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Review Article

A REVIEW ON NANOPARTICLES OF *MORINGA OLEIFERA* EXTRACT: PREPARATION, CHARACTERIZATION, AND ACTIVITY

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ABSTRACT

Nanoparticles have revolutionized biomedicine, especially in the field of drug delivery due to their intriguing properties such as systemic stability, level of solubility, and target site specificity. It can, however, be both beneficial and damaging depending on the properties in different environments, thus highlighting the importance of nanotoxicology studies before use in humans. Green nanotechnology has drawn major attention because of its ecofriendly and economical biosynthetic protocols. Synthesis of metallic nanoparticles (NPs) using plant secondary metabolites is considered as a safer and cheaper option. Metallic nanoparticles (NPs) have a great role in many scientific fields such as medicine, physics, mechanics, pharmaceutics, and other. Plants contain phytochemicals that has been used traditionally for the treatment of various diseases, and proved to be nontoxic to healthy tissues. These phytochemicals play an important role in bio-reduction processes as reducing and stabilizing agents and renders NPs selective toxicity towards diseased tissues. This review focuses on the synthesis of certain metal and metal oxide nanoparticles (M/MO NPs) using an extract of *Moringa oleifera* plant. *Moringa oleifera* is an example of a tree with significant nutritional and therapeutic benefits. It is abundant in macronutrients, micronutrients, and other bioactive components that are essential for optimal bodily function and disease prevention. These components produce smaller particles and give a compelling impact on the activities of M/MO nanoparticles. This review paper is an attempt to compile up various research as well as reports related to nanoparticles such as FeO, CuO, ZnO, NiO, MgO, Ag, and Au.

Keywords: *Moringa oleifera*, Nanomaterials, Antioxidant, Metal oxide, Disease prevention

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INTRODUCTION

Moringa oleifera (*M. oleifera*) is a type of tropical plant that is easy to grow in tropical areas such as Indonesia. *M. oleifera* is a plant that is rich in nutrients and is often called the ''miracle tree'' because all parts of this plant are very useful, especially in the health sector. Nutrient content is found in all parts of the *M. oleifera* plant, from leaves, bark, flowers, fruit (pods), and roots, which are often used as medicinal plants. One of the most prominent components of the *M. oleifera* plant is antioxidants, especially in leaves, which contain the highest antioxidants [1]. Based on phytochemical testing, *M. oleifera* leaves contain tannins, steroids, and triterpenoids, such as flavonoids, saponins, antarquinones, and alkaloids, all of which are antioxidants. According to research results, fresh *M. oleifera* leaves have 7 times more antioxidant power than vitamin C [2]. One of the flavonoid derivatives, namely quercetin, has antioxidant power 4-5 times stronger than vitamin C and vitamin E [3].

M. oleifera Lam is a plant that can be eaten and is also used as a herbal medicine. It is full of nutrients and does many different things in the body. Polysaccharides are an important part of how *M. oleifera* Lam works (MOPs) [4]. The antioxidant properties of *M. oleifera* have a better effect than Vitamin E *in vitro* and inhibit lipid peroxidation by breaking down the *peroxyl radical* chain [5]. Use of natural antioxidants is currently considered safer because natural antioxidants are obtained from plant extracts. In the form of extracts, it has a weakness, namely the low solubility in water, so that it reduces its bioavailability. The efficiency of drug use can always be hampered by the ability of the drug itself to reach its site of action. Fig. 1 shows the special biological activities of different source form *M. oleifera* Lam polysaccharides.

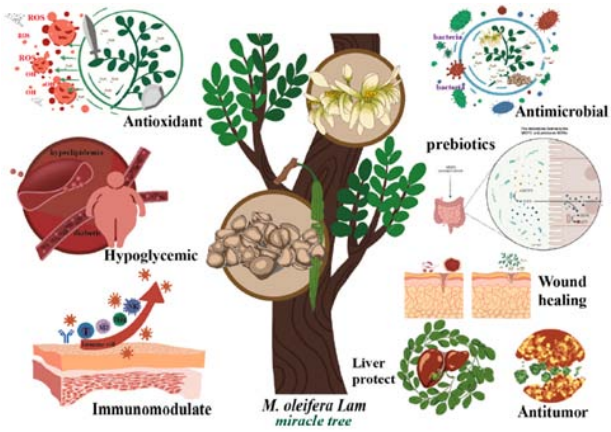

Fig. 1: The special biological activities of different source form *M. oleifera Lam polysaccharides* (MOPs) [4]

Nanoparticles are one strategy to increase the bioavailability of herbal active compounds. Nanoparticles are solid colloidal particles with a diameter of 1–1000 nm [6]. To synthesis nanomaterial of various shapes and dimensions, two different methods of approaches have been widely used, namely *bottom-up* and *top-down* approaches. Nanotechnology is regarded as one of the most significant modern sciences employed in a variety of technologies; its impact has been readily apparent in recent years. Nanoparticles are separated from the element's core materials by their distinct properties, such as melting point and interaction speed with other substances, which have given them a unique significance. