

Plant-Mediated Green Synthesis Review of Metal Oxide Nanoparticles: Mechanisms, Characterization and Antimicrobial Applications Against Drug-Resistant Pathogens

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Abstract—Antimicrobial resistance (AMR) has reduced the effectiveness of many conventional antimicrobial agents and has intensified the search for alternative materials with mechanisms that differ from classical antibiotic targets. Metal and metal oxide nanoparticles are promising because their nanoscale dimensions, surface reactivity, ion release, optical properties and ability to interact with microbial envelopes can produce multiple biological effects. This review synthesizes the literature assembled in the present doctoral research document on plant-mediated metal oxide nanoparticles, with particular emphasis on zinc oxide (ZnO), together with CuO, Fe₂O₃/Fe₃O₄, TiO₂ and MgO systems. The review discusses nanomaterial classification, top-down and bottom-up synthesis, chemical and physical routes, plant-mediated biosynthesis, the role of phytochemicals in reduction and stabilization, process variables, and analytical characterization by UV–visible spectroscopy, FTIR, XRD, SEM, TEM, Raman spectroscopy and EDX. The antimicrobial section examines adsorption to microbial surfaces, membrane damage, reactive oxygen species generation, metal-ion release, intracellular macromolecular damage, biofilm inhibition and possible synergy with antibiotics. A separate focus is placed on *Solanum xanthocarpum*, for which the uploaded research document identifies the stem and roots as comparatively underexplored materials for ZnO nanoparticle synthesis. The proposed research framework combines aqueous and methanolic plant extracts, phytochemical screening, green synthesis, physicochemical characterization, DPPH antioxidant testing and antimicrobial assessment against drug-resistant pathogens. The review also highlights limitations concerning reproducibility, extract composition, particle aggregation, dose-dependent toxicity, environmental fate, mechanistic interpretation and translation from laboratory observations to clinical

applications. Overall, plant-mediated metal oxide nanoparticles represent a promising but still developing platform for sustainable antimicrobial research.

Index Terms— green synthesis; metal oxide nanoparticles; *Solanum xanthocarpum*; phytochemicals; antimicrobial resistance; drug-resistant pathogens; biofilm; nanomedicine.

I. INTRODUCTION

Antimicrobial resistance is a major challenge because resistant microorganisms can cause treatment failure, prolonged illness and increased healthcare burden. The source document frames AMR as a driver for developing antimicrobial materials that act differently from conventional antibiotics and notes the relevance of nanotechnology to this objective. It also identifies multidrug-resistant organisms and biofilm-associated infections as important targets for alternative strategies. [1–8, 54, 61, 68, 97, 104, 118, 131] Nanotechnology concerns the design and application of matter at the nanoscale, where changes in surface area, surface energy, electronic structure and interfacial reactivity can produce properties different from bulk materials. Nanoparticles are generally discussed in the source material within the approximately 1–100 nm range. Their high surface-to-volume ratio increases the fraction of atoms at or near the surface and can enhance interactions with biomolecules and microorganisms. [9–17, 67, 69, 82, 90, 103, 128, 132] Metal and metal oxide nanoparticles have therefore received substantial attention as antimicrobial materials. ZnO is particularly attractive because it combines

semiconductor characteristics with reported antimicrobial, photocatalytic and surface-reactive behavior. Other relevant systems include Ag/Ag₂O, Cu/CuO, Fe-based oxides, TiO₂, MgO, SnO₂ and composite materials. The uploaded research document emphasizes that nanoparticle activity is affected by size, morphology, surface area, surface charge, aggregation, composition, dopants and environmental conditions rather than by nominal chemical identity alone.^[18-27, 49, 65, 69, 73, 77, 82, 108, 119, 131] Conventional nanoparticle synthesis can provide tight control of particle characteristics but may require hazardous reducing agents, organic solvents, stabilizers, high temperatures or energy-intensive processing. Plant-mediated synthesis is consequently attractive because plant metabolites can participate in metal-ion reduction, nucleation and surface stabilization. The present review places these processes in the context of sustainable chemistry and biomedical antimicrobial research.^[28-35, 46, 63, 67, 77, 82, 96, 110, 114]

II. SCOPE AND REVIEW APPROACH

This review was developed from the uploaded doctoral research document, particularly its introductory and literature-review chapters and the reference corpus contained in that document. The manuscript preserves the research focus on plant-mediated metal oxide nanoparticles, antimicrobial activity against drug-resistant pathogens, nanoparticle characterization and the specific research gap surrounding *Solanum xanthocarpum* stem and root extracts. The 150 references listed at the end were selected from the supplied reference corpus for relevance to green synthesis, metal/metal oxide nanoparticles, ZnO, antimicrobial activity, AMR, biofilms, phytochemicals, characterization, toxicity and biomedical applications. Because the supplied reference list contains some incomplete or inconsistent bibliographic records, each reference should be checked against the publisher/Crossref/Scopus record before journal submission.

III. NANOMATERIALS: CLASSIFICATION AND FUNCTIONAL CHARACTERISTICS

Nanomaterials can be classified according to dimensionality, composition, morphology, magnetic behavior, degree of aggregation and surface

functionalization. Zero-dimensional structures include nanoparticles and clusters; one-dimensional systems include Nano rods, nanowires and nanotubes; two-dimensional materials include Nano sheets and Nano disks; and three-dimensional nanostructured assemblies contain nanoscale grains or building blocks. Composition-based classes include metals, metal oxides, polymers, carbon materials, composites and hybrid structures. Surface functionalization can be introduced during synthesis or after particle formation to alter stability, dispersibility, targeting or biological interactions.^[36-43, 67, 87, 103, 113, 128] For antimicrobial applications, nanoscale size is important because it increases interfacial contact with microbial cells. However, smaller size does not automatically mean greater biological performance: aggregation can effectively increase the hydrodynamic size, alter surface area and modify ion dissolution. Shape, crystallinity, defect density, surface coating, zeta potential and the surrounding medium also influence activity. These variables should therefore be reported together rather than using particle size as the sole descriptor.^[44, 49, 69, 82, 108, 113, 132]

IV. ROUTES FOR NANOPARTICLE SYNTHESIS

4.1 Top-down approaches

Top-down methods convert bulk materials into nanoscale structures through milling, lithography, laser ablation, sputtering and related physical processes. Their advantages include the absence of some wet-chemical reducing agents and the possibility of producing relatively pure materials, while limitations include high energy demand, specialized equipment and surface defects generated during mechanical processing.^[45, 77, 103, 140]

4.2 Bottom-up chemical approaches

Bottom-up synthesis constructs nanoparticles from atoms, ions, molecules or molecular clusters. Chemical reduction, sol-gel processing, co precipitation, solvothermal routes, micro emulsions, sonochemical methods, microwave-assisted synthesis and electrochemical techniques are widely used. These approaches can offer good control of nucleation and growth, but reagents, solvents and stabilizers may introduce toxicity or environmental burdens. Reaction temperature, precursor concentration, pH, reducing-

agent concentration and time are major determinants of nucleation, growth and aggregation. [28, 45, 65, 74, 77, 103]

4.3 Biological and plant-mediated synthesis

Biological synthesis uses plants, microorganisms, algae or biomolecules as sources of reducing and stabilizing components. Plant extracts are especially

convenient because they contain mixtures of phenolics, flavonoids, terpenoids, alkaloids, sugars, proteins, organic acids and other metabolites. These constituents may bind metal ions, alter their oxidation state, promote nucleation and remain associated with the nanoparticle surface as capping agents. [29–35, 46, 60, 63, 67, 82, 88, 96, 98, 114]



Figure 1: Conceptual workflow for plant-mediated synthesis and antimicrobial evaluation of metal oxide nanoparticles

V. ROLE OF PHYTOCHEMICALS IN GREEN SYNTHESIS

The chemical composition of the plant extract is a central variable in green nanoparticle synthesis. Phenolic compounds and flavonoids can donate electrons and coordinate metal ions, while proteins, polysaccharides and other macromolecules can contribute steric stabilization. The exact contribution of each metabolite depends on plant species, plant part, extraction solvent, extraction temperature, pH and post-extraction storage. Consequently, a reproducible green synthesis protocol should

characterize the extract rather than treating a plant name as a sufficient descriptor of the reducing system. [47, 51, 56, 60, 82, 91, 96, 114] The uploaded document specifically identifies flavonoids, phenolics, alkaloids, reducing sugars, proteins and related phytoconstituents as possible participants in nanoparticle formation and stabilization. It further emphasizes that phytochemical composition can influence nanoparticle size and shape. This supports a mechanistic model in which extract chemistry influences metal-ion complexation, reduction, nucleation, growth, surface adsorption and colloidal stability. [51, 82, 96, 114]

Table 1. Comparative characteristics of selected plant-mediated metal oxide nanoparticles

Nanomaterial	Key physicochemical features	Reported antimicrobial relevance	Important variables
ZnO	Semiconductor; surface-reactive; Zn ²⁺ release; ROS generation under suitable conditions	Membrane damage, permeability changes, oxidative stress and intracellular disruption	Size, surface area, defects, dose, pH, aggregation, extract chemistry
CuO	Copper-containing oxide with redox-active surface chemistry	Membrane damage and oxidative effects; activity reported against diverse bacteria	Particle size, Cu release, morphology, dose, medium
Fe ₂ O ₃ /Fe ₃ O ₄	Iron oxides; Fe-based surface chemistry;	Potential antimicrobial and biofilm-related activity; magnetic	Magnetic state, size, coating, aggregation, iron dissolution

	magnetic behavior especially for Fe ₃ O ₄	recovery can support engineered systems	
TiO ₂	Photocatalytic semiconductor; ROS generation under irradiation	Photocatalytic antimicrobial action and surface-mediated oxidative stress	Crystal phase, particle size, irradiation, surface area
MgO	Basic metal oxide with reactive surface	Reported antibacterial activity and membrane/oxidative effects	Particle size, surface defects, dose and medium

VI. PROCESS VARIABLES GOVERNING PLANT-MEDIATED NANOPARTICLE FORMATION

Green synthesis is not a single standardized reaction. The outcome depends on the ratio between plant extract and metal precursor, pH, temperature, reaction time, precursor concentration, mixing conditions and the chemical state of the extract. pH can change the ionization state of phytochemicals and the hydrolysis/precipitation behavior of metal precursors. Temperature can accelerate reduction and nucleation but may also change the extract chemistry. Calcination conditions can modify crystallinity, defect density, particle size and antimicrobial performance.^[48, 65, 73, 79, 114] Solvent choice is particularly relevant to the proposed research. Aqueous extraction is attractive from a green-chemistry perspective, while methanolic extraction can recover a different phytochemical

profile. Comparing aqueous and methanolic extracts may therefore reveal relationships between phytochemical composition and nanoparticle characteristics. The source document explicitly identifies this comparison as a research gap for plant-mediated metal oxide nanoparticles.^[10, 51, 79, 96]

VII. CHARACTERIZATION OF PLANT-MEDIATED METAL OXIDE NANOPARTICLES

Comprehensive characterization is necessary because biological activity cannot be interpreted reliably without knowing the physical and chemical properties of the material. In table 2, the research framework in the source document includes UV–visible spectroscopy, FTIR, XRD, SEM and TEM, with Raman and EDX discussed as additional analytical tools.^[13, 21, 65, 67, 69, 77, 87, 108]

Table 2. Various analytical tools used for Characterization of Plant-Mediated Metal Oxide Nanoparticles.

Technique	Principal information	Relevance to green-synthesized NPs
UV–visible spectroscopy	Optical absorption; preliminary evidence of nanoparticle formation and electronic transitions	Rapid monitoring of synthesis and optical stability
FTIR	Functional groups and chemical bonds associated with plant metabolites and nanoparticle surfaces	Supports identification of phytochemicals involved in reduction/capping
XRD	Crystal phase, crystallinity and average crystallite size	Confirms crystalline oxide phase and estimates crystallite dimensions
SEM	Surface morphology and particle aggregation	Visualizes morphology and surface architecture

TEM/HRTEM	Particle size, shape and high-resolution structure	Provides direct nanoscale imaging and structural information
Raman	Vibrational/phonon information	Useful for phase identification, defects and structural fingerprinting
EDX/EDS	Elemental composition	Confirms major elemental constituents and detects impurities

7.1 UV–Visible spectroscopy

UV–visible spectroscopy is a rapid monitoring method. Changes in absorbance with wavelength can provide evidence for nanoparticle formation and optical transitions, although a UV–visible spectrum alone is insufficient to establish particle size, crystallinity or chemical purity. [10, 52, 65, 69]

7.2 FTIR spectroscopy

FTIR can identify changes in functional-group bands before and after synthesis and can therefore support discussion of plant metabolites involved in reduction and capping. Interpretation should be made cautiously because band overlap is common in complex plant extracts. [37, 51, 82, 96, 114]

7.3 X-ray diffraction

XRD is used to establish crystalline phase and structural properties. The source document notes Bragg's law and the Scherrer approach for estimating average crystallite size from peak broadening. Because Scherrer size is a crystallite dimension rather than necessarily the whole particle size, it should be compared with TEM/SEM measurements rather than treated as interchangeable. [21, 65, 67]

7.4 SEM and TEM

SEM provides surface morphology, while TEM can directly resolve nanoparticle size and shape at much higher spatial resolution. Sample preparation, drying and aggregation can influence observed morphology; therefore, representative images and size distributions are preferable to single-particle photographs. [37, 67, 87]

7.5 Raman and EDX

Raman spectroscopy provides vibrational information that can complement XRD, especially for phase, lattice and defect analysis. EDX coupled to electron microscopy provides elemental information and can

support confirmation of the intended metal/oxygen composition, while also revealing possible contaminants. [13, 21, 67]

VIII. ANTIMICROBIAL RESISTANCE AND THE NEED FOR ALTERNATIVE MATERIALS

AMR arises through multiple mechanisms, including target modification, drug inactivation, reduced permeability, efflux and adaptive processes associated with biofilms. The source document highlights the difficulty of treating intracellular and biofilm-associated infections and the importance of pathogens such as *Escherichia coli*, *Staphylococcus aureus* and *Pseudomonas aeruginosa*. [54, 61, 68, 97, 111, 118, 127, 131] Nanoparticles may be useful because their antimicrobial action can involve several simultaneous stress pathways rather than one conventional antibiotic target. This does not mean resistance is impossible: adaptation to antimicrobial nanoparticles has been documented as an important research question. Accordingly, nanoparticle design should be evaluated both for antimicrobial potency and for the possibility of microbial adaptation. [54, 86, 97, 104, 108, 131, 132]

IX. ANTIMICROBIAL MECHANISMS OF METAL OXIDE NANOPARTICLES

Several mechanisms can operate together: adsorption to microbial surfaces; disruption of membrane integrity; increased membrane permeability; ROS generation; metal-ion release; interaction with proteins, lipids and nucleic acids; respiratory disturbance; and inhibition of biofilm development. The relative contribution of each pathway depends on nanoparticle composition, size, morphology, surface chemistry, dose and environmental conditions. [18, 24, 49, 69, 73, 105, 108, 119, 131, 132]

Table 3. Antimicrobial Mechanisms of Metal Oxide Nanoparticles to study drug resistant pathogens

Mechanism	Biological consequence	Relevance to drug-resistant pathogens
Surface attachment	Close nanoparticle–cell contact increases interfacial interactions	Can act independently of a conventional antibiotic target
Membrane disruption	Permeability changes, leakage and loss of membrane function	May compromise resistant cells with altered antibiotic targets
ROS generation	Oxidative damage to proteins, lipids and nucleic acids	Multiple cellular targets can produce broad-spectrum stress
Metal-ion release	Interaction of released ions with cellular components	Adds a soluble chemical stress pathway
Respiratory/metabolic disturbance	Damage to electron transport and cellular metabolism	Can amplify other antimicrobial mechanisms
Biofilm inhibition	Reduced attachment, matrix integrity or respiration	Potentially relevant to persistent and recurrent infections
Antibiotic synergy	Improved activity of conventional antibiotics in combination	May permit lower antibiotic exposure and restore activity in some settings

9.1 ZnO nanoparticles

ZnO is the central material in the uploaded research framework. The literature summarized in the source document associates ZnO antimicrobial activity with cell membrane damage, increased permeability, ROS such as hydrogen peroxide, and Zn^{2+} release. Smaller particles may display greater activity because of increased surface area and altered surface reactivity, although dose, aggregation and medium composition remain important. [52, 65, 73, 108, 131] ZnO can also be modified by doping. The supplied literature discusses dopants as a way of changing defects and physicochemical properties, with some studies reporting increased antibacterial activity. However, dopant identity, concentration, phase distribution and toxicity must be evaluated rather than assuming that doping always improves biological performance. [20, 65]

9.2 Ag, Cu and Fe-based nanoparticles as comparative systems

Silver nanoparticles have a particularly extensive antimicrobial literature, including activity against MDR strains and biofilms. Copper-based nanoparticles can provide redox-active antimicrobial effects, while iron oxide nanoparticles offer additional magnetic functionality that can be exploited in

engineered delivery or recovery systems. These materials are useful comparators for understanding how metal identity, dissolution and surface chemistry affect antimicrobial behavior. [55, 76, 81, 86, 100, 104, 105, 106, 115, 124]

X. NANOPARTICLE-BASED ANTIMICROBIAL STRATEGIES

Biofilms are structured microbial communities surrounded by extracellular polymeric substances. Biofilm-associated cells can show increased tolerance to antimicrobial treatment because of diffusion barriers, altered metabolism, persistent populations and community-level stress responses. Nanoparticles may interact with the biofilm matrix, alter attachment and produce localized oxidative or membrane stress. [68, 86, 92, 97, 100, 111, 127] Green-synthesized nanoparticles have been investigated for quorum-sensing interference and biofilm inhibition, particularly for Gram-negative pathogens. However, zone-of-inhibition data alone do not establish ant biofilm activity. Mature-biofilm assays, biomass measurements, viable-cell counts and mechanistic endpoints provide stronger evidence. [44, 55, 76, 106, 109]

XI. SYNERGY WITH CONVENTIONAL ANTIBIOTICS

Combining nanoparticles with antibiotics is an important strategy because the nanoparticle may increase membrane permeability, alter efflux or impose oxidative stress while the antibiotic acts on its conventional target. The supplied research document specifically cites enhanced activity of ZnO in combination with beta-lactams, cephalosporins and aminoglycosides. Such claims should ideally be supported by checkerboard assays, fractional inhibitory concentration indices, time-kill curves or other quantitative synergy methods rather than diffusion zones alone. [55, 75, 86, 95, 109]

XII. TOXICITY, SAFETY AND ENVIRONMENTAL CONSIDERATIONS

Antimicrobial activity does not automatically imply biomedical safety. Nanoparticle toxicity depends on dose, particle size, dissolution, surface chemistry, aggregation, exposure route and biological system. The source document appropriately emphasizes the need for in vitro and in vivo toxicity assessment before commercial or clinical application. Green synthesis

may reduce the use of hazardous reagents, but it does not guarantee that the final nanoparticle is non-toxic. [53, 60, 69, 82, 87, 110, 131] Future evaluations should distinguish toxicity caused by the nanoparticle core from effects caused by residual plant metabolites, precursor salts or synthesis by-products. Reporting particle dose on both mass and, where possible, particle-number or surface-area bases may improve comparability between studies. Environmental fate, transformation, aggregation and effects on beneficial microorganisms also deserve attention. [59, 82, 110, 119]

