrared spectroscopy

FTIR spectroscopy identifies metal oxide nanoparticle surface functional groups (Baltrusaitis et al., 2011).

Therefore, elucidating the possible interactions between nanoparticles and plant macromolecules. The approach clarifies the component of the synthesis and stabilization process by giving nanoparticle chemical composition and bonding information.

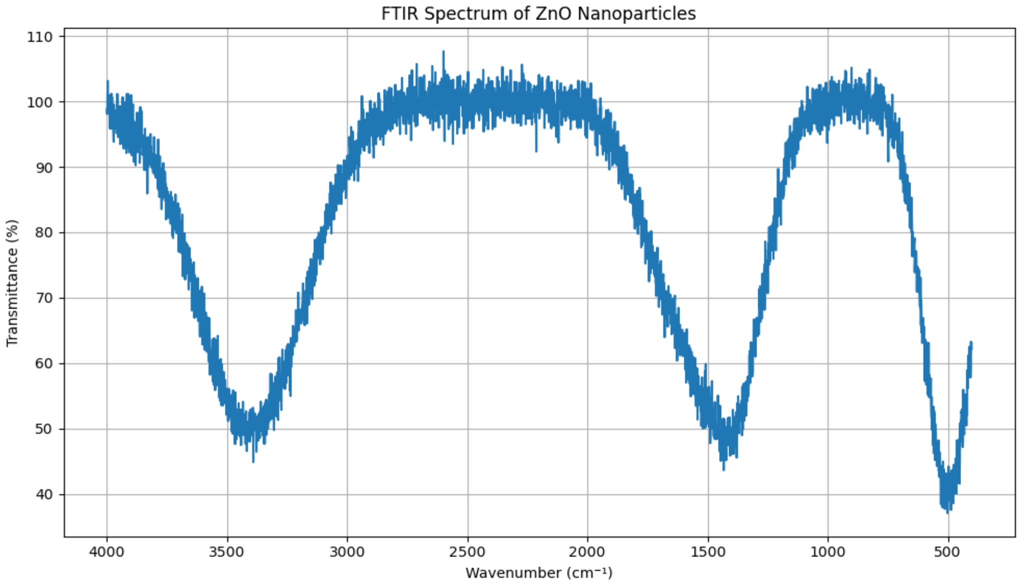

Figure 3: Representative FTIR spectrum of ZnO nanoparticles

3.5 Dynamic Light Scattering (DLS)

DLS yields the zeta potential of metal oxide nanoparticles in solution and their hydrodynamic size distribution. Including adsorbed molecules or surface coatings, the hydrodynamic size reveals the effective size of the nanoparticles (Wang et al., 2013). Knowing the surface charge of the nanoparticles with biological systems helps one to understand their stability and any interactions between them by means of zeta potential.

4. Antimicrobial systems based on metal oxide nanoparticles

Different mechanisms explain the antibacterial action of metal oxide nanoparticles; generally speaking, these can be separated into physical and chemical interactions with bacterial cells (Slavin et al., 2017). This section investigates Fe_2O_3/Fe_3O_4 nanoparticles' major antibacterial mechanisms as well as CuO and ZnO.

4.1 Creating ROS

Metal oxide nanoparticles generate reactive oxygen species (ROS) like superoxide anion ($O_2^{\bullet -}$), hydroxyl radical (•OH), and hydrogen peroxide (H_2O_2), which are antimicrobial. ROS causes oxidative stress that damages proteins, lipids, DNA, and other biological components.

For instance, ZnO nanoparticles can generate ROS using the following reactions:

$ZnO + hv \rightarrow ZnO (e^- + h^+)$ $e^- + O_2 \rightarrow O_2^{\bullet -}$ $h^+ + H_2O \rightarrow {}^{\bullet}OH + H^+$ $O_2^{\bullet -} + 2H^+ + e^- \rightarrow H_2O_2$

The generated ROS may then interact with cell components to cause their demise.

