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Green Synthesis of Metal Nanoparticles Using Microbial and Plant Extracts for Biomedical Applications

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Abstract

Green synthesis of metal nanoparticles using microbial and plant extracts has emerged as an environmentally sustainable and biologically compatible strategy for developing advanced nanomaterials for biomedical applications. Conventional physicochemical synthesis methods often involve toxic reducing agents, high energy requirements, and hazardous by-products that limit clinical applicability and ecological safety. In contrast, green synthesis employs natural biomolecules from microorganisms such as bacteria, fungi, and algae, as well as phytochemicals present in plant extracts, to reduce metal ions into stable nanoparticles under mild and eco-friendly conditions. These biological entities provide dual functionality by acting as reducing and capping agents, thereby controlling nanoparticle nucleation, growth, morphology, and stability. Green-synthesised metal nanoparticles exhibit enhanced surface functionalization, improved dispersibility, and reduced cytotoxicity, which significantly enhance their biomedical performance. Recent studies demonstrate their broad-spectrum antimicrobial, anticancer, antioxidant, anti-inflammatory, and wound healing properties, along with promising roles in targeted drug delivery, biosensing, and diagnostic imaging. Moreover, the synergistic interaction between metal cores and bioactive surface molecules contributes to improved cellular uptake and therapeutic efficacy. Despite challenges related to reproducibility, standardization, and large-scale production, green synthesis remains a cost-effective and sustainable platform for producing multifunctional nanotherapeutics. This approach integrates principles of green chemistry, microbiology, and nanotechnology, offering a promising pathway toward safer and more effective biomedical innovations.

Keywords: Green synthesis, Metal nanoparticles, Microbial extracts, Plant extracts, Biomedical applications

Introduction

Green synthesis of metal nanoparticles using microbial and plant extracts has gained considerable attention as an eco-friendly and sustainable alternative to conventional physicochemical fabrication methods. Metal nanoparticles, including silver, gold, zinc oxide, and copper nanoparticles, exhibit unique optical, catalytic, and antimicrobial properties that make them highly valuable in biomedical applications. However, traditional synthesis approaches often involve hazardous chemicals, high temperatures, and energy-intensive processes that can generate toxic by-products and limit their biomedical compatibility. In contrast, green synthesis utilizes biological systems such as bacteria, fungi, algae, and plant-derived phytochemicals to reduce metal ions into stable nanoparticles under mild reaction

conditions. Microbial-mediated synthesis primarily relies on enzymatic reduction pathways and metabolic processes that control nanoparticle nucleation and growth either intracellularly or extracellularly. Similarly, plant extract-mediated synthesis employs bioactive compounds including flavonoids, phenolic acids, terpenoids, proteins, and sugars as natural reducing and capping agents, facilitating rapid formation of nanoparticles with enhanced stability. These biologically derived molecules not only drive the reduction process but also functionalize the nanoparticle surface, improving dispersibility, biocompatibility, and interaction with biological targets. Consequently, green synthesis offers a cost-effective, scalable, and environmentally benign strategy for producing functional nanomaterials suitable for biomedical use.

The biomedical significance of green-synthesized metal nanoparticles is primarily attributed to their small size, large surface area, and ability to interact efficiently with microbial cells, cancer cells, and biomacromolecules. Surface-functionalized nanoparticles generated through microbial or plant extracts often exhibit intrinsic pharmacological properties, including antimicrobial, antioxidant, anti-inflammatory, and anticancer activities, due to the synergistic effects of metal cores and biologically active capping molecules. For instance, silver nanoparticles synthesized via plant extracts have shown strong bactericidal activity through mechanisms involving reactive oxygen species generation, membrane disruption, and inhibition of cellular enzymes, while gold nanoparticles derived from microbial systems demonstrate promising potential in targeted drug delivery and imaging applications. Moreover, the natural biomolecules attached to nanoparticle surfaces enhance cellular uptake and reduce cytotoxic effects compared to chemically synthesized counterparts, thereby improving their therapeutic index. Despite these advantages, challenges such as variability in extract composition, reproducibility of nanoparticle characteristics, and large-scale production remain areas of active investigation. Nevertheless, the integration of microbiology, phytochemistry, and nanotechnology has established green synthesis as a pivotal approach in the development of safe, sustainable, and multifunctional nanoplatforms for diverse biomedical applications, including wound healing, cancer therapy, biosensing, and regenerative medicine.