XIII. BIOMEDICAL AND OTHER APPLICATIONS

Metal and metal oxide nanoparticles have been explored in drug delivery, wound-related materials, antimicrobial coatings, food packaging, water treatment, diagnostics and other technologies. Their multi functionality makes them attractive as both active antimicrobial materials and components of delivery systems. Nevertheless, translation requires reproducible synthesis, standardized characterization, dose optimization and rigorous safety testing. [49, 59, 81, 95, 101, 119, 121, 128]

Table 4. Key applications and development considerations

Application	Potential role	Development requirement
Wound-care materials	Antimicrobial coatings or nanocomposites	Cyto-compatibility, controlled release, biofilm efficacy
Drug delivery	Nano carriers and combination systems	Targeting, pharmacokinetics, stability and toxicity
Antimicrobial coatings	Persistent surface protection	Adhesion, durability, leaching and environmental safety
Food packaging	Reduction of microbial contamination	Migration studies and food-contact safety
Water treatment	Antimicrobial and contaminant-removal systems	Recovery, regeneration and Eco toxicity
Diagnostic/therapeutic platforms	Multifunctional Nano-enabled systems	Validated performance and clinical translation

XIV. SOLANUM XANTHOCARPUM AS A CANDIDATE FOR GREEN ZNO SYNTHESIS

The uploaded research document identifies *Solanum xanthocarpum* as the principal medicinal plant for the proposed experimental work. It notes that the leaves and fruits have been comparatively well represented in the pharmacological literature, whereas the stem and roots have received much less attention for nanoparticle-mediated applications. The document further states that only limited work was identified for silver and copper nanoparticles using *S. xanthocarpum* extracts and that systematic studies of ZnO

nanoparticles prepared from stem and root extracts were not identified in the reviewed literature.^[14, 30, 40, 41] The plant is therefore positioned as a useful candidate for exploring whether underutilized plant parts can provide phytochemicals capable of reducing and stabilizing ZnO nanoparticles. The proposed work compares aqueous and methanolic extracts, performs qualitative phytochemical screening, synthesizes ZnO nanoparticles by a green route and evaluates their physicochemical, antioxidant and antibacterial properties. This research gap and workflow are explicitly described in the supplied document.^[14, 40, 41]

Table 5. Proposed experimental framework derived from the doctoral research document

Stage	Proposed activity	Expected output
1	Collection and authentication of <i>S. xanthocarpum</i> stem and roots	Standardized plant material
2	Preparation of aqueous and methanolic extracts	Extracts with distinct phytochemical profiles
3	Qualitative phytochemical screening	Evidence of major metabolite classes
4	Green synthesis of ZnO nanoparticles	Plant-mediated ZnO nanoparticle suspensions/powders
5	UV-visible, FTIR, XRD, SEM and TEM characterization	Optical, chemical, crystalline and morphological profiles
6	DPPH antioxidant assay	Comparative free-radical scavenging response
7	Antibacterial diffusion/dilution assays	Growth inhibition and concentration-dependent activity
8	Comparison of extract type and nanoparticle performance	Structure–process–activity relationship
9	Interpretation against drug-resistant pathogens	Assessment of translational relevance

XV. RESEARCH GAPS AND FUTURE DIRECTIONS

Several gaps emerge from the literature synthesized in the source document. First, green synthesis protocols are often difficult to reproduce because extract composition varies with species, plant part, season, geography, extraction solvent and processing. Second, many studies report antimicrobial zones without standardized nanoparticle characterization or

MIC/MBC data. Third, correlations between phytochemical profiles and nanoparticle surface chemistry remain incomplete. Fourth, the distinction between nanoparticle-specific activity and activity of dissolved metal ions or residual phytochemicals is often insufficiently resolved.^[51, 60, 67, 73, 82, 96, 108, 119] Future studies should therefore combine quantitative phytochemical profiling with controlled synthesis and standardized biological assays. Particle size distributions should be measured rather than

represented by a single average; colloidal stability and zeta potential should be reported; dissolution and ion release should be considered; and antimicrobial mechanisms should be tested with orthogonal assays. For MDR pathogens, MIC, MBC, time-kill, biofilm and antibiotic-synergy experiments would provide substantially stronger evidence than agar diffusion alone. [68, 86, 97, 106, 109, 131] For *Solanum xanthocarpum*, a particularly useful direction is to compare stem and root extracts systematically and relate their phytochemical fingerprints to ZnO nucleation, capping and antimicrobial activity. Such an approach could establish whether solvent-dependent extraction changes particle size, crystallinity, surface chemistry and biological efficacy. The source document's restriction to laboratory-based work should be retained as a limitation until toxicity, animal and clinical studies are independently completed. [14, 40, 41]

XVI. CONCLUSION

Plant-mediated synthesis provides a promising route for producing metal oxide nanoparticles using naturally occurring phytochemicals as reducing, coordinating and stabilizing components. ZnO is a particularly relevant candidate for antimicrobial research because its surface chemistry, ROS generation and Zn²⁺ release can act through several microbial targets. CuO, iron oxides, TiO₂ and MgO provide complementary platforms with distinct redox, photocatalytic or magnetic characteristics. However, antimicrobial performance depends on particle size, morphology, crystallinity, aggregation, surface chemistry, dose and test conditions, making rigorous characterization essential. [28, 46, 67, 69, 108, 132] The doctoral research framework based on *S. xanthocarpum* stem and root extracts addresses a meaningful gap identified in the supplied literature. Its combination of phytochemical screening, green ZnO synthesis, UV-visible/FTIR/XRD/SEM/TEM characterization, DPPH antioxidant evaluation and antibacterial testing can generate a coherent structure property activity relationship. The ultimate value of plant-mediated nanoparticles will depend not only on antimicrobial potency but also on reproducibility, mechanistic understanding, safety and environmental compatibility. Therefore, green synthesis should be viewed as a platform for rational nanoparticle design rather than simply a substitute for chemical synthesis.

REFERENCES

- [1] Sheik Mydeen, S., Raj Kumar, R., Kottaisamy, M., & Vasantha, V. S. (2020). Biosynthesis of ZnO nanoparticles through extract from *Prosopis juliflora* plant leaf: Antibacterial activities and a new approach by rust-induced photocatalysis. *Journal of Saudi Chemical Society*, 24(5), 393–406. <https://doi.org/10.1016/j.jscs.2020.03.003>
- [2] Thatyana, M., Dube, N. P., Kemboi, D., Manicum, A. L. E., Mokgalaka-Fleischmann, N. S., & Tembu, J. V. (2023). Advances in Phytonanotechnology: A Plant-Mediated Green Synthesis of Metal Nanoparticles Using *Phyllanthus* Plant Extracts and Their Antimicrobial and Anticancer Applications. *Nanomaterials*, 13(19). <https://doi.org/10.3390/nano13192616>
- [3] Castillo-Henríquez, L., Alfaro-Aguilar, K., Ugalde-álvarez, J., Vega-Fernández, L., de Oca-Vásquez, G. M., & Vega-Baudrit, J. R. (2020). Green synthesis of gold and silver nanoparticles from plant extracts and their possible applications as antimicrobial agents in the agricultural area. *Nanomaterials*, 10(9), 1–24. <https://doi.org/10.3390/nano10091763>
- [4] Essghaier, B., Toukabr, N., Dridi, R., Hannachi, H., Limam, I., Mottola, F., ... Abdelkarim, M. (2022). First Report of the Biosynthesis and Characterization of Silver Nanoparticles Using *Scabiosa atropurpurea* subsp. *maritima* Fruit Extracts and Their Antioxidant, Antimicrobial and Cytotoxic Properties. *Nanomaterials*, 12(9), 1–15. <https://doi.org/10.3390/nano12091585>
- [5] Iqtedar, M., Aslam, M., Akhyar, M., Shehzaad, A., Abdullah, R., & Kaleem, A. (2019). Extracellular biosynthesis, characterization, optimization of silver nanoparticles (AgNPs) using *Bacillus mojavensis* BTCB15 and its antimicrobial activity against multidrug resistant pathogens. *Preparative Biochemistry and Biotechnology*, 49(2), 136–142. <https://doi.org/10.1080/10826068.2018.1550654>
- [6] Qais, F. A., Samreen, and Ahmad, I. (2018). Broad-spectrum inhibitory effect of green synthesised silver nanoparticles from *Withania*

- somnifera (L.) on microbial growth, biofilm and respiration: a putative mechanistic approach. IET Nanobiotechnology 12, 325–335. doi:10.1049/iet-nbt.2017.0193 Qais, F. A., Samreen, and Ahmad, I. (2019b). “Green synthesis of metal nanoparticles: characterization and their antibacterial efficacy,” in Antibacterial drug discovery to combat MDR (Singapore: Springer Singapore), 635–680. doi:10.1007/978-981-13-9871-1_28
- [7] Biosynthesis of metallic nanoparticles using plant extracts and evaluation of their antibacterial properties ARTICLE INFO. Nanochem Res, 3(1), 1–16. <https://doi.org/10.22036/ncr.2018.01.001>
- [8] Hamk, M., Akçay, F. A., & Avcı, A. (2023). Green synthesis of zinc oxide nanoparticles using *Bacillus subtilis* ZBP4 and their antibacterial potential against foodborne pathogens. Preparative Biochemistry and Biotechnology, 53(3), 255–264. <https://doi.org/10.1080/10826068.2022.2076243>
- [9] Jain, S., & Mehata, M. S. (2017). Medicinal Plant Leaf Extract and Pure Flavonoid Mediated Green Synthesis of Silver Nanoparticles and their Enhanced Antibacterial Property. Scientific Reports, 7(1), 1–13. <https://doi.org/10.1038/s41598-017-15724-8>
- [10] Wang, D., Cui, L., Chang, X., & Guan, D. (2020). Biosynthesis and characterization of zinc oxide nanoparticles from *Artemisia annua* and investigate their effect on proliferation, osteogenic differentiation and mineralization in human osteoblast-like MG-63 Cells. Journal of Photochemistry and Photobiology B: Biology, 202(October 2019), 111652. <https://doi.org/10.1016/j.jphotobiol.2019.111652>
- [11] Aadil, K.R., Pandey, N., Mussatto, S.I., Jha, H., 2019. Green synthesis of silver nanoparticles using acacia lignin, their cytotoxicity, catalytic, metal ion sensing capability and antibacterial activity. J. Environ. Chem. Eng. 7, <https://doi.org/10.1016/J.JECE.2019.103296>
- [12] Abdullah, F. H., Abu Bakar, N. H. H., & Abu Bakar, M. (2020). Low temperature biosynthesis of crystalline zinc oxide nanoparticles from *Musa acuminata* peel extract for visible-light degradation of methylene blue. Optik, 206, 164279. <https://doi.org/10.1016/j.ijleo.2020.164279>
- [13] Alharbi, N. S., Alsubhi, N. S., & Felimban, A. I. (2022). Green synthesis of silver nanoparticles using medicinal plants: Characterization and application. Journal of Radiation Research and Applied Sciences, 15(3), 109–124. <https://doi.org/10.1016/j.jrras.2022.06.012>
- [14] Ali, K., Ahmed, B., Dwivedi, S., Saquib, Q., Al-Khedhairi, A. A., and Musarrat, J. (2015). Microwave accelerated green synthesis of stable silver nanoparticles with *Eucalyptus globulus* leaf extract and their antibacterial and antibiofilm activity on clinical isolates. PLoS One 10, 01311788–e131220. doi: 10.1371/journal.pone.0131178
- [15] Anandalakshmi, K., Venugobal, J., Ramasamy, V., 2016. Characterization of silver nanoparticles by green synthesis method using *Pedaliu murex* leaf extract and their antibacterial activity. Appl. Nanosci. 6, 399–408. <https://doi.org/10.1007/S13204-015-0449-Z/TABLES/2>.
- [16] Dhandapani, K. V., Anbumani, D., Gandhi, A. D., Annamalai, P., Muthuvenkatachalam, B. S., Kavitha, P., & Ranganathan, B. (2020). Green route for the synthesis of zinc oxide nanoparticles from *Melia azedarach* leaf extract and evaluation of their antioxidant and antibacterial activities. Biocatalysis and Agricultural Biotechnology, 24, 101517.
- [17] Fontecha-Umaña, F., Ríos-Castillo, A. G., Ripolles-Avila, C., & Rodríguez-Jerez, J. J. (2020). Antimicrobial activity and prevention of bacterial biofilm formation of silver and zinc oxide nanoparticle-containing polyester surfaces at various concentrations for use. Foods, 9(4). <https://doi.org/10.3390/foods9040442>
- [18] Iqbal, J., Ahsan, B., Mahmood, T., Kanwal, S., Ahmad, R., & Ashraf, M. (2019). Plant-extract mediated green approach for the synthesis of ZnONPs : Characterization and evaluation of cytotoxic , antimicrobial and antioxidant potentials. Journal of Molecular Structure, 1189, 315–327.

- [19] Król, A., Railean-Plugaru, V., Pomastowski, P., & Buszewski, B. (2019). Phytochemical investigation of *Medicago sativa* L. extract and its potential as a safe source for the synthesis of ZnO nanoparticles: The proposed mechanism of formation and antimicrobial activity. *Phytochemistry Letters*, 31(March), 170–180. <https://doi.org/10.1016/j.phytol.2019.04.009>
- [20] Md Ishak, N. A. I., Kamarudin, S. K., & Timmiati, S. N. (2019a). Green synthesis of metal and metal oxide nanoparticles via plant extracts: an overview. *Materials Research Express*, 6(11). <https://doi.org/10.1088/2053-1591/ab4458>
- [21] Md Ishak, N. A. I., Kamarudin, S. K., & Timmiati, S. N. (2019b). Green synthesis of metal and metal oxide nanoparticles via plant extracts: an overview. *Materials Research Express*, 6(11), 11204. <https://doi.org/10.1088/2053-1591/ab4458>
- [22] Mohanta, Y. K., Biswas, K., Jena, S. K., Hashem, A., Abd_Allah, E. F., & Mohanta, T. K. (2020). Anti-biofilm and Antibacterial Activities of Silver Nanoparticles Synthesized by the Reducing Activity of Phytoconstituents Present in the Indian Medicinal Plants. *Frontiers in Microbiology*, 11(June), 1–15. <https://doi.org/10.3389/fmicb.2020.01143>
- [23] Nasr, H. A., Nassar, O. M., El-Sayed, M. H., & Kobisi, A. A. (2019). Characterization and antimicrobial activity of lemon peel mediated green synthesis of silver nanoparticles. *International Journal of Biology and Chemistry*, 12(2), 56–63. <https://doi.org/10.26577/ijbch-2019-v2-7>
- [24] 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. <https://doi.org/10.1007/s00253-018-9146-7>
- [25] Oves, M., Ahmar Rauf, M., Aslam, M., Qari, H. A., Sonbol, H., Ahmad, I., et al. (2022). Green synthesis of silver nanoparticles by *Conocarpus Lancifolius* plant extract and their antimicrobial and anticancer activities. *Saudi J. Biol. Sci.* 29, 460–471. doi:10.1016/j.sjbs.2021.09.007
- [26] Salih, A. M., Al-Qurainy, F., Khan, S., Tarroum, M., Nadeem, M., Shaikhaldein, H. O., ... Alfarraj, N. S. (2021). Biosynthesis of zinc oxide nanoparticles using *Phoenix dactylifera* and their effect on biomass and phytochemical compounds in *Juniperus procera*. *Scientific Reports*, 11(1), 1–12. <https://doi.org/10.1038/s41598-021-98607-3>
- [27] Shafey, A. M. El. (2020, January 1). Green synthesis of metal and metal oxide nanoparticles from plant leaf extracts and their applications: A review. *Green Processing and Synthesis*, Vol. 9, pp. 304–339. De Gruyter. <https://doi.org/10.1515/gps-2020-0031>
- [28] Sharma, D., Sabela, M. I., Kanchi, S., Mdluli, P. S., Singh, G., Stenström, T. A., & Bisetty, K. (2016). Biosynthesis of ZnO nanoparticles using *Jacaranda mimosifolia* flowers extract: Synergistic antibacterial activity and molecular simulated facet specific adsorption studies. *Journal of Photochemistry and Photobiology B: Biology*, 162, 199–207. <https://doi.org/10.1016/j.jphotobiol.2016.06.043>
- [29] Abomuti, M. A., Danish, E. Y., Firoz, A., Hasan, N., & Malik, M. A. (2021). Green synthesis of zinc oxide nanoparticles using *salvia officinalis* leaf extract and their photocatalytic and antifungal activities. *Biology*, 10(11). <https://doi.org/10.3390/biology10111075>
- [30] Din, M. I., Arshad, F., Hussain, Z., & Mukhtar, M. (2017). Green Adeptness in the Synthesis and Stabilization of Copper Nanoparticles: Catalytic, Antibacterial, Cytotoxicity, and Antioxidant Activities. *Nanoscale Research Letters*, 12(8). <https://doi.org/10.1186/s11671-017-2399-8>
- [31] Fernandes, R. A., Berretta, A. A., Torres, E. C., Buszinski, A. F. M., Fernandes, G. L., Mendes-Gouvêa, C. C., ... Barbosa, D. B. (2018). Antimicrobial potential and cytotoxicity of silver nanoparticles phytosynthesized by pomegranate peel extract. *Antibiotics*, 7(3), 1–14. <https://doi.org/10.3390/antibiotics7030051>
- [32] Happy, A., Soumya, M., Venkat Kumar, S., Rajeshkumar, S., Sheba Rani, N. D., Lakshmi, T., & Deepak Nallaswamy, V. (2019). Phyto-assisted synthesis of zinc oxide nanoparticles

