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Review Article

Role of Moringa oleifera on Green Synthesis of Metal/Metal Oxide Nanomaterials

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Being an environmentally benign method biosynthesis of nanomaterial paying much more attention to researchers, it has many advantages over other routes, such as one pot, facile synthesis, and cost-effective; synthesized material can have good affinity due to surface modification and hence became a most attractive candidate for medicinal and biological applications. Moreover, biosynthesis creates a bridge of interdisciplinary research. Biosynthesis can be done by using bacteria, microbes, plant extracts, etc. In this study, we focus on the synthesis of some metal and metal oxide nanomaterials (M/MO NMs) by using an extract of parts from the Moringa oleifera plant. It is a natural source that can serve as a capping, stabilizing, and reducing/oxidizing agent due to the presence of some of the phytochemical parameters. Moreover, it is a rich source of antioxidants, including quercetin and chlorogenic acids, such as flavonoids, phenolics, astragalin, anthocyanins, cinnamates, and carotenoids, as well as a good source of carotene, iron, potassium, calcium, terpenes, quinines, saponins, alkaloids, proteins, tannins, and vitamin. These components produce smaller particles and give a compelling impact on the activities of M/MO NMs nanoparticles. Here, we discuss nanoparticles such as FeO, CuO, ZnO, NiO, MgO, Ag, and Au.

1. Introduction

Nanotechnology is the most rapidly developing discipline in advanced material science research ([1] [2][3]. It will play a crucial role in several essential technologies due to advancements in organizing nanoscale structures into specified unique structures [4][5]) based on particular features such as size and distribution morphology ([6]; [7]). It is becoming more popular in the domestic and commercial fields [8]), including chemical science [9], physical science, biomedical sciences, drug delivery ([10] [11], photocatalysis, and optoelectronic devices [12]. [13]. For example, nanoscale Ge and Si quantum dots (>10 nm) could be produced in a controlled manner for innovative optoelectronic device applications such as electroluminescent devices [14] and ZnO-based nanomedicine for biomedical applications [15]. Nanoparticles are fascinating because of their unique surface area, which causes physical and chemical changes in their parameters compared to the original materials of the chemical compounds [16]; [17]). At the nanoscale, controlling the size and shape can thus be used to create and manufacture materials that give a variety of applications, including

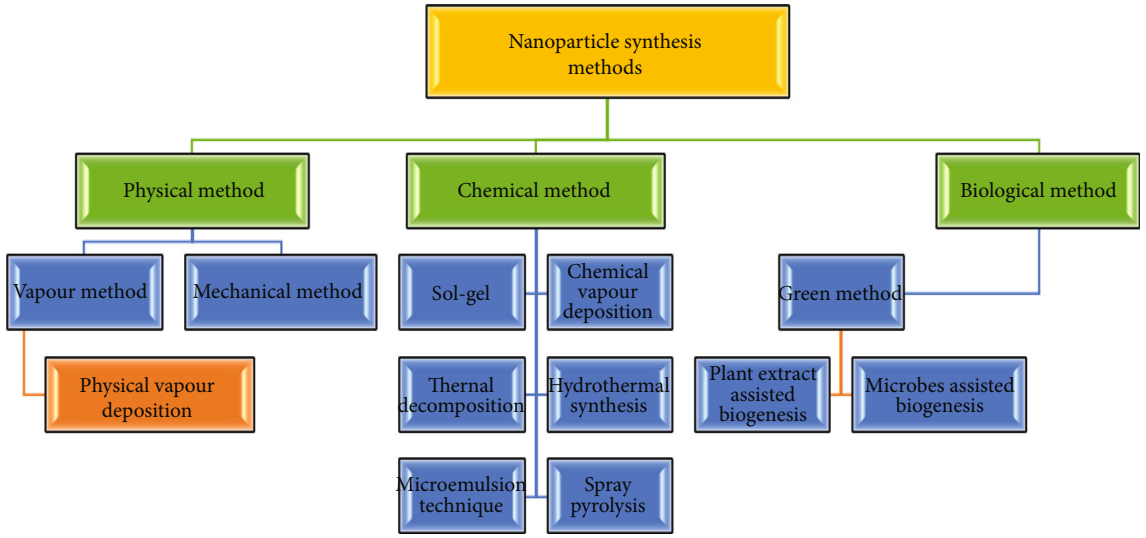

Figure 1: Overview of different types of nanoparticle synthesis methods.