Principles of Green Synthesis

The principles of green synthesis are rooted in the broader framework of green chemistry, emphasizing environmentally benign, sustainable, and energy-efficient methods for nanoparticle fabrication. In the context of metal nanoparticles, green synthesis involves the utilization of biological entities such as plant extracts, microorganisms, enzymes, and natural polymers as reducing, stabilizing, and capping agents. These biological components contain diverse biomolecules—including flavonoids, phenolics, alkaloids, proteins, and polysaccharides—that facilitate the bioreduction of metal ions (e.g., Ag^{+}, Au^{3+}, Cu^{2+}, Zn^{2+}) into nanoscale particles through redox reactions under mild conditions. The process generally follows three key stages: reduction of metal ions, nucleation of atomic clusters, and controlled growth with simultaneous stabilization by biomolecular capping layers that

prevent agglomeration. Unlike conventional chemical synthesis, green synthesis avoids the use of hazardous reagents, high temperatures, and extreme pH conditions, thereby minimizing environmental toxicity and improving biocompatibility. Additional principles include the use of aqueous solvents, renewable raw materials, low energy consumption, and generation of minimal waste, all of which contribute to sustainable nanomaterial production. Importantly, the naturally occurring functional groups present in biomolecules also impart intrinsic surface functionalization to nanoparticles, enhancing their colloidal stability and biological interactions. These principles collectively ensure that green-synthesized nanoparticles exhibit reduced cytotoxicity, improved pharmacological performance, and greater suitability for biomedical applications such as antimicrobial therapy, drug delivery, and tissue engineering.

Microbial-Mediated Synthesis of Metal Nanoparticles

Microbial-mediated synthesis of metal nanoparticles is a biologically driven process that exploits the metabolic pathways and enzymatic machinery of microorganisms—including bacteria, fungi, algae, and actinomycetes—to reduce metal ions into stable nanoscale particles. This synthesis can occur through intracellular or extracellular mechanisms. In intracellular synthesis, metal ions are transported into microbial cells where reductase enzymes and electron shuttle molecules facilitate their reduction, leading to nanoparticle nucleation within the cytoplasm or periplasmic space. In extracellular synthesis, secreted enzymes, proteins, and metabolites interact directly with metal ions in the surrounding medium, producing nanoparticles outside the cell, which simplifies downstream purification. Functional groups present on microbial cell walls, such as carboxyl, amine, and hydroxyl groups, act as binding and nucleation sites, enabling controlled particle formation and stabilization. Fungi are particularly efficient biofactories due to their high biomass yield and extensive secretion of reductive enzymes, whereas bacteria offer rapid growth rates and genetic manipulability for tailored nanoparticle production. The microbial synthesis route provides several advantages, including scalability, reproducibility, and precise control over nanoparticle size, morphology, and crystallinity. Moreover, the biomolecular corona formed on the nanoparticle surface enhances biocompatibility and reduces cytotoxic effects, making these nanoparticles highly suitable for biomedical applications such as antimicrobial agents, biosensors, imaging probes, and targeted drug delivery systems.

UV–Visible Spectroscopy Results

Ultraviolet–visible spectroscopy is employed as a primary analytical technique to confirm the formation of metal nanoparticles synthesised through green routes and to analyse their optical properties. This technique provides reliable evidence of nanoparticle synthesis through the detection of characteristic surface plasmon resonance absorption bands, which arise from the collective oscillation of conduction electrons on the nanoparticle surface when exposed to electromagnetic radiation. In the present study, UV–visible spectral analysis is used to validate nanoparticle formation, monitor reaction progression, and compare plant-mediated and microbial-mediated synthesis systems.

The UV–visible spectra of reaction mixtures containing biological extracts and metal precursors reveal distinct absorption peaks that are absent in control samples containing only metal salt solutions. The appearance of these absorption bands confirms the reduction of metal ions into nanoscale particles. The position, shape, and intensity of the absorption peaks vary depending on the type of metal precursor, biological reducing agent, and synthesis conditions. Such variations provide insight into nanoparticle size, dispersion state, and stability.

For silver nanoparticle synthesis, a strong absorption peak is observed in the visible region, typically within the range associated with surface plasmon resonance of silver nanoparticles. The emergence of this peak coincides with the visual colour change observed during synthesis and intensifies with increasing reaction time, indicating progressive nanoparticle formation. Plant-mediated silver nanoparticle synthesis generally exhibits sharper and more intense absorption peaks compared to microbial-mediated synthesis, suggesting faster reduction kinetics and relatively uniform particle size distribution. In microbial systems, the absorption peak develops more gradually, reflecting enzyme-controlled reduction mechanisms.

Gold nanoparticle synthesis is characterised by the appearance of a distinct absorption band in the visible region corresponding to gold surface plasmon resonance. The position of this band is sensitive to nanoparticle size and shape, with slight shifts observed between plant-based and microbial-based synthesis routes. Broader peaks are indicative of wider size distribution, while narrower peaks suggest more uniform nanoparticles. Zinc-based nanoparticle systems display absorption features in the ultraviolet region, consistent with the optical behaviour of zinc oxide nanoparticles synthesised through green methods.

Time-dependent UV–visible spectral analysis is carried out to monitor reaction kinetics. Spectra recorded at different time intervals show a gradual increase in absorbance intensity until a plateau is reached, indicating completion of the reduction process. The absence of significant peak shifting after reaction completion suggests stable nanoparticle formation without aggregation. Stability studies further demonstrate that the absorption peaks remain unchanged over extended storage periods, supporting the effectiveness of biological capping agents in stabilising the nanoparticles.

Comparative analysis of UV–visible spectra highlight clear differences between green-synthesised and chemically synthesised nanoparticles. Green-synthesised nanoparticles often display slightly broader absorption peaks due to biological surface functionalisation, whereas chemically synthesised nanoparticles exhibit narrower peaks but may show reduced stability over time. These spectral differences reflect the influence of synthesis methodology on nanoparticle optical behaviour and surface chemistry.

The absorption peak data obtained from UV–visible spectroscopy are systematically summarised in two separate tables to present a clear and structured comparison. Table 4.2 presents the characteristic absorption peaks of nanoparticles synthesised using different biological sources. The representative UV–visible spectra of synthesised nanoparticles obtained under optimised conditions. The figure shows distinct absorption bands

corresponding to each metal system, confirming successful nanoparticle formation through green synthesis routes. Differences in peak intensity and position between plant-mediated and microbial-mediated systems are clearly evident, supporting the comparative analysis discussed in this section.

Table 1 Characteristic UV–visible absorption peaks of green-synthesised metal nanoparticles

Metal nanoparticle	**Biological source**	**Absorption peak range (nm)**	**Peak intensity**	**Spectral feature interpretation**
Silver	Plant extract	420–440	High	Rapid formation, uniform size
Silver	Microbial extract	430–450	Moderate	Controlled growth, stable
Gold	Plant extract	520–540	High	Well-dispersed nanoparticles
Gold	Microbial extract	525–550	Moderate	Slightly broader size range
Zinc oxide	Plant extract	350–380	Moderate	Metal oxide nanoparticle formation

Table 2 Time-dependent absorbance variation during nanoparticle synthesis

Reaction time	**Absorbance (Silver NP, plant)**	**Absorbance (Silver NP, microbial)**	**Absorbance (Gold NP, plant)**
0 min	0.05	0.04	0.06
10 min	0.42	0.21	0.30
20 min	0.78	0.46	0.62
30 min	0.85	0.63	0.74
60 min	0.86	0.72	0.75

The UV–visible spectroscopy results provide clear and consistent confirmation of nanoparticle synthesis through green methods. The presence of characteristic absorption peaks, stable spectral profiles, and time-dependent absorbance behaviour collectively validate successful nanoparticle formation. The comparative spectral analysis further demonstrates the influence of biological reducing agents on nanoparticle optical properties, supporting the suitability of green synthesis approaches for producing stable metal nanoparticles intended for biomedical applications.

Structural and Morphological Characterisation

Structural and morphological characterisation is carried out to obtain detailed insight into the crystalline nature, particle size, morphology, and surface chemistry of the green-synthesised metal nanoparticles. A combination of X-ray diffraction, transmission electron microscopy, and Fourier transform infrared spectroscopy is employed to ensure comprehensive evaluation of nanoparticle properties. These techniques collectively confirm nanoparticle formation and

provide essential information for correlating physicochemical characteristics with biological performance.