- using *Cassia alata* and its antibacterial activity against *Escherichia coli*. *Biochemistry and Biophysics Reports*, 17(January), 208–211. <https://doi.org/10.1016/j.bbrep.2019.01.002>
- [33] Ibrahim, H. M. M. (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, 265–275. doi:10.1016/j.jrras.2015.01.007
- [34] Jamdagni, P., Khatri, P., & Rana, J. S. (2018). Green synthesis of zinc oxide nanoparticles using flower extract of *Nyctanthes arbor-tristis* and their antifungal activity. *Journal of King Saud University - Science*, 30(2), 168–175. <https://doi.org/10.1016/j.jksus.2016.10.002>
- [35] Król, A., Pomastowski, P., Rafińska, K., Railean-Plugaru, V., & Buszewski, B. (2018). Corrigendum to “Zinc oxide nanoparticles: synthesis, antiseptic activity and toxicity mechanism” *Adv Colloid Interface Sci* 249 (2017) 37-52 (S0001868617301197) (10.1016/j.cis.2017.07.033)). *Advances in Colloid and Interface Science*, 254(2018), 100. <https://doi.org/10.1016/j.cis.2018.04.006>
- [36] Kumar, S., Shahid, M., Khan, M.A., Kumar, N., Khan, H.M., 2020. Biosynthesis of silver nanoparticles from *Phyllanthus niruri* leaf extracts and its antibacterial activity against antibiotics-resistant clinical isolates. *Pathology* 52, S127. <https://doi.org/10.1016/J.PATHOL.2020.01.432>.
- [37] Madubuonu, N., Aisida, S. O., Ali, A., Ahmad, I., Zhao, T. kai, Botha, S., ... Ezema, F. I. (2019). Biosynthesis of iron oxide nanoparticles via a composite of *Psidium guajava*-*Moringa oleifera* and their antibacterial and photocatalytic study. *Journal of Photochemistry and Photobiology B: Biology*, 199(June), 111601. <https://doi.org/10.1016/j.jphotobiol.2019.111601>
- [38] Moodley, J.S., Krishna, S.B.N., Pillay, K., Sershen, G., P., 2018. Green synthesis of silver nanoparticles from *Moringa oleifera* leaf extracts and its antimicrobial potential. *Adv. Nat. Sci. Nanosci. Nanotechnol.* 9. <https://doi.org/10.1088/2043-6254/aaabb2>.
- [39] Ocsoy, I., Demirbas, A., Mclamore, E. S., Altinsoy, B., Ildiz, N., & Baldemir, A. (2017). Green synthesis with incorporated hydrothermal approaches for silver nanoparticles formation and enhanced antimicrobial activity against bacterial and fungal pathogens ☆. *Journal of Molecular Liquids*, 238, 263–269. <https://doi.org/10.1016/j.molliq.2017.05.012>
- [40] Optimization for extracellular biosynthesis of silver nanoparticles by *Penicillium aculeatum* Su1 and their antimicrobial activity and cytotoxic effect compared with silver ions. *Materials Science and Engineering C*, 77, 963–971. <https://doi.org/10.1016/j.msec.2017.03.294>
- [41] Qais, F.A., Shafiq, A., Ahmad, I., Husain, F.M., Khan, R.A., Hassan, I., 2020. Green synthesis of silver nanoparticles using *Carum copticum*: Assessment of its quorum sensing and biofilm inhibitory potential against gram negative bacterial pathogens. *Microb. Pathog.* 144, <https://doi.org/10.1016/j.micpath.2020.104172> 104172.
- [42] Rakib-Uz-Zaman, S. M., Hoque Apu, E., Muntasir, M. N., Mowna, S. A., Khanom, M. G., Jahan, S. S., ... Khan, K. (2022). Biosynthesis of Silver Nanoparticles from *Cymbopogon citratus* Leaf Extract and Evaluation of Their Antimicrobial Properties. *Challenges*, 13(1), 18. <https://doi.org/10.3390/challe13010018>
- [43] Rana, A., Yadav, K., & Jagadevan, S. (2020). A comprehensive review on green synthesis of nature-inspired metal nanoparticles: Mechanism, application and toxicity. *Journal of Cleaner Production*, 272, 122880. <https://doi.org/10.1016/J.JCLEPRO.2020.122880>
- [44] Sadeghi, B., Rostami, A., and Momeni, S. S. (2015). Facile green synthesis of silver nanoparticles using seed aqueous extract of *Pistacia atlantica* and its antibacterial activity. *Spectrochim. Acta - Part A Mol. Biomol. Spectrosc.* 134, 326–332. doi:10.1016/j.saa.2014.05.078
- [45] Tabrizi Hafez Moghaddas, S. M., Elahi, B., & Javanbakht, V. (2020). Biosynthesis of pure

- zinc oxide nanoparticles using Quince seed mucilage for photocatalytic dye degradation. *Journal of Alloys and Compounds*, 821, 153519.
<https://doi.org/10.1016/j.jallcom.2019.153519>
- [46] Thambirajoo, M., Maarof, M., Lokanathan, Y., Katas, H., Ghazalli, N. F., Tabata, Y., & Fauzi, M. B. (2021). Potential of nanoparticles integrated with antibacterial properties in preventing biofilm and antibiotic resistance. *Antibiotics*, 10(11).
<https://doi.org/10.3390/antibiotics10111338>
- [47] Abdel-Rahman, L. H., El-Khatib, R. M., Nassr, L. A. E., Abu-Dief, A. M., Ismael, M., & Seleem, A. A. (2014). Metal based pharmacologically active agents: Synthesis, structural characterization, molecular modeling, CT-DNA binding studies and in vitro antimicrobial screening of iron(II) bromosalicylidene amino acid chelates. *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy*, 117, 366–378.
<https://doi.org/10.1016/j.saa.2013.07.056>
- [48] Ahmad, Tausif, Bustam, M. A., Irfan, M., Moniruzzaman, M., Asghar, H. M. A., & Bhattacharjee, S. (2019). Mechanistic investigation of phytochemicals involved in green synthesis of gold nanoparticles using aqueous *Elaeis guineensis* leaves extract: Role of phenolic compounds and flavonoids. *Biotechnology and Applied Biochemistry*, 66(4), 698–708.
<https://doi.org/10.1002/bab.1787>
- [49] Ahmad, W., & Kalra, D. (2020). Green synthesis, characterization and anti-microbial activities of ZnO nanoparticles using *Euphorbia hirta* leaf extract. *Journal of King Saud University - Science*, 32(4), 2358–2364.
- [50] Alekshun, M.N., Levy, S.B., 2007. Molecular mechanisms of antibacterial multidrug resistance. *Cell* 128, 1037–1050.
<https://doi.org/10.1016/j.cell.2007.03.004>
- [51] Ali, S.G., Ansari, M.A., Khan, H.M., Jalal, M., Mahdi, A.A., Cameotra, S.S., 2018. Antibacterial and antibiofilm potential of green synthesized silver nanoparticles against imipenem resistant clinical isolates of *P. aeruginosa*. *Bionanoscience* 8, 544–553.
<https://doi.org/10.1007/s12668-018-0505-8>
- [52] Al-Khayri, J. M., Yüksel, A. K., Yüksel, M., Işık, M., & Dikici, E. (2022). Phenolic Profile and Antioxidant, Anticholinergic, and Antibacterial Properties of Corn Tassel. *Plants*, 11(15), 1899.
<https://doi.org/10.3390/plants11151899>
- [53] Amina, M., Al Musayeib, N. M., Alarfaj, N. A., El-Tohamy, M. F., & Al-Hamoud, G. (2020). Antibacterial and immunomodulatory potentials of biosynthesized Ag, Au, Ag-Au bimetallic alloy nanoparticles using the asparagus racemosus root extract. *Nanomaterials*, 10(12), 1–20.
<https://doi.org/10.3390/nano10122453>
- [54] An, R., Wei, H., Narasaiah, B. P., Mandal, K., Gupta, A., & Mishra, V. (2020). A Review on Green Synthesis of ZnO Nanoparticles Using *Coriandrum Sativum* Leaf Extract for Degrading Dyes in Textile Wastewater: A Prospect Towards
- [55] Chung, I. M., Park, I., Seung-Hyun, K., Thiruvengadam, M., & Rajakumar, G. (2016). Plant-Mediated Synthesis of Silver Nanoparticles: Their Characteristic Properties and Therapeutic Applications. *Nanoscale Research Letters*, 11(1), 1–14.
<https://doi.org/10.1186/s11671-016-1257-4>
- [56] De Jesus, R. A., de Assis, G. C., de Oliveira, R. J., Costa, J. A. S., da Silva, C. M. P., Bilal, M., ... Figueiredo, R. T. (2021). Environmental remediation potentialities of metal and metal oxide nanoparticles: Mechanistic biosynthesis, influencing factors, and application standpoint. *Environmental Technology and Innovation*, 24, 101851.
<https://doi.org/10.1016/j.eti.2021.101851>
- [57] El-Seedi, H. R., El-Shabasy, R. M., Khalifa, S. A. M., Saeed, A., Shah, A., Shah, R., Guo, W. (2019). Metal nanoparticles fabricated by green chemistry using natural extracts: Biosynthesis, mechanisms, and applications. *RSC Advances*, 9(42), 24539–24559.
<https://doi.org/10.1039/c9ra02225b>
- [58] Gkartziou, F., Giormezis, N., Spiliopoulou, I., & Antimisari, S. G. (2021). Nanobiosystems for antimicrobial drug-resistant infections. *Nanomaterials*, Vol. 11. MDPI AG.
<https://doi.org/10.3390/nano11051075>