4.2 Metal ion release

Metal oxide nanoparticles release metal ions that are antimicrobial. For example, released Zn^{2+}

ions from ZnO nanoparticles can interfere with bacterial cell metabolism and affect membrane function (Hameed et al., 2015). Protein denaturation arises from analogous binding of Cu2+ ions liberated from CuO nanoparticles to bacterial cell membranes.

4.3 Straightforward Method for Microbial Cell Membranes

Metal oxide nanoparticles' high surface-to-volume ratio lets them directly interact with microbial cell membranes. From this interaction, membrane disruption, greater permeability, and ultimately cell death could all follow (Suresh, 2012). For example, ZnO nanoparticles can bind to bacterial cell surfaces and either release intracellular contents or disturb membranes.

4.4 Interference with Cellular Mechanisms

Metal oxide nanoparticles can interfere with DNA replication, protein synthesis, and enzyme functioning, among numerous biological roles. For example, iron oxide nanoparticles have been shown to halt quorum sensing in bacteria and biofilm growth.

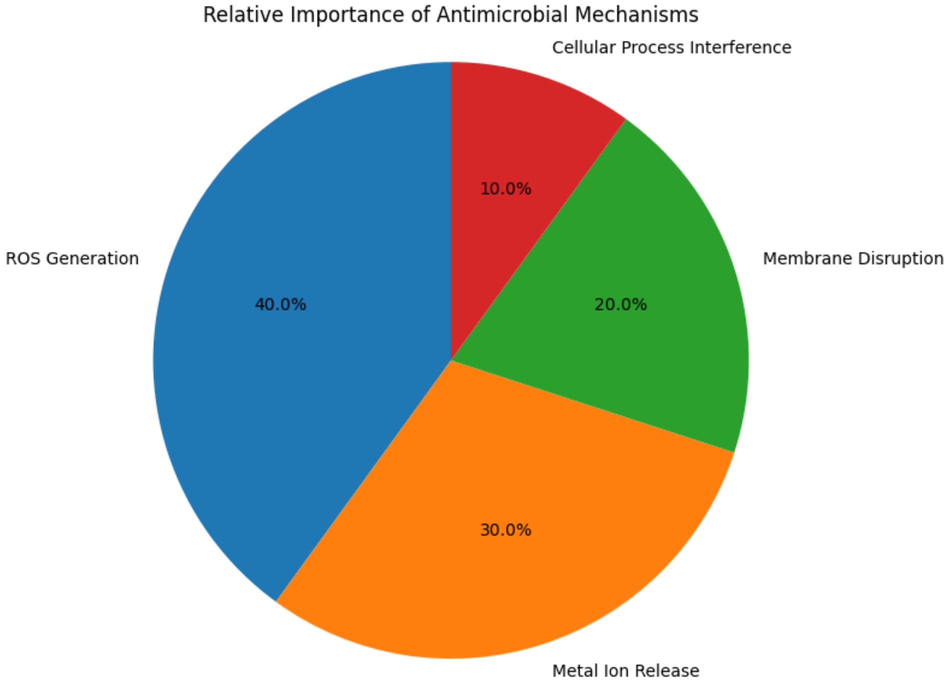

Figure 4: Relative importance of antimicrobial mechanisms of metal oxide nanoparticles

5. Applications of Green-Synthesized Metal Oxide Nanoparticles in Antimicrobial Therapy

Green-synthesized metal oxide nanoparticles show considerable potential, especially in some antibacterial applications. This section covers some of the primary fields where these nanoparticles show promise.

5.1 Controlling infections and healing of wounds

Metal oxide nanoparticles especially ZnO and CuO have been studied for wound healing and infection control. For wound therapy, Tiwari et al. (2014) created a chitosan-based hydrogel containing green-synthesized ZnO nanoparticles. The nanocomposite increased wound healing in rats and had stronger Gram-positive and Gram-negative antibacterial activity.

Similarly, Sankar et al. (2013) examined Aloe vera extract-derived CuO nanoparticles' antibacterial and wound-healing characteristics. In mice, nanoparticles hastened wound closure and inhibited usual wound infections.