antimicrobial activities [18, 19], anticancer activities [20–22], antidiabetic activities [23], biosensing [24], catalysis [25], medication delivery, tumour hyperthermia, and agriculture sector [26] which are just a few of the applications for these particles [27]. Various techniques and methods have been documented for synthesizing M/MO NPs (Figure 1) like hydrothermal, sol-gel, chemical vapour deposition, gas-phase technique, microwave-assisted, microemulsion, electrochemical method, laser irradiation, and solvothermal method [28, 29]. The overview of some of the nanoparticles synthesis methods is shown in Figure 1.

Chemical and physical method approaches are not as practical as biosynthesis processes. Due to the stabilizing and reducing agent nature, the biosynthetic technique involves the utilization of harmless materials, more cost-effective and environmentally friendly, as shown in Figure 2, such as a biocompatible and benign extract from a plant [30]. Plant-mediated nanoparticles are simple to make, easily available, inexpensive, and readily scaled up. The presence of metabolites and phytochemicals in plant leaf extracts such as terpenoids, alkaloids, flavonoids, proteins, peptides, and tannins increased the biosynthetic manufacturing of nanoparticles [31, 32]. The extract's inherent components determine the nanoparticles' various shapes, sizes, and morphologies. The use of plant parts extracts in nanoparticle synthesis is commonly referred to as a green synthesis method approach [33]. The idea of nanoparticles may be linked to the mechanism of nanoparticle production in plants. Plant-mediated nanoparticles are being investigated as a possible next-generation disinfectant, with uses in clinical care, consumer items, and other industrial settings [34]. The antibacterial, antifungal, anticancer, anti-HIV, antidiabetic, high catalytic, and photochemical activity nanoparticles have also gotten much attention [35, 36].

Several research groups have shown considerable interest in its unique qualities and discovered excellent uses in various fields. Researchers have devised several synthetic approaches for nanoparticle manufacturing, revealing a significant advantage to ecosystems and biodiversity via clean, harmless, and ecologically friendly processes, including bacteria, fungus, and plants [37]. However, several nanoparticle compositions have exhibited toxicity at the nanodimensions [38, 39]. Nanomaterials and green chemistry are collaborating to develop ecologically, or ecofriendly benign M/MO nanoparticles are utilizing plants, microbes, and other natural resources to solve toxicity problems [40].

Figure 2: Advantages of green synthesis method.

Parts of Moringa oleifera plants have been reported to various phytochemical parameters [41]; it is a good source of antioxidants, including quercetin and chlorogenic acids, such as flavonoids, phenolics, astragalin, anthocyanins, cinnamates, and carotenoids, as well as a rich source of carotene, Fe, K, Ca, terpenes, quinines, saponins, alkaloids, proteins, tannins, and vitamin C [42, 43]. As shown in Figure 3, the advantages of Moringa oleifera, thus improving