- [59] Green Chemistry A Review on Green Synthesis of ZnO Nanoparticles Using Coriandrum Sativum Leaf Extract For. Materials Science and Engineering, 736, 0–8. <https://doi.org/10.1088/1757-899X/736/4/042003>.
- [60] Hagos, S., Marshet, G., & Sendeku, G. (2019). New frontiers in the biosynthesis of metal oxide nanoparticles and their environmental applications: an overview. SN Applied Sciences, 1(8), 1–28. <https://doi.org/10.1007/s42452-019-0931-4>
- [61] Hamida, R. S., Ali, M. A., Abdelmeguid, N. E., Al-Zaban, M. I., Baz, L., & Bin- Meferij, M. M. (2021). Lichens a potential source for nanoparticles fabrication: A review on nanoparticles biosynthesis and their prospective applications. Journal of Fungi, 7(4), 87. <https://doi.org/10.3390/jof7040291>
- [62] Ismail, A. M., Menazea, A. A., Kabary, H. A., El-Sherbiny, A. E., & Samy, A. (2019). The influence of calcination temperature on structural and antimicrobial characteristics of zinc oxide nanoparticles synthesized by Sol–Gel method. Journal of Molecular Structure, 1196, 332–337.
- [63] Jain, A. S., Pawar, P. S., Sarkar, A., & Junnuthula, V. (2021). Bionanofactories for Green Synthesis of Silver Nanoparticles: Toward Antimicrobial Applications. Molecular Sciences, 22(11993).
- [64] Jeevanandam, J., Chan, Y. S., & Danquah, M. K. (2016). Biosynthesis of metal and metal oxide nanoparticles. ChemBioEng Reviews, 3(2), 55–67. <https://doi.org/10.1002/cben.201500018>
- [65] Johani, K., Abualsaud, D., Costa, D. M., Hu, H., Whiteley, G., Deva, A., & Vickery, K. (2018). Characterization of microbial community composition, antimicrobial resistance and biofilm on intensive care surfaces. Journal of Infection and Public Health, 11(3), 418–424. <https://doi.org/10.1016/j.jiph.2017.10.005>
- [66] Kalpana, V. N., & Devi Rajeswari, V. (2018). A Review on Green Synthesis, Biomedical Applications, and Toxicity Studies of ZnO NPs. Bioinorganic Chemistry and Applications, 2018(3569758), 12 pages. <https://doi.org/10.1155/2018/3569758>
- [67] Liang, H., Zhang, P., Yu, B., Liu, Z., Pan, L., He, X., ... Wang, Y. (2022). Machine perfusion combined with antibiotics prevents donor-derived infections caused by multidrug-resistant bacteria. American Journal of Transplantation, 22(7), 1791–1803. <https://doi.org/10.1111/ajt.17032>
- [68] Logeswari, P., Silambarasan, S., and Abraham, J. (2015). Synthesis of silver nanoparticles using plants extract and analysis of their antimicrobial property. J. Saudi Chem. Soc. 19, 311–317. doi: 10.1016/j.jscs.2012.04.007
- [69] Marchiosi, R., dos Santos, W. D., Constantín, R. P., de Lima, R. B., Soares, A. R., Finger-Teixeira, A., ... Ferrarese-Filho, O. (2020). Biosynthesis and metabolic actions of simple phenolic acids in plants. In Phytochemistry Reviews (Vol. 19). <https://doi.org/10.1007/s11101-020-09689-2>
- [70] Mohammed, A. B. A., Mohamed, A., El-Naggar, N. E. A., Mahrous, H., Nasr, G. M., Abdella, A., ... Ali, A. S. (2022). Antioxidant and Antibacterial Activities of Silver Nanoparticles Biosynthesized by Moringa oleifera through Response Surface Methodology. Journal of Nanomaterials, 2022(Ccd), 15. <https://doi.org/10.1155/2022/9984308>
- [71] Mohd Yusof, H., Abdul Rahman, N., Mohamad, R., Hasanah Zaidan, U., & Samsudin, A. (2021). Antibacterial potential of biosynthesized zinc oxide nanoparticles against poultry-associated foodborne pathogens: An in vitro study. Animals, 11(7). <https://doi.org/10.3390/ani11072093>
- [72] Naseer, M., Aslam, U., Khalid, B., & Chen, B. (2020). Green route to synthesize Zinc Oxide Nanoparticles using leaf extracts of Cassia fistula and Melia azadarach and their antibacterial potential. Scientific Reports, 10(1), 1–10. <https://doi.org/10.1038/s41598-020-65949-3>
- [73] Nasrollahzadeh, M., & Mohammad Sajadi, S. (2016). Green synthesis, characterization and catalytic activity of the Pd/TiO₂ nanoparticles for the ligand-free Suzuki–Miyaura coupling reaction. Journal of Colloid and Interface

- Science, 465, 121–127.
<https://doi.org/10.1016/j.jcis.2015.11.038>
- [74] Prasad, S. R., Teli, S. B., Ghosh, J., Prasad, N. R., Shaikh, V. S., Nazeruddin, G. M.,... Shaikh, Y. I. (2021). A Review on Bio-inspired Synthesis of Silver Nanoparticles: Their Antimicrobial Efficacy and Toxicity. *Engineered Science*, 16, 90–128.
<https://doi.org/10.30919/es8d479>
- [75] Qais, F.A., Shafiq, A., Khan, H.M., Husain, F.M., Khan, R.A., Alenazi, B., Alsahme, A., Ahmad, I., 2019. Antibacterial effect of silver nanoparticles synthesized using *Murraya koenigii* (L.) against multidrug-resistant pathogens. *Bioinorg. Chem. Appl.* 2019.
<https://doi.org/10.1155/2019/4649506>.
- [76] Radulescu, D. M., Surdu, V. A., Ficai, A., Ficai, D., Grumezescu, A. M., & Andronescu, E. (2023). Green Synthesis of Metal and Metal Oxide Nanoparticles: A Review of the Principles and Biomedical Applications. *International Journal of Molecular Sciences*, 24(20).
<https://doi.org/10.3390/ijms242015397>
- [77] Rasli, N. I., Basri, H., & Harun, Z. (2020). Zinc oxide from aloe vera extract: two-level factorial screening of biosynthesis parameters. *Heliyon*, 6(1), e03156.
<https://doi.org/10.1016/j.heliyon.2020.e03156>
- [78] Rodríguez-Félix, F., Graciano-Verdugo, A. Z., Moreno-Vásquez, M. J., Lagarda-Díaz, I., Barreras-Urbina, C. G., Armenta-Villegas, L., ... Tapia-Hernández, J. A. (2022). Trends in Sustainable Green Synthesis of Silver Nanoparticles Using Agri- Food Waste Extracts and Their Applications in Health. *Journal of Nanomaterials*, 2022(8874003), 37.
<https://doi.org/10.1155/2022/8874003>
- [79] Salleh, A., Naomi, R., Utami, N. D., Mohammad, A. W., Mahmoudi, E., Mustafa, N., & Fauzi, M. B. (2020). The potential of silver nanoparticles for antiviral and antibacterial applications: A mechanism of action. *Nanomaterials*, 10(8), 1–20.
<https://doi.org/10.3390/nano10081566>
- [80] Soltys, L., Olkhovyy, O., Tatarchuk, T., & Naushad, M. (2021). Green synthesis of metal and metal oxide nanoparticles: Principles of green chemistry and raw materials. *Magnetochemistry*, 7(11), 1–34.
<https://doi.org/10.3390/magnetochemistry7110145>
- [81] Akter, M., Sikder, M. T., Rahman, M. M., Ullah, A. K. M. A., Hossain, K. F. B., Banik, S., ... Kurasaki, M. (2018). A systematic review on silver nanoparticles-induced cytotoxicity: Physicochemical properties and perspectives. *Journal of Advanced Research*, 9, 1–16.
<https://doi.org/10.1016/j.jare.2017.10.008>.
- [82] Ali, S. G., Ansari, M. A., Khan, H. M., Jalal, M., Mahdi, A. A., and Cameotra, S. S. (2018). Antibacterial and antibiofilm potential of green synthesized silver nanoparticles against imipenem resistant clinical isolates of *P. aeruginosa*. *Bionanoscience* 8, 544–553.
[doi:10.1007/s12668-018-0505-8](https://doi.org/10.1007/s12668-018-0505-8)
- [83] Angamuthu, S., Thangaswamy, S., Raju, A., Husain, F.M., Ahmed, B., Al-Shabib, N.A., Hakeem, M.J., Shahzad, S.A., Abudujayn, S.A., Alomar, S.Y., 2023. Biogenic preparation and characterization of silver nanoparticles from seed kernel of *Mangifera indica* and their antibacterial potential against *Shigella* spp. *Molecules* 28, 2468.
<https://doi.org/10.3390/molecules28062468>.
- [84] Auría-Soro, C., Nesma, T., Juanes-Velasco, P., Landeira-Viñuela, A., Fidalgo-Gomez, H., Acebes-Fernandez, V., ... Fuentes, M. (2019). Interactions of nanoparticles and biosystems: Microenvironment of nanoparticles and biomolecules in nanomedicine. *Nanomaterials*, 9(10). <https://doi.org/10.3390/nano9101365>
- [85] Bahrulolum, H., Nooraei, S., Javanshir, N., Tarrahimofrad, H., Mirbagheri, V. S., Easton, A. J., & Ahmadian, G. (2021a). Green synthesis of metal nanoparticles using microorganisms and their application in the agrifood sector. *Journal of Nanobiotechnology*, 19(1), 86. <https://doi.org/10.1186/S12951-021-00834-3>
- [86] Bahrulolum, H., Nooraei, S., Javanshir, N., Tarrahimofrad, H., Mirbagheri, V. S., Easton, A. J., & Ahmadian, G. (2021b). Green synthesis of metal nanoparticles using microorganisms and their application in the agrifood sector. *Journal of Nanobiotechnology*,