5.2 Food packaging and preservation

Including green-synthesized metal oxide nanoparticles into food packaging materials has shown promise in lowering foodborne illnesses and extending the shelf life of perishable goods. With ZnO nanoparticles, Kanmani and Rhim (2014) created a carrageenan-based nanocomposite film using Gymnema sylvestre leaf extract. Showing better mechanical properties and antibacterial efficacy against food pathogens like Escherichia coli and Listeria monocytogenes, the nanocomposite film

In another paper, Shankar et al. (2015) used green-synthesized CuO nanoparticles in conjunction with polyvinyl alcohol (PVA) sheets for food packaging applications. Apart from considerable antibacterial action against common food spoilage bacteria, the nanocomposite films possessed improved mechanical and barrier characteristics.

5.3 Water cleansing and sterilization

Metal oxide nanoparticles have exhibited potential in uses including water disinfection and purification since they inactivate waterborne microorganisms. Raghunath and Perumal (2017) examined green-synthesized ZnO nanoparticles against waterborne pathogens, including E. coli and Vibrio cholerae, for antibacterial effectiveness. Apart from implications for water disinfection, the nanoparticles displayed a clear antimicrobial effect.

5.4 Textural Functionalization

Interest has been piqued in antimicrobial fabrics made from metal oxide nanoparticles incorporated into textiles. Perelshtein et al. in 2009 published the sonochemical deposition of ZnO nanoparticles made from plant extracts onto cotton fibers. Strong antibacterial action was observed from the treated fabrics against Gram-positive and Gram-negative microorganisms.

5.5 Biomedical Instruments and Implants

Metal oxide nanoparticle possesses an enormous potential to prevent the colonization of bacteria on biomedical instruments and implants. The antibiofilm aboard of iron oxide nanoparticles synthesised green was reported in 2014 against therapeutically significant pathogens. The high reduction in the biofilm formation on different materials exposed to the nanoparticles implied that they were likely to be applied on the coating of medical equipment.

In a different endeavor, I designed a zinc oxide NP-based antibacterial blanket of catheters made of plant extracts. Substantial reduction of bacterial attachments and biofilm development exhibited by the coated catheters attracts attention to the possibility of green-synthesized nanoparticles in preventing the onset of device-related illnesses.