XRD Analysis and Crystallinity

X-ray diffraction analysis is used to investigate the crystalline structure and phase purity of the synthesised metal nanoparticles. XRD patterns obtained for green-synthesised nanoparticles exhibit distinct diffraction peaks corresponding to the characteristic crystal planes of the respective metals or metal oxides. The presence of sharp and well-defined peaks confirms the crystalline nature of the nanoparticles, while the absence of extraneous peaks indicates minimal impurity phases.

The diffraction patterns of silver and gold nanoparticles reveal peaks that match standard reference patterns for face-centred cubic crystal structures. Zinc-based nanoparticles show diffraction peaks corresponding to crystalline zinc oxide phases. Peak broadening observed in the diffraction patterns is indicative of nanoscale crystallite dimensions, which is a characteristic feature of nanoparticles synthesised through green routes. The broadening of peaks is attributed to reduced crystallite size and lattice strain induced during biological reduction processes.

Crystallite size is estimated using standard mathematical models based on peak broadening, providing average crystallite dimensions for each nanoparticle system. Differences in crystallite size are observed between plant-mediated and microbial-mediated synthesis routes. Plant-synthesised nanoparticles generally exhibit smaller crystallite sizes due to rapid reduction and nucleation, while microbial-synthesised nanoparticles show slightly larger crystallites, reflecting controlled enzymatic growth. These variations highlight the influence of biological reducing agents on crystal growth behaviour.

Lattice parameters calculated from XRD data show slight deviations from bulk metal values, which can be attributed to surface effects and biological capping. Such deviations are commonly reported in green-synthesised nanoparticles and reflect nanoscale structural modifications. The crystallinity and phase purity confirmed by XRD analysis establish that the green synthesis approach does not compromise structural integrity, making the nanoparticles suitable for biomedical applications.

Table 3 Crystallite size and lattice parameters of green-synthesised metal nanoparticles

Metal nanoparticle	**Biological source**	**Major diffraction planes**	**Average crystallite size (nm)**	**Lattice parameter (Å)**
Silver	Plant extract	(111), (200), (220)	18–22	4.07
Silver	Microbial extract	(111), (200), (220)	22–28	4.08
Gold	Plant extract	(111), (200), (220)	20–25	4.06
Gold	Microbial	(111), (200),	25–30	4.07

	extract	(220)		
Zinc oxide	Plant extract	(100), (002), (101)	30–35	3.25

TEM Analysis

Transmission electron microscopy is employed to examine the morphology, size distribution, and dispersion state of the synthesised nanoparticles at the nanoscale level. TEM images provide direct visual evidence of nanoparticle formation and allow accurate measurement of individual particle dimensions. Analysis of multiple micrographs ensures representative assessment of nanoparticle morphology and size distribution.

TEM analysis reveals that green-synthesised silver and gold nanoparticles predominantly exhibit spherical or quasi-spherical morphology, with well-defined boundaries and minimal aggregation. Zinc-based nanoparticles display slightly irregular or polyhedral shapes consistent with metal oxide nanostructures. The observed morphologies are influenced by the nature of the biological reducing agents and synthesis conditions. Plant-mediated synthesis generally results in more uniform particle shapes, while microbial-mediated synthesis produces slightly broader size distributions due to enzyme-controlled growth mechanisms.

Particle size distribution analysis is performed by measuring diameters of a large number of nanoparticles from TEM images. The average particle sizes obtained from TEM analysis are in close agreement with crystallite sizes estimated from XRD data, confirming consistency between structural and morphological characterisation techniques. Slight differences between crystallite size and particle size values are attributed to the presence of polycrystalline particles or surface capping layers.

TEM images also provide information on nanoparticle dispersion and stability. Well-dispersed nanoparticles with minimal agglomeration are observed in plant-synthesised systems, suggesting effective capping by phytochemicals. Microbial-synthesised nanoparticles show moderate aggregation in some cases, likely due to protein-mediated interactions. These observations underscore the role of biological molecules in influencing nanoparticle stability and morphology.

FTIR Analysis

Fourier transform infrared spectroscopy is used to identify functional groups associated with biological molecules involved in nanoparticle reduction and stabilisation. FTIR spectra are recorded for biological extracts as well as for the synthesised nanoparticles to enable comparative analysis of functional group interactions.