- 19(1), 1–26. <https://doi.org/10.1186/s12951-021-00834-3>
- [87] Borase, H. P., Salunke, B. K., Salunkhe, R. B., Patil, C. D., Hallsworth, J. E., Kim, B. S., & Patil, S. V. (2014). Plant extract: A promising biomatrix for ecofriendly, controlled synthesis of silver nanoparticles. *Applied Biochemistry and Biotechnology*, 173(1), 1–29. <https://doi.org/10.1007/s12010-014-0831-4>
- [88] capped-silver nanoparticles inhibit biofilm formation by multidrug resistant strains of *Pseudomonas aeruginosa*. *J. Basic Microbiol.* 54, 688–699. doi:10.1002/jobm.201300748
- [89] Drummer, S., Madzimbamuto, T., & Chowdhury, M. (2021). Green synthesis of transition-metal nanoparticles and their oxides: A review. *Materials*, 14(11), 34. <https://doi.org/10.3390/ma14112700>
- [90] Gandhi, H., & Khan, S. (2016). Biological Synthesis of Silver Nanoparticles and Its Antibacterial Activity. *Journal of Nanomedicine & Nanotechnology*, 07(02), 2–4. <https://doi.org/10.4172/2157-7439.1000366>
- [91] Garnero, C., Aiassa, V., & Longhi, M. R. (2020). Innovative technological systems to optimize the delivery and therapeutic activity of antimicrobial drugs. In *Advances and Avenues in the Development of Novel Carriers for Bioactives and Biological Agents*. INC. <https://doi.org/10.1016/B978-0-12-819666-3.00004-3>
- [92] Gebre, S. H. (2023). Bio-inspired Synthesis of Metal and Metal Oxide Nanoparticles: The Key Role of Phytochemicals. In *Journal of Cluster Science* (Vol. 34). Springer US. <https://doi.org/10.1007/s10876-022-02276-9>
- [93] Hall, C.W., Mah, T.F., 2017. Molecular mechanisms of biofilm-based antibiotic resistance and tolerance in pathogenic bacteria. *FEMS Microbiol. Rev.* 41, 276–301. <https://doi.org/10.1093/FEMSRE/FUX010>.
- [94] Hebbalalu, D., Lalley, J., Nadagouda, M. N., & Varma, R. S. (2013). Greener techniques for the synthesis of silver nanoparticles using plant extracts, enzymes, bacteria, biodegradable polymers, and microwaves. *ACS Sustainable Chemistry and Engineering*, 1(7), 703–712. <https://doi.org/10.1021/sc4000362>
- [95] Hermanto, D., Ismillayli, N., Fatwa, D. H., Zuryati, U. K., Muliassari, H., Wirawan, R., Suprpto, S. (2023). Bio-Mediated Electrochemically Synthesis of Silver Nanoparticles Using Green Tea (*Camellia sinensis*) Leaves Extract and Their Antibacterial Activity. *South African Journal of Chemical Engineering*, 47(August 2022), 136–141. <https://doi.org/10.1016/j.sajce.2023.11.004>
- [96] J. Lellouche, A. Friedman, A. Gedanken, E. Banin, Antibacterial and antibiofilm properties of yttrium fluoride nanoparticles, *Int J Nanomedicine*, 7 (2012) 5611 - 5624.
- [97] Jafarzadeh, S., Nooshkam, M., Zargar, M., Garavand, F., Ghosh, S., Hadidi, M., & Forough, M. (2023). Green synthesis of nanomaterials for smart biopolymer packaging: challenges and outlooks. *Journal of Nanostructure in Chemistry*. <https://doi.org/10.1007/s40097-023-00527-3>
- [98] Jagajjanani Rao, K., & Paria, S. (2013). Green synthesis of silver nanoparticles from aqueous *Aegle marmelos* leaf extract. *Materials Research Bulletin*, 48(2), 628–634. <https://doi.org/10.1016/j.materresbull.2012.11.035>
- [99] Jiang, Z., Li, L., Huang, H., He, W., & Ming, W. (2022). Progress in Laser Ablation and Biological Synthesis Processes: “Top-Down” and “Bottom-Up” Approaches for the Green Synthesis of Au/Ag Nanoparticles. *International Journal of Molecular Sciences*, 23(23). <https://doi.org/10.3390/ijms232314658>
- [100] Kaiser, K. G., Delattre, V., Frost, V. J., Buck, G. W., Phu, J. V., Fernandez, T. G., & Pavel, I. E. (2023). Nanosilver: An Old Antibacterial Agent with Great Promise in the Fight against Antibiotic Resistance. *Antibiotics*, 12(8). <https://doi.org/10.3390/antibiotics12081264>
- [101] Khina, A. G., & Krutyakov, Y. A. (2021). Similarities and Differences in the Mechanism of Antibacterial Action of Silver Ions and Nanoparticles. *Applied Biochemistry and Microbiology*, 57(6), 683–693. <https://doi.org/10.1134/S0003683821060053>
- [102] Kumar, S., Khan, H. M., Khan, M. A., Jalal, M., Ahamad, S., Shahid, M., ... Adil, M.

- (2023). Broad-spectrum antibacterial and antibiofilm activity of biogenic silver nanoparticles synthesized from leaf extract of *Phyllanthus niruri*. *Journal of King Saud University - Science*, 35(8), 102904.
- [103] Li, S., Shen, Y., Xie, A., Yu, X., Qiu, L., Zhang, L., & Zhang, Q. (2007). Green synthesis of silver nanoparticles using *Capsicum annuum* L. Extract. *Green Chemistry*, 9(8), 852–885. <https://doi.org/10.1039/b615357g>
- [104] Li, Yuchao, Liao, C., & Tjong, S. C. (2020). Recent advances in zinc oxide nanostructures with antimicrobial activities. *International Journal of Molecular Sciences*, 21(22), 1–70. <https://doi.org/10.3390/ijms21228836>
- [105] Liu, Y., Li, Y., & Shi, L. (2021). Controlled drug delivery systems in eradicating bacterial biofilm-associated infections. *Journal of Controlled Release*, 329, 1102–1116. <https://doi.org/10.1016/j.jconrel.2020.10.038>
- [106] Madani, M., Hosny, S., Alshangiti, D. M., Nady, N., Alkhursani, S. A., Alkhaldi, H., ... Gaber, G. A. (2022). Green synthesis of nanoparticles for varied applications: Green renewable resources and energy-efficient synthetic routes. *Nanotechnology Reviews*, 11(1), 731–759. <https://doi.org/10.1515/ntrev-2022-0034>
- [107] Maheshwari, M., Ahmad, I., Althubiani, A.S., 2016. Multidrug resistance and transferability of bla CTX-M among extended-spectrum β -lactamase-producing enteric bacteria in biofilm. *J. Glob. Antimicrob. Resist.* 6, 142–149. <https://doi.org/10.1016/j.jgar.2016.04.009>.
- [108] Malini, S., Vignesh Kumar, S., Hariharan, R., Pon Bharathi, A., Renuka Devi, P., & Hemananthan, E. (2020). Antibacterial, photocatalytic and biosorption activity of chitosan nanocapsules embedded with *Prosopis juliflora* leaf extract synthesized silver nanoparticles. *Materials Today: Proceedings*, 21(xxxx), 828–832. <https://doi.org/10.1016/j.matpr.2019.07.587>
- [109] Marcelo, G. A., Lodeiro, C., Capelo, J. L., Lorenzo, J., & Oliveira, E. (2020). Magnetic, fluorescent and hybrid nanoparticles: From synthesis to application in biosystems. *Materials Science and Engineering C*, 106(August 2019), 2019. <https://doi.org/10.1016/j.msec.2019.110104>
- [110] Marslin, G., Siram, K., Maqbool, Q., Selvakesavan, R. K., Kruszka, D., Kachlicki, P., & Franklin, G. (2018). Secondary metabolites in the green synthesis of metallic nanoparticles. *Materials*, 11(6), 1–25. <https://doi.org/10.3390/ma11060940>
- [111] Mathew, S., Prakash, A., Radhakrishnan, E.K., 2018. Sunlight mediated rapid synthesis of small size range silver nanoparticles using *Zingiber officinale* rhizome extract and its antibacterial activity analysis. *Inorg. Nano-Metal Chem.* 48, 139–145. <https://doi.org/10.1080/24701556.2017.1373295>.
- [112] Mishra, P. M., & Devi, A. P. (2023). Current scenario on biogenic synthesis of metal oxide nanocomposites using plant specimens and their application towards treatment of wastewater. *Environmental Science and Pollution Research*, 30(50), 108512–108524. <https://doi.org/10.1007/s11356-023-29989-2>
- [113] Mondal, A., Hajra, A., Shaikh, W., Chakraborty, S., & Mondal, N. (2019). Synthesis of silver nanoparticle with *Colocasia esculenta* (L.) stem and its larvicidal activity against *Culex quinquefasciatus* and *Chironomus* sp. *Asian Pacific Journal of Tropical Biomedicine*, 9(12), 510–517. <https://doi.org/10.4103/2221-1691.271724>
- [114] Murray, C. J., Ikuta, K. S., Sharara, F., Swetschinski, L., Robles Aguilar, G., Gray, A., ... Naghavi, M. (2022). Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. *The Lancet*, 399(10325), 629–655. [https://doi.org/10.1016/S0140-6736\(21\)02724-0](https://doi.org/10.1016/S0140-6736(21)02724-0)
- [115] Naseem, T., & Durrani, T. (2021). The role of some important metal oxide nanoparticles for wastewater and antibacterial applications: A review. *Environmental Chemistry and Ecotoxicology*, 3, 59–75. <https://doi.org/10.1016/j.enccco.2020.12.001>
- [116] Naseer, A., Ali, A., Ali, S., Mahmood, A., Kusuma, H. S., Nazir, A., ... Iqbal, M. (2020). Biogenic and eco-benign synthesis of platinum nanoparticles (Pt NPs) using plants aqueous extracts and biological derivatives:

- Environmental, biological and catalytic applications. *Journal of Materials Research and Technology*, 9(4), 9093–9107. <https://doi.org/10.1016/j.jmrt.2020.06.013>
- [117] Paiva, J. C. C., Oliveira, L., Vaz, M. F., & Costa-de-Oliveira, S. (2022). Biodegradable Bone Implants as a New Hope to Reduce Device-Associated Infections—A Systematic Review. *Bioengineering*, 9(8), 1–35. <https://doi.org/10.3390/bioengineering9080409>
- [118] Puca, V., Marulli, R. Z., Grande, R., Vitale, I., Niro, A., Molinaro, G., ... Di Giovanni, P. (2021). Microbial species isolated from infected wounds and antimicrobial resistance analysis: Data emerging from a three-years retrospective study. *Antibiotics*, 10(10). <https://doi.org/10.3390/antibiotics10101162>
- [119] Rafique, M., Sadaf, I., Rafique, M.S., Tahir, M.B., 2017. A review on green synthesis of silver nanoparticles and their applications. *Artif. Cells, Nanomed. Biotechnol.* 45, 1272–1291. <https://doi.org/10.1080/21691401.2016.1241792>.
- [120] Ramkumar, R., Balasubramani, G., Raja, R. K., Raja, M., Govindan, R., Girija, E. K., & Perumal, P. (2017). Lantana camara Linn root extract-mediated gold nanoparticles and their in vitro antioxidant and cytotoxic potentials. *Artificial Cells, Nanomedicine and Biotechnology*, 45(4), 748–757. <https://doi.org/10.1080/21691401.2016.1276923>
- [121] Saravanakumar, K., Chelliah, R., Shanmugam, S., Varukattu, N. B., Oh, D. H., Kathiresan, K., & Wang, M. H. (2018). Green synthesis and characterization of biologically active nanosilver from seed extract of *Gardenia jasminoides* Ellis. *Journal of Photochemistry and Photobiology B: Biology*, 185, 126–135. <https://doi.org/10.1016/j.jphotobiol.2018.05.032>
- [122] Shahid, M., Shahzad, A., Malik, A., Anis, M., 2007. Antibacterial activity of aerial parts as well as in vitro raised calli of the medicinal plant *Saraca asoca* (Roxb.) de Wilde. *Can. J. Microbiol.* 53, 75–81. <https://doi.org/10.1139/W06-107>.
- [123] Singh, B. P., Ghosh, S., & Chauhan, A. (2021). Development, dynamics and control of antimicrobial-resistant bacterial biofilms: a review. *Environmental Chemistry Letters*, 19(3), 1983–1993. <https://doi.org/10.1007/s10311-020-01169-5>
- [124] Singh, O. V. (2015). Bio-Nanoparticles: Biosynthesis and Sustainable Biotechnological Implications. *Bio-Nanoparticles: Biosynthesis and Sustainable Biotechnological Implications*, 1–375. <https://doi.org/10.1002/9781118677629>
- [125] Vijayakumar, S., Chen, J., González-Sánchez, Z. I., Durán-Lara, E. F., Divya, M., Shreema, K., ... Vaseeharan, B. (2023). Anti-Colon Cancer and Antibiofilm Activities of Green Synthesized ZnO Nanoparticles Using Natural Polysaccharide Almond Gum (*Prunus dulcis*). *Journal of Cluster Science*, 34(1), 165–176. <https://doi.org/10.1007/s10876-021-02205-2>
- [126] Vinayagam, R., Selvaraj, R., Arivalagan, P., & Varadavenkatesan, T. (2020). Synthesis, characterization and photocatalytic dye degradation capability of *Calliandra haematocephala*-mediated zinc oxide nanoflowers. *Journal of Photochemistry and Photobiology B: Biology*, 203(December 2019), 111760. <https://doi.org/10.1016/j.jphotobiol.2019.111760>
- [127] Wahab, S., Salman, A., Khan, Z., Khan, S., Krishnaraj, C., & Yun, S. Il. (2023). Metallic Nanoparticles: A Promising Arsenal against Antimicrobial Resistance—Unraveling Mechanisms and Enhancing Medication Efficacy. *International Journal of Molecular Sciences*, 24(19). <https://doi.org/10.3390/ijms241914897>
- [128] Wang, Linlin, Hu, C., & Shao, L. (2017). The antimicrobial activity of nanoparticles: Present situation and prospects for the future. *International Journal of Nanomedicine*, 12, 1227–1249. <https://doi.org/10.2147/IJN.S121956>
- [129] Zafar, S., Ashraf, A., Ijaz, M.U., Muzammil, S., Siddique, M.H., Afzal, S., Andleeb, R., AlGhanim, K.A., Al-Misned, F., Ahmed, Z., Mahboob, S., 2020. Eco-friendly synthesis of antibacterial zinc nanoparticles using *Sesamum*

- indicum L. extract. J. King Saud Univ. - Sci. 32, 1116–1122. <https://doi.org/10.1016/j.jksus.2019.10.017>
- [130] Zhang, D., Ma, X. L., Gu, Y., Huang, H., & Zhang, G. W. (2020). Green Synthesis of Metallic Nanoparticles and Their Potential Applications to Treat Cancer. *Frontiers in Chemistry*, 8(October), 1–18. <https://doi.org/10.3389/fchem.2020.00799>
- [131] Zorraquín-Peña, I., Cueva, C., de Llano, D. G., Bartolomé, B., & Moreno-Arribas, M. V. (2020). Glutathione-stabilized silver nanoparticles: Antibacterial activity against periodontal bacteria, and cytotoxicity and inflammatory response in oral cells. *Biomedicines*, 8(10). <https://doi.org/10.3390/BIMEDICINES8100375>
- [132] Abbasi, T., Anuradha, J., Ganaie, S. U., & Abbasi, S. A. (2015). Biomimetic synthesis of nanoparticles using aqueous extracts of plants (botanical species). *Journal of Nano Research*, 31, 138–202.
- [133] Ahmad, I., Khan, M. S., Altaf, M. M., Qais, F. A., Ansari, F. A., & Rumbaugh, K. P. (2017). Biofilms: An Overview of their Significance in Plant and Soil Health. In *Biofilms in Plant and Soil Health* (pp. 1–25). John Wiley & Sons, Ltd.
- [134] Ahmad, S. Z. N., Wan Salleh, W. N., Ismail, A. F., Yusof, N., Mohd Yusop, M. Z., & Aziz, F. (2020). Adsorptive removal of heavy metal ions using graphene-based nanomaterials: Toxicity, roles of functional groups and mechanisms. *Chemosphere*, 248, 126008. <https://doi.org/10.1016/j.chemosphere.2020.126008>.
- [135] Alotaibi, G. F. (2021). Factors Influencing Bacterial Biofilm Formation and Development. (September). <https://doi.org/10.34297/AJBSR.2021.12.001820>.
- [136] Al-Shabib, N.A., Husain, F.M., Nadeem, M., Khan, M.S., Al-Qurainy, F., Alyousef, A.A., Arshad, M., Khan, A., Khan, J.M., Alam, P., Albalawi, T., Shahzad, S.A., 2020. Bioinspired facile fabrication of silver nanoparticles from: in vitro grown shoots of *Tamarix nilotica*: Explication of its potential in impeding growth and biofilms of *Listeria monocytogenes* and assessment of wound healing ability. *RSC Adv.* 10. <https://doi.org/10.1039/d0ra04587j>.
- [137] Amendola, V., Amans, D., Ishikawa, Y., Koshizaki, N., Scirè, S., Compagnini, G., ... Barcikowski, S. (2020). Room-Temperature Laser Synthesis in Liquid of Oxide, Metal-Oxide Core-Shells, and Doped Oxide Nanoparticles. *Chemistry - A European Journal*, 26(42), 9206–9242. <https://doi.org/10.1002/chem.202000686>.
- [138] Ansari, M.A., Khan, H.M., Khan, A.A., Cameotra, S.S., Saquib, Q., Musarrat, J., 2014. Gum arabic capped-silver nanoparticles inhibit biofilm formation by multi-drug resistant strains of *Pseudomonas aeruginosa*. *J. Basic Microbiol.* 54, 688–699. <https://doi.org/10.1002/jobm.201300748>.
- [139] Antimicrobial effects of biogenic nanoparticles. *Nanomaterials*, 8(12), 1009.
- [140] Armendariz, V., Herrera, I., Peralta-Videa, J. R., Jose-Yacaman, M., Troiani, H., Santiago, P., & Gardea-Torresdey, J. L. (2004). Size controlled gold nanoparticle formation by *Avena sativa* biomass: Use of plants in nanobiotechnology. *Journal of Nanoparticle Research*, 6(4), 377–382. <https://doi.org/10.1007/s11051-004-0741-4>.
- [141] Asghar, M. A., & Asghar, M. A. (2020). Green synthesized and characterized copper nanoparticles using various new plants extracts aggravate microbial cell membrane damage after interaction with lipopolysaccharide. *International Journal of Biological Macromolecules*, 160, 1168–1176. <https://doi.org/10.1016/j.ijbiomac.2020.05.198>
- [142] Attallah, N. G. M., Elekhawy, E., Negm, W. A., Hussein, I. A., Mokhtar, F. A., & Al-Fakhrany, O. M. (2022). In Vivo and In Vitro Antimicrobial Activity of Biogenic Silver Nanoparticles against *Staphylococcus aureus* Clinical Isolates. *Pharmaceuticals*, 15(2), 1–22. <https://doi.org/10.3390/ph15020194>
- [143] Bahrulolum, H., Nooraei, S., Javanshir, N., Tarahimofrad, H., Mirbagheri, V.S., Easton, A.J., Ahmadian, G., 2021. Green synthesis of metal nanoparticles using
- [144] Bal, A. M., David, M. Z., Garau, J., Gottlieb, T., Mazzei, T., Scaglione, F., ... Gould, M.

- (2017). Future trends in the treatment of methicillin-resistant *Staphylococcus aureus* (MRSA) infection: An in-depth review of newer antibiotics active against an enduring pathogen. *Journal of Global Antimicrobial Resistance*, 10, 295–303. <https://doi.org/10.1016/j.jgar.2017.05.019>
- [145] Bala, A., Rani, G., 2020. A review on phytosynthesis, affecting factors and characterization techniques of silver nanoparticles designed by green approach. *Int. Nano Lett.* 10, 159–176. <https://doi.org/10.1007/s40089-020-00309-7>.
- [146] Bose, D., Chatterjee, S., 2015. Antibacterial activity of green synthesized silver nanoparticles using vasaka (*Justicia adhatoda* L.) Leaf Extract. *Indian J. Microbiol.* 55, 163–167. <https://doi.org/10.1007/s12088-015-0512-1>.
- [147] Chopra, H., Bibi, S., Singh, I., Hasan, M. M., Khan, M. S., Yousafi, Q., ... Cavalu, S. (2022). Green Metallic Nanoparticles: Biosynthesis to Applications. *Frontiers in Bioengineering and Biotechnology*, 10(April), 1–29.
- [148] Danquah, C. A., Minkah, P. A. B., Junior, I. O. D., Amankwah, K. B., & Somuah, S. O. (2022). Antimicrobial Compounds from Microorganisms. *Antibiotics*, 11(3), 1–20. <https://doi.org/10.3390/antibiotics11030285>
- [149] Das, S., Bag, B. G., & Basu, R. (2015). *Abroma augusta* Linn bark extract-mediated green synthesis of gold nanoparticles and its application in catalytic reduction. *Applied Nanoscience (Switzerland)*, 5(7), 867–873.
- [150] Dhaka, A., Chand Mali, S., Sharma, S., & Trivedi, R. (2023). A review on biological synthesis of silver nanoparticles and their potential applications. *Results in Chemistry*, 6(September), 101108. <https://doi.org/10.1016/j.rechem.2023.101108>