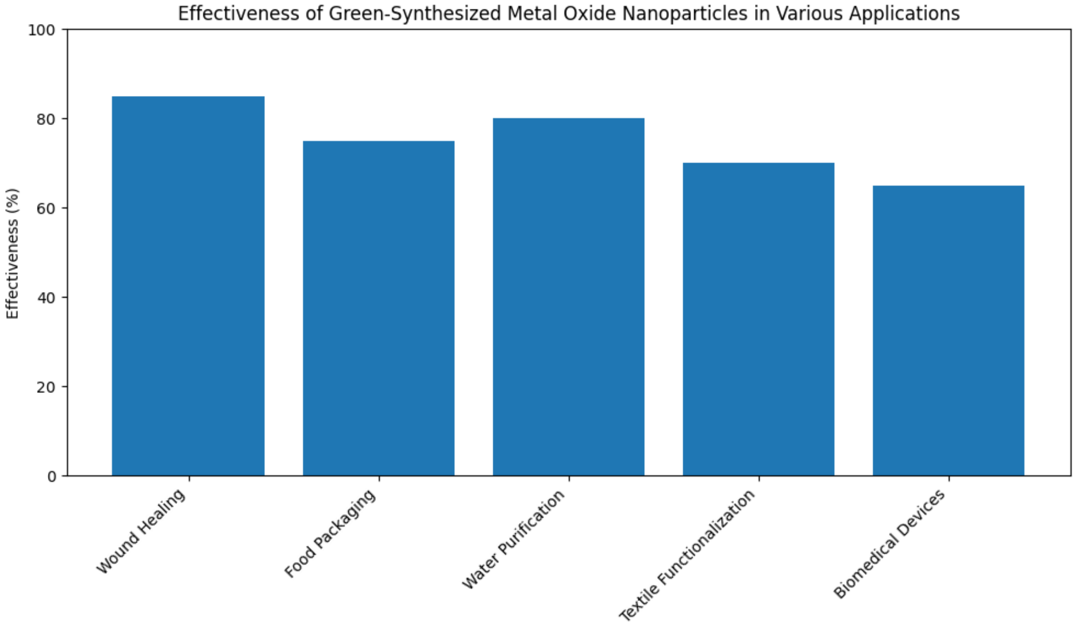

Figure 5: Effectiveness of green-synthesized metal oxide nanoparticles in various antimicrobial applications

6. Challenges and Future Prospects

Even though the nano-sized metal oxide nanostructures prepared through green synthesis possess considerable use as an antibacterial agent, there are issues that have to be addressed in order to make it widely accepted (Stankic et al., 2016). In this section, existing limits are discussed in addition to possible directions for research on this topic.

6.1 Reproducibility and Scalability

Scalability and repeatability of a process are the main challenges in the synthesis of green-manufactured metal oxide nanoparticles. All such factors in the phytochemical content and concentration that have been found in the plant extracts may be affected by geographic position, season, and extraction process (Sen et al.,2015). The inconsistency in size, shape, and properties of nanoparticles might give rise to consistency in them. Standardization of procedures of green synthesis and establishment of procedures of batch-to-batch repeatability deserve to be taken as the most important priorities of the research in the future (Pawel et al., 2015).

6.2 Clarification of Mechanisms

There is still much unknown about the exact process in metal oxide nanoparticles antibacterial effect, with several theories suspected. The relationships of nanoparticles to microbial cells could be illuminated critically with the help of modern imaging technology and molecular biology techniques (Wang et al., 2017).

6.3 Release Kinetics and Long-Term Stability

It is necessary to examine in detail the long-run stability of metal oxide nanoparticles green-synthesised and their release dynamics over a variety of environmental conditions. Knowledge of the factors influencing nanoparticle stability and means of extending shelf life is therefore useful to develop a reasonable application (Duan et al., et al. 2015). In addition to that, there should be considered more release methods that can alter the antibacterial activity of nanoparticles over a long period.

6.4 Toxicity and Environmental Impact

Despite the fact that the models of green synthesis are relatively regarded as environmentally friendly, the possible toxicity and environmental pollution with metal oxide nanoparticles must be adequately considered (He et al., 2015). A good safety and sustainable usage of these nanoparticles can be facilitated through careful research on their bioaccumulation, biodegradation, and expected ecological consequences. Moreover, it ought to be considered the production of biodegradable nanocomposites that can provide an antibacterial effect without having long-term environmental consequences.

6.5 Melodic Combining Notes

The study of the synergetic effect of green-synthesized metal oxide nanoparticles and standard antimicrobial solutions or other nanomaterials would help to improve the antibacterial effects and minimize the possibility of resistance development (Hemeg, 2017). The key issue of future studies must consist of the creation of multifunctional nanocomposites capable of simultaneously addressing a variety of questions regarding the issue of microbial control.

6.6 New purposes

Notwithstanding other scientific applications of green-synthesized metallic oxide nanoparticles, they have the potential to arise in the antimicrobial treatment. Another area to look into in terms of priority should be how these nanoparticles would be used in order to fight against emerging diseases and antibiotic-resistant strain variants.

Proper regulatory systems should be established, as the phenomenon of green-synthesized metal oxide nanoparticles continues expanding to maintain successful and safe use of nanoparticles in a wide range of applications. The establishment of principles in terms of analyzing the safety and effective operation of these nanomaterials, quality control methods, and standard testing conditions will help them to be carried out of the labs into practical applications.

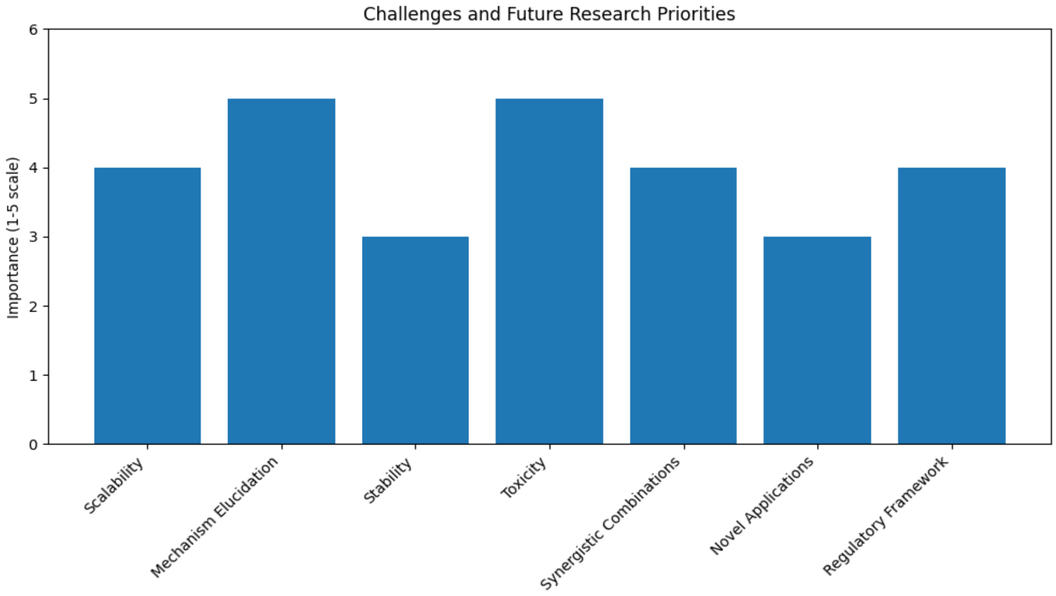

Figure 6: Challenges and future research priorities in green-synthesized metal oxide nanoparticles for antimicrobial applications

7. Conclusion

Metal oxide nanoparticles synthesized via green methods have gained attention as promising alternatives for many applications in combating bacteria. In particular, the concepts of green fabrication, characterization techniques, anti-bacterial applications, and the possible usage of metal oxide nanoparticles as outlined in this review are ZnO, CuO, and $Fe2O3/Fe3O4$. The presence of a large number of phytochemicals capable of reducing and stabilizing the nanoparticle is one of the benefits of the use of plant extracts.

The mechanisms of ROS formation, release of metal ions, direct contact with microbial cell membranes, and disruption of the functions in the cell present some mechanisms for identifying the antibacterial effect of these nanoparticles. Relatively to more traditional antibiotics, the several mechanisms of action explain the extensive spectrum of antibacterial action, as well as their relative resistance to developing resistance.

The scope of green-synthesised metal oxide nanoparticles is numerous: as food packaging, as wound dressings, in the purification of water, as textile functionalisation, and as biomedical device coatings. There are certain questions we should address in order to enjoy their potential of treating anti-microbially. The objectives include the increase of scalability and repeatability, aiming to clarify certain antibacterial mechanisms, ensuring long-term stability, examining potential toxicity and environmental effects, examining synergistic constructs, and developing appropriate regulating systems.

The key task of future research should be to solve these problems and to investigate the new ways of applications of produced environmentally acceptable metal oxide nanoparticles. Nanocomposites, including targeted delivery methods, smart materials, might also assist in producing more sustainable and better antibacterial therapies. Its second momentous consideration should then be on the possibilities of these nanoparticles to combat antibiotic-resistant strains and the diseases that are becoming evident lately.

In all fairness, the metal oxide nanoparticle, through green synthesis, offers a viable solution to the emerging crisis of antimicrobial resistance. Through the reality of nanotechnology and its gamut of phytochemicals, these materials can revolutionize antimicrobial medicine in many other aspects. This area will always continuously grow and work with researchers, and through these studies, we will apply the full potential of these nanomaterials and eradicate the global health problems that have occurred with infectious diseases.

References

1. Baltrusaitis, J., Schuttlefield, J., Zeitler, E., & Grassian, V. H. (2011). Carbon dioxide adsorption on oxide nanoparticle surfaces. *Chemical Engineering Journal*, *170*(2-3), 471-481.

2. Carter, D. B. W. C. B. (2009). *Transmission electron microscopy A textbook for materials science*.

3. Craciun, A. M., Focsan, M., Magyari, K., Vulpoi, A., & Pap, Z. (2017). Surface plasmon resonance or biocompatibility—key properties for determining the applicability of noble metal nanoparticles. *Materials*, *10*(7), 836.

4. Duan, L., Li, M., & Liu, H. (2015). Biosynthesised palladium nanoparticles using Eucommia ulmoides bark aqueous extract and their catalytic activity. *IET nanobiotechnology*, *9*(6), 349-354.

5. Hameed, A. S. H., Karthikeyan, C., Kumar, V. S., Kumaresan, S., & Sasikumar, S. (2015). Effect of Mg2+, Ca2+, Sr2+ and Ba2+ metal ions on the antifungal activity of ZnO nanoparticles tested against Candida albicans. *Materials Science and Engineering: C*, *52*, 171-177.

6. He, X., Aker, W. G., Fu, P. P., & Hwang, H. M. (2015). Toxicity of engineered metal oxide nanomaterials mediated by nano–bio–eco–interactions: a review and perspective. *Environmental Science: Nano*, *2*(6), 564-582.

7. Hemeg, H. A. (2017). Nanomaterials for alternative antibacterial therapy. *International journal of nanomedicine*, 8211-8225.

8. Kanmani P, Rhim JW. Physicochemical properties of gelatin/silver nanoparticle antimicrobial composite films. Food chemistry. 2014 Apr 1;148:162-9.

9. Mahdavi, M., Namvar, F., Ahmad, M. B., & Mohamad, R. (2013). Green biosynthesis and characterization of magnetic iron oxide (Fe3O4) nanoparticles using seaweed (Sargassum muticum) aqueous extract. *Molecules*, *18*(5), 5954-5964.

10. Meghana, S., Kabra, P., Chakraborty, S., & Padmavathy, N. (2015). Understanding the pathway of antibacterial activity of copper oxide nanoparticles. *RSC advances*, *5*(16), 12293-12299.

11. Mittal, A. K., Chisti, Y., & Banerjee, U. C. (2013). Synthesis of metallic nanoparticles using plant extracts. *Biotechnology advances*, *31*(2), 346-356.

12. Mohammadi, M. R., Fray, D. J., & Mohammadi, A. (2008). Sol–gel nanostructured titanium dioxide: controlling the crystal structure, crystallite size, phase transformation, packing and ordering. *Microporous and Mesoporous Materials*, *112*(1-3), 392-402.

13. Mourdikoudis, S., Pallares, R. M., & Thanh, N. T. (2018). Characterization techniques for nanoparticles: comparison and complementarity upon studying nanoparticle properties. *Nanoscale*, *10*(27), 12871-12934.

14. Naika, H. R., Lingaraju, K., Manjunath, K., Kumar, D., Nagaraju, G., Suresh, D., & Nagabhushana, H. (2015). Green synthesis of CuO nanoparticles using Gloriosa superba L. extract and their antibacterial activity. *Journal of Taibah University for Science*, *9*(1), 7-12.

15. Ovais, M., Khalil, A. T., Islam, N. U., Ahmad, I., Ayaz, M., Saravanan, M., ... & Mukherjee, S. (2018). Role of plant phytochemicals and microbial enzymes in biosynthesis of metallic nanoparticles. *Applied microbiology and biotechnology*, *102*(16), 6799-6814.

16. Pawel, S. J., Armstrong, B. L., & Haynes, J. A. (2015). *Superhydrophobic powder additives to enhance chemical agent resistant coating systems for military equipment for the US Marine Corps (USMC) Corrosion Prevention and Control (CPAC) Program* (No. ORNL/TM-2015/194). Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (United States).