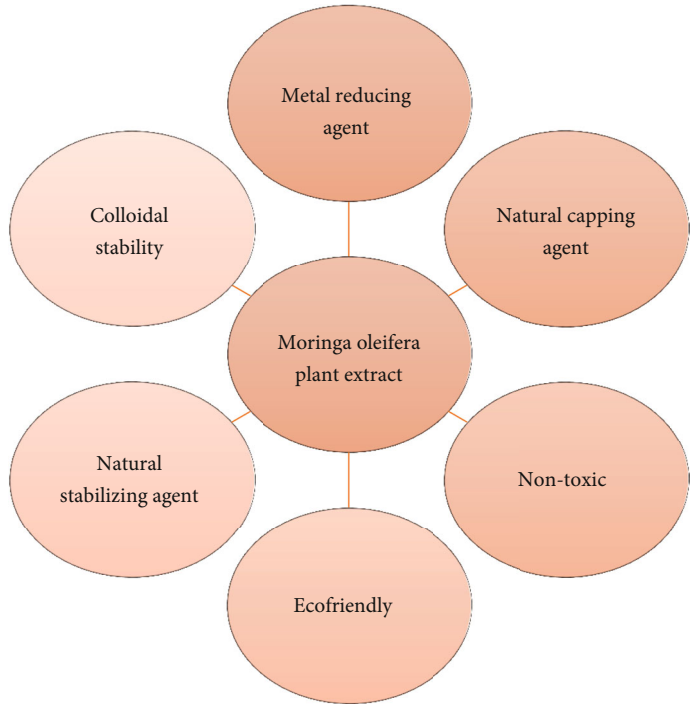

Figure 3: Advantages of Moringa oleifera plant leaf extract.

the shelf life of fat-containing foods, act as a good metal-reducing, capping, and stabilizing agent [44–46]. The recent work of this review is Moringa oleifera plant leaf extracts utilized for the biosynthesis of FeO, NiO, MgO, CuO, ZnO, Ag, and Au nanoparticles since it has been acting as an environmentally ecofriendly process. Researchers and scientists have been drawn to this path to synthesize M/MO NPs using Moringa oleifeara leaf extract because of the readily available, safe use, and rich sources of diverse metabolites.

2. Biosynthesis of Metal Nanoparticles

The Moringa oleifera plant synthesized M/MO NPs in many processes (Figure 4). The method consists of three steps: primary treatment, biosynthesis, and characterization of nanomaterials. Moringa oleifera plant extract was utilized as a reducing/oxidizing, capping, and stabilizing agent in producing the M/MO NPs. According to the literature survey, some of the M/MO NPs, their synthesis, and comparative study have been discussed in Table 1.

2.1. Iron Oxide (FeO) NPs. Aisida et al. [47], in their research worked, synthesized a green and environmentally friendly approach for nanoparticles in which using an aqueous extract of the Moringa oleifera plant serves as a reductant and capping agent. MO leaf powder extract and $FeCl_3$ solution were used to synthesize dark-brown-capped MO-FeO NPs. UV-Vis spectroscopy confirmed the noticeable color change from orange to dark brown (Figure 5), leading to FeO NPs. The rod-like morphologies of NPs were shown by SEM and TEM, with a 15 nm average particle size. In terms of antimicrobial activity, biosynthesized FeO NPs inhibited growth more effectively than chemical FeO NPs against antimicrobial. Additionally, smaller particles have a greater surface area and bioactivity, making them excellent antimicrobial agents against harmful microorganisms.

Tovar et al. [48] almost have similar work as previous authors. Using the MO leaf extract and (Iron (III) chloride hexahydrate) for the synthesis of FeO NPs, in this process, the Moringa oleifera acted as a capping agent. The germination rate and development of corn seeds were studied using synthesized FeO NPs loaded with N, P, and K. Moringa, and chitosan had a favourable influence on corn plant speed germination parameters, with no adverse effects on seed germination.

MO FeO NP possesses structural and superparamagnetic properties and suitable particle sizes for biomedical applications [47] performed two parts in which the Moringa oleifera (MO) leaves were dried at room temperature (RT) and sunlight (SL). MO acted as a capping agent; both solutions were gradually reduced from brown to dark black by adding FeCl3.6H2O solution. The FeO NPs obtained were characterized and the size of RT FeO and SL FeO NPs measured by SEM was 16 to 18 nm and 18 to 20 nm, respectively. XRD analysis showed a BCC lattice structure for RT, while SL exhibited a quasicrystalline structure.