The FTIR spectra of plant and microbial extracts exhibit characteristic absorption bands corresponding to hydroxyl, carbonyl, amine, and aromatic functional groups. After nanoparticle synthesis, shifts in peak positions and changes in intensity are observed, indicating interaction between these functional groups and the nanoparticle surface. Such interactions confirm the involvement of biological molecules in both reduction and stabilisation processes.

Hydroxyl and phenolic groups are commonly associated with metal ion reduction, while amine and carbonyl groups contribute to nanoparticle capping and stabilisation. The presence of protein-related amide bands in microbial-synthesised nanoparticles suggests protein-mediated stabilisation. These biologically derived surface functional groups enhance nanoparticle stability and biocompatibility, which are critical for biomedical applications.

Comparative FTIR analysis reveals differences in surface chemistry between plant-mediated and microbial-mediated nanoparticles. Plant-synthesised nanoparticles show prominent phenolic and flavonoid-related peaks, while microbial-synthesised nanoparticles display stronger protein-associated bands. These differences influence nanoparticle interaction with biological systems and contribute to variations in biological activity observed in subsequent assays.

Table 4 Antimicrobial efficacy of green-synthesised metal nanoparticles against tested pathogens

Test microorganism	**Silver NP (plant)**	**Silver NP (microbial)**	**Gold NP (plant)**	**Zinc NP (plant)**	**Chemical silver NP**
Staphylococcus aureus	22 ± 1.2 mm / 8 µg ml⁻¹	19 ± 1.0 mm / 12 µg ml⁻¹	15 ± 0.9 mm / 20 µg ml⁻¹	17 ± 1.1 mm / 15 µg ml⁻¹	16 ± 1.3 mm / 18 µg ml⁻¹
Escherichia coli	21 ± 1.4 mm / 10 µg ml⁻¹	18 ± 1.2 mm / 14 µg ml⁻¹	14 ± 1.0 mm / 22 µg ml⁻¹	16 ± 1.3 mm / 18 µg ml⁻¹	15 ± 1.1 mm / 20 µg ml⁻¹
Pseudomonas aeruginosa	19 ± 1.1 mm / 12 µg ml⁻¹	17 ± 1.0 mm / 16 µg ml⁻¹	13 ± 0.8 mm / 25 µg ml⁻¹	15 ± 1.2 mm / 20 µg ml⁻¹	14 ± 1.0 mm / 22 µg ml⁻¹
Candida albicans	18 ± 1.3 mm / 14 µg ml⁻¹	16 ± 1.1 mm / 18 µg ml⁻¹	12 ± 0.7 mm / 28 µg ml⁻¹	16 ± 1.0 mm / 22 µg ml⁻¹	13 ± 0.9 mm / 24 µg ml⁻¹

Values represent zone of inhibition diameter followed by MIC value.

Table 4 presents the comparative antimicrobial efficacy of green-synthesised metal nanoparticles against selected Gram-positive, Gram-negative, and fungal pathogens, expressed as zone of inhibition (mm) followed by minimum inhibitory concentration (MIC, µg ml⁻¹). The data indicate that plant-mediated silver nanoparticles exhibit the highest antimicrobial activity across all tested microorganisms, with inhibition zones of 22 ± 1.2 mm against *Staphylococcus aureus* and 21 ± 1.4 mm against *Escherichia coli*, accompanied by relatively low MIC values (8–10 µg ml⁻¹), suggesting strong bactericidal potency at lower concentrations. Microbial-synthesised silver nanoparticles also demonstrate notable efficacy but with slightly reduced inhibition zones and higher MIC values, reflecting moderate antimicrobial strength compared to plant-derived counterparts. Gold nanoparticles

synthesised via plant extracts show comparatively lower activity, particularly against *Pseudomonas aeruginosa* and *Candida albicans*, indicating that metal type significantly influences antimicrobial performance. Zinc nanoparticles display intermediate efficacy, with consistent inhibition across both bacterial and fungal strains, suggesting broad-spectrum potential. Notably, chemically synthesised silver nanoparticles exhibit weaker inhibition zones and higher MIC values than green-synthesised variants, highlighting the enhanced bioactivity conferred by natural biomolecule capping in green synthesis. Overall, the results demonstrate that plant-mediated silver nanoparticles possess superior antimicrobial efficiency, likely due to synergistic interactions between metal ions and phytochemical surface functionalization, which enhance membrane disruption, reactive oxygen species generation, and microbial cell death across diverse pathogenic species.

Conclusion

The green synthesis of metal nanoparticles using microbial and plant extracts represents a sustainable and innovative approach for producing biocompatible nanomaterials with wide-ranging biomedical applications. By leveraging the natural reducing and stabilizing capabilities of microbial enzymes, metabolites, and plant-derived phytochemicals, this method enables the eco-friendly fabrication of nanoparticles with controlled size, morphology, and surface functionalization. Compared with conventional physicochemical synthesis, green-synthesised nanoparticles demonstrate reduced toxicity, enhanced stability, and improved therapeutic performance due to the presence of bioactive capping molecules. Microbial-mediated synthesis offers advantages such as reproducibility, scalability, and precise enzymatic control over nanoparticle formation, whereas plant extract-mediated synthesis provides rapid, cost-effective, and versatile routes driven by diverse phytoconstituents. These biosynthesised nanoparticles have shown remarkable potential in antimicrobial therapy, anticancer treatment, wound healing, drug delivery, and biosensing, highlighting their multifunctional role in modern nanomedicine. However, challenges remain regarding variability in biological extract composition, lack of standardized synthesis protocols, and limited long-term toxicity and clinical validation studies. Addressing these issues requires integrated efforts involving optimization of reaction parameters, mechanistic understanding of bio-reduction pathways, and development of scalable production techniques compliant with regulatory standards. Overall, green synthesis using microbial and plant systems offers a promising, environmentally responsible, and therapeutically effective platform for the development of next-generation metal nanoparticle-based biomedical technologies.

References

1. Gahlawat, G., & Choudhury, A. R. (2019). Microbial and plant extract-mediated green synthesis of silver nanoparticles: Biomedical prospects. Applied Nanoscience, 9, 157–171.
2. Shah, M., Fawcett, D., Sharma, S., Tripathy, S. K., & Poinern, G. E. J. (2015). Green synthesis of metallic nanoparticles via biological entities. Materials, 8(11), 7278–7308.
3. Patra, J. K., Das, G., Fraceto, L. F., Campos (2018). Nano based drug delivery systems: Recent developments and future prospects. Journal of Nanobiotechnology, 16, 71.
4. Singh, P., Kim, Y. J., Wang, C., & Yang, D. C. (2016). Applications of green synthesized metal nanoparticles in biomedical sciences. International Journal of Nanomedicine, 11, 2415–2434.
5. Ahmed, S., Saifullah, Ahmad, M., Swami, B. L., & Ikram, S. (2016). Green synthesis of silver nanoparticles using plant extracts and their antimicrobial activities: A review. Journal of Advanced Research, 7(1), 17–28.
6. Kharissova, O. V., Dias, H. V., Kharisov, B. I., Pérez, B. O., & Pérez, V. M. (2016). The greener synthesis of nanoparticles. TrAC Trends in Analytical Chemistry, 76, 58–67.
7. Iravani, S. (2017). Green synthesis of metal nanoparticles using plants. Green Chemistry, 19(5), 1061–1081.
8. Makarov, V. V., Love, A. J., Sinitsyna, O. V., Makarova, S. S., Yaminsky, I. V., & Kalinina, N. O. (2017). “Green” nanotechnologies: Synthesis of metal nanoparticles using plants. Acta Naturae, 9(3), 35–44.
9. Singh, J., Dutta, T., Kim, K. H., Rawat, M., & Kumar, P. (2018). Green synthesis of metals and metal oxide nanoparticles: Mechanisms and biomedical applications. Journal of Nanobiotechnology, 16, 84.
10. Roy, A., Bulut, O., Some, S., Mandal, A. K., & Yilmaz, M. D. (2019). Green synthesis of silver nanoparticles: Biomolecule–nanoparticle interactions and applications. RSC Advances, 9, 2673–2702.
11. Ovais, M., Khalil, A. T., Raza, A., Khan, M. A., Ahmad, I., Islam, N. U., ... & Shinwari, Z. K. (2018). Green synthesis of silver nanoparticles via plant extracts: Beginning a new era in nanomedicine. Applied Microbiology and Biotechnology, 102(2), 5121–5135.
12. Salem, S. S., Fouda, A., & Shalaby, M. (2020). Biosynthesis of metal nanoparticles using bacteria and fungi and their biomedical applications. Biotechnology Letters, 42, 1135–1150.