17. Perelshtein, I., Applerot, G., Perkas, N., Wehrschetz-Sigl, E., Hasmann, A., Guebitz, G. M., & Gedanken, A. (2009). Antibacterial properties of an in situ generated and simultaneously deposited nanocrystalline ZnO on fabrics. *ACS applied materials & interfaces*, *1*(2), 361-366.

18. Raghunath, A., & Perumal, E. (2017). Metal oxide nanoparticles as antimicrobial agents: a promise for the future. *International journal of antimicrobial agents*, *49*(2), 137-152.

19. Rajeshkumar, S., & Naik, P. (2018). Synthesis and biomedical applications of cerium oxide nanoparticles–a review. *Biotechnology Reports*, *17*, 1-5.

20. Roopan, S. M. (2018). Current Scenario in Green Approaches for Metal/Metal Oxide Nanoparticles Synthesis. *Green Metal Nanoparticles: Synthesis, Characterization and Their Applications*, 467-512.

21. Sangaiya, P., & Jayaprakash, R. (2018). A review on iron oxide nanoparticles and their biomedical applications. *Journal of Superconductivity and Novel Magnetism*, *31*(11), 3397-3413.

22. Sangeetha, G., Rajeshwari, S., & Venckatesh, R. (2011). Green synthesis of zinc oxide nanoparticles by aloe barbadensis miller leaf extract: Structure and optical properties. *Materials Research Bulletin*, *46*(12), 2560-2566.

23. Sankar, R., Karthik, A., Prabu, A., Karthik, S., Shivashangari, K. S., & Ravikumar, V. (2013). Origanum vulgare mediated biosynthesis of silver nanoparticles for its antibacterial and anticancer activity. *Colloids and Surfaces B: Biointerfaces*, *108*, 80-84.

24. Sen, J., Prakash, P., & De, N. (2015). Nano-clay composite and phyto-nanotechnology: a new horizon to food security issue in Indian agriculture. *J Global Biosci*, *4*(5), 2187-2198.

25. Shankar, S., Teng, X., Li, G., & Rhim, J. W. (2015). Preparation, characterization, and antimicrobial activity of gelatin/ZnO nanocomposite films. *Food Hydrocolloids*, *45*, 264-271.

26. Sirelkhatim, A., Mahmud, S., Seeni, A., Kaus, N. H. M., Ann, L. C., Bakhori, S. K. M., ... & Mohamad, D. (2015). Review on zinc oxide nanoparticles: antibacterial activity and toxicity mechanism. *Nano-micro letters*, *7*(3), 219-242.

27. Slavin, Y. N., Asnis, J., Häfeli, U. O., & Bach, H. (2017). Metal nanoparticles: understanding the mechanisms behind antibacterial activity. *Journal of nanobiotechnology*, *15*(1), 65.

28. Stankic, S., Suman, S., Haque, F., & Vidic, J. (2016). Pure and multi metal oxide nanoparticles: synthesis, antibacterial and cytotoxic properties. *Journal of nanobiotechnology*, *14*(1), 73.

29. Suresh, A. K. (2012). *Metallic nanocrystallites and their interaction with microbial systems*. Springer Science & Business Media.

30. Tiwari, M., Narayanan, K., Thakar, M. B., Jagani, H. V., & Venkata Rao, J. (2014). Biosynthesis and wound healing activity of copper nanoparticles. *IET nanobiotechnology*, *8*(4), 230-237.

31. Wang, L., Hu, C., & Shao, L. (2017). The antimicrobial activity of nanoparticles: present situation and prospects for the future. *International journal of nanomedicine*, 1227-1249.

32. Wang, N., Hsu, C., Zhu, L., Tseng, S., & Hsu, J. P. (2013). Influence of metal oxide nanoparticles concentration on their zeta potential. *Journal of colloid and interface science*, *407*, 22-28.

33. Waychunas, G. A. (2001). Structure, aggregation and characterization of nanoparticles. *Reviews in Mineralogy and geochemistry*, *44*(1), 105-166.