2.2. Copper Oxide (CuO) NPs. The researchers [54] used MO leaf extract as a capping agent and copper acetate solution to synthesize nanocrystalline CuO powder (fine dark black). A simple green chemistry strategy made CuO NPs from Moringa oleifera leaf extract, and XRD, FE-SEM, EDX, FT-IR, UV-DRS, and PL were used to characterize. CuO NPs show good antifungal activity [56] used Moringa oleifera (MO) leaf extract for the synthesis of CuO microspheres. The color of the solution changed from bluish to dark green during

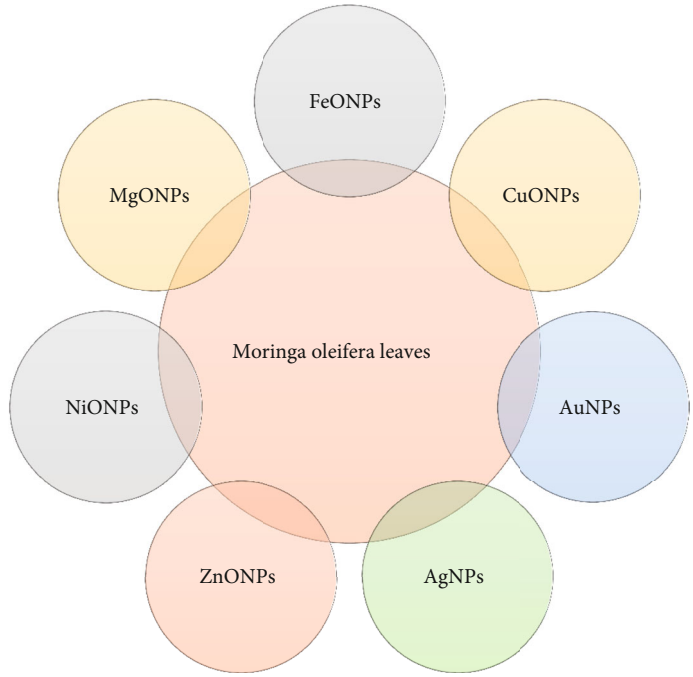

Figure 4: Green synthesis of M/MO NPs using MO leaves.

stirring, indicating that the biological components included in the MO leaf extract converted Cu $(NO_3)_2 3H_2O$ to Cu^{2+} ions. The formation of monoclinic crystal-structured CuO was revealed by the XRD pattern, which confirms the conversion of Cu $(NO_3)_2 3H_2O$ to Cu^{2+} ions by phytochemicals contained in the MO leaf extract. As seen by SEM micrographs, it shows the cluster-like morphologies that mimic hierarchical CuO microspheres. In the FTIR spectrum, the asymmetric stretching deformation vibration bands correspond to Cu–O bonds, which imparted monoclinic unit crystal formation, and the synthesized NPs show better antibacterial activity.

2.3. Zinc Oxide (ZnO) NPs. Elumalai et al. [62] employed a straightforward and environmentally safe chemical route to synthesize zinc oxide nanoparticles (ZnO NPs) from Moringa oleifera leaf extract. UV–Vis, XRD, FESEM, EDX, FT–IR, and PL evaluated the ZnO NPs. The hexagonal wurtzite structure of NPs was found by the XRD investigation. The functional groups act as a stabilizing agent in the leaf extract for the ZnO NPs confirmed by FT–IR. The size (16–20 nm) and morphology (spherical and agglomerated) were characterized by FE-SEM. The typical absorption peak of Zn NPs was seen in UV–Vis absorption. Antimicrobial activity studies confirmed the presence of a maximum inhibition zone [64] biosynthesized NiO NP and ZnO NP using extracts of Moringa Oleifera leaves as an efficient chelating and oxidant/reductant of $[Ni(H_2O)_6](NO_3)_2$ and $Zn(NO_3)_2.6H_2O$. XRD. Attenuated Total Reflection-FTIR, UV-Vis-NIR, and PL methods explore the NiO NP and ZnO NP structural and optical characteristics of these two semiconductors created in the same process. Pure cubic NiO-NPs and pure wurtzite ZnO-NPs with average crystallite sizes of 17.80 nm and 10.81 nm, respectively, were formed, according to the structural study. The diffuse reflectance investigation revealed that their band gaps were 4.28 eV and 3.35 eV, respectively.

2.4. Nickel Oxide (NiO) NPs. Ezhilarasi et al. [66] synthesized the nickel oxide nanoparticles (NiO-NPs) using the green method. It shows cytotoxicity and antibacterial activity. In this process, the color changed from dark brown to reddish ink, and after applying temperature, a light-yellow powder of NiO NPs was produced. The NiO NMps were single crystalline with a face-centred cubic phase and two strong PL at 305.46 nm and 410 nm. XRD and FTIR verified the formation of a pure NiO phase (average size 9.69 nm). HR-TEM confirmed the creation of nano and microstructures (agglomerated spherical shape). With different doses of NiO NPs generated from Moringa oleifera plant extract, the in vitro cytotoxicity and antibacterial activity were tested.

2.5. Magnesium Oxide (MgO) NPs. Fatiqin et al. [68] green synthesized magnesium oxide nanoparticles (MgO NPs) were achieved in this work by combining Moringa oleifera leaf extracts with a magnesium chloride solution. The produced MgO NPs vary from 20 to 50 nm (spherical shape). The absorption of MgO nanoparticles in the UV-Vis spectrum is at 280 nm. The inhibition zones showed the antibacterial activity of MgO NPs against S. aureus and E. coli. [69] used an aqueous extract of Moringa oleifera (MO) leaves as a green agent to produce nanosize MgO (MgO NPs) from MgCl2 solution. UV-Vis absorption was used to validate the formation of MgO NPs in this synthesis. XRD investigation validated the spherical crystal structure of MgO NPs. Using SEM, TEM, and particle size analyzer (PSA) data,

Table 1: Summary of parameters and conditions for biosynthesized nanoparticles from Moringa oleifera plant.

NPs	Precursor	MO extract conc. (g/ml)	Reaction Temp./ Time	Size (nm)/Morphology	Photocatalytic/biological activity	References
FeO	0.5 M $FeCl_3$	10 g, capping agent	100°C, 24 hrs	15.01 ± 6.03 nm rod like	Antibacterial test	Aisida, S. O. et al. [47]
FeO	1.60g of $FeCl_3.6H_2O$	2 g, reducing agent	250°C, 15 hrs	66 ± 20 nm agglomeration	—	[48]
FeO	0.5 M $FeCl_3$	10 g/100ml, reductant	100°C, 24 hrs	76 ± 2.0 nonuniform rod like	Photocatalytic and antibacterial activity	[49]
FeO	0.15 M FeCl3 6H2O	30g	60°C	26.2 nm, irregular spherical	—	Aisida, S. O. et al. [50]
FeO	0.01 M FeCl3	20 gm reductant	500°C, 5 hrs	Below 5 nm (quantum dots)	—	[51]
FeO	0.1 M (Fe(NO3)3.9H2O	60g/lit, Reductant	50°C	Less than 100nm, spherical agglomerated	—	[52]
FeO	0.5 M FeCl2.7H2O	Reducing power	—	45 nm irregular shape	Antioxidant and antibacterial activities	[53]
CuO	0.01 M Cu(CH3COO)2.H2O	5 gm	400°C, 1 hr	35-95 nm, quasispherical shape	Antifungal activity	[54]
CuO	CuSO4 5H2O	60g, natural reducing agent	50°C	Lower to 100 nm aggregation	—	[55]
CuO	1 gm Cu(NO3)2·3H2O	5 gm, reducing and stabilizing agent	200°C for 1 h	Average size 45.30nm, cluster-like	Bactericidal activity	[56]
CuO	2 g/20 ml copper acetate tetrahydrate	20 gm/100 ml, reducing and capping agent	400°C for 2 h	Average size 12 nm aggregates	Antioxidant and anticancer activity	[57]
CuO	3gm/10 ml copper (II) nitrate	3 gm biocapping agent	100°C, 1 h	12 and 18 nm spherical	Antimicrobial activity	[58]
ZnO	1 mM Zn(NO3)2·6H2O	5 gm reducing agent	60°C 20 min	—	—	Manokari, M., and Shekhawat, M. S. [59].
ZnO	(Zn(NO3)2 6H2O)	30 gm, reducing agent	500°C, 1 hr	16 to 31.9 nm spherical shape	Electrochemical activity	[60]
ZnO	2.1 g zinc acetate	5 g, stabilizing and accelerating agents	350°C, 5 hrs	52 nm, spherical	Photocatalytic and antibacterial activity	[61]
ZnO	2 g, (Zn (NO3)2.6H2O)	20 gm, stabilizing agent	400°C for 2 hrs	16– 20 nm spherical and agglomerated particles	Antimicrobial activity	[62]
ZnO	1.5 g Zn(NO3)2.6H2O	5 g (flowers, seeds, and leaves) chelating agent	500°C, 2 hrs	(13.2, 13.9, and 10.8 nm)	Photocatalytic activity	[63]
NiO	3 g/100 ml nickel nitrate hexahydrate	9 gm/300 ml, chelating reduction/ oxidizing agent	500°C, 2 hrs	Average size 17.80nm	—	[64]
NiO	1.82 g/100 ml, nickel nitrate	2 gm/200 ml, reducing agent and capping agent	500°C, 3 min	Average size 12 nm, spherical shape	Photocatalytic and antimicrobial activity	[65]
NiO	0.1 mM Ni (NO3)2	20 g/100 ml acts as a fuel	400°C, 9 hrs	9.69 nm agglomerated spherical shape	Cytotoxicity and antibacterial activity	[66]
MgO	1 mM MgCl2.6H2O	4 gm biocapping and bioreducing agent	600°C	60-100 nm spherical shape	Antioxidant and antibacterial activities	[67]
MgO	1 mM MgCl2.6H2O	4 gm reducing agent	600°C for 5 hrs	20-50 nm spherical shape	Antibacterial activity	[68]

Table 1: Continued.

NPs	Precursor	MO extract conc. (g/ml)	Reaction Temp./ Time	Size (nm)/Morphology	Photocatalytic/biological activity	References
MgO	1 mM MgCl2.6H2O	4 g green agent	600°C for 5 hrs	40–70 nm spherical shape	Antioxidant, antibacterial, and antifungal	[69]
MgO	MgCl2.6H2O	4gm/100 ml reducing agent and stabilizing agent	600°C for 5 hrs	40 to 100 nm cubic shape	—	[70]
Ag	1 mM AgNO3	20 gm reducing agent	—	46 nm spherical shape	—	[71]
Ag	1 mM AgNO3	10 g reducing agent	—	9-11 nm agglomerated	Antimicrobial activity	[72]
Ag	1 mM AgNO3	20 g reducing agent	—	8 nm monodispersed spherical shape	Antimicrobial activity	[73]
Ag	1 mM AgNO3	5 g (stem barks) reducing agent	60°C	40 nm spherical shape	Anticancer activity	[74]
Ag	1 mM AgNO3	10 g reducing agent	60–80°C, 20 min	57 nm spherical shape	Antimicrobial activity	[75]
Ag	0.001 M,0.01 M, and 0.1 M AgNO3	3, 5, and7 g reducing agent	—	15–25 nm disperse and semispherical shapes	Antibacterial activity	[76]
Ag	1 mM AgNO3	Reducing agent	37°C for 24 hours	Uniform-sized	Antibacterial activity	[77]
Au	1 mM (HAuCl43H2O, ACS reagent)	20 g capping agent and reducing agent	—	100 nm triangular, hexagonal, and spherical	Catalytic activity and anticancer	[78]
Au	0.0254 mmol/L HAuCl4, 3H2O	43.6 mg/ml reducing and stabilizing agent	30°C, 10 min	20-60 nm spherical shape	—	[79]
Au	1 mM HAuCl4.3H2O	20 g bioreduction	—	15.2 nm spherical, oval, and hexagonal shape	Antioxidant, antidiabetic, and anticancer activities	[80]
Au	1 mM HAuCl4	5 gm reducing and capping agent	—	96 nm	Anticancer activity	[81]
Au	1 mM HAuCl4.3H2O	5 g bioreduction	—	10–20 nm spherically shaped	Anticancer activity	[82]

Figure 5: Biosynthesis of FeO nanorods.

the particle size of the synthesized MgO NPs was determined to be between 40 and 70 nm. The NPs showed excellent antibacterial and antifungal activity.

2.6. Silver (Ag) NPs. Moodley et al. [72] described silver nanoparticles (AgNPs) synthesized from Moringa oleifera leaf extracts and studied their antibacterial activities. UV–Vis spectrum analysis was used to establish the synthesis of AgNPs by reducing Ag + ($AgNO_3$). A UV–Vis spectrometer was used to scan NP solutions and the control from 190 to 900 nm. Surface plasmon resonance at 450 nm and 440 nm verified the production of silver nanoparticles in both fresh and freeze-dried leaf samples. According to FTIR spectroscopic technique, flavonoids, terpenoids, and polysaccharides predominate and are useful for the reduction as well as capping agents during the synthesis of Ag NPs. According to the X-ray diffraction examination, shows 9 and 11 nm NPs size. The antimicrobial activity of Ag NPs was shown in both bacterial and fungal strains.

Vasanth et al. [74], in their work, synthesized colloidal silver nanoparticles (AgNPs) from Moringa olifera (MO) stem bark extract. Morphology was studied using electron and atomic force microscopic imaging (40 nm, and pentagon-shaped). Human cervical cancer cells (HeLa) were used to analyze the effects of produced AgNPs, and cell morphology was assessed using 4,6-diamidino-2-phenylindole (DAPI) staining. The effectiveness of AgNPs was investigated using fluorescence-activated cell sorting (FACS), and it was discovered that they trigger death in HeLa cells via generating reactive oxygen species (ROS).

2.7. Gold (Au) NPs. Anand et al. [78] used 1 M chloroauric acid with Moringa oleifera (MO) aqueous flower extract for the AuNP synthesis. The UV-Vis spectrophotometer (200–800 nm) was used to describe the formation of the colloidal solution of Au NP. TEM was analyzed to particle size (100 nm) that was triangular, hexagonal, and irregular spherical. Primary analytical tests analyzed AuNP and functional group interaction in floral extract and FTIR, and the 1H-NMR technique was used to investigate capping agents. Catalytic reduction of nitrophenol and nitroaniline using Au NP, which were analyzed by UV-Vis, revealed a fast decrease in some minutes, suggesting industrial effluent degradation. Furthermore, AuNPs might have anticancer activities. [79] worked on an ecofriendly method to synthesize gold nanoparticles (AuNPs) by reducing chloroauric acid with Moringa oleifera leaf extract which acts as a reducing agent. The chloroauric acid solution was reduced and transformed to AuNPs in the size range of 20-60 nm (spherical shape) using leaf extract. The MO plant extract contains several phytochemicals that function as reducers and stabilizers. These are environmentally acceptable synthesizing stabilized gold nanoparticles suitable for various biological applications.

3. Conclusion

This review summarised that Moringa oleifera plant leaves have active compounds that serve as capping, reducing, and stabilizing agents and produce biosynthesized M/MO NPs. Several approaches were gathered, and it was found that Moringa oleifera plant leaves can readily biosynthesize numerous types of M/MO nanoparticles. Biosynthesised ZnO and AgNPs outperform chemically produced NPs in terms of antibacterial characteristics. However, not all articles discuss the size of NPs resulting from the concentration of Moringa oleifera plant leaf extract or temperature changes. In general, the size of the nanoparticles was determined by manipulating the concentration of Moringa oleifera leaf extract and the temperature during biosynthesis.

Data Availability

All relevant data are included within the article.

Conflicts of Interest

All authors declare that there is no conflict of interest.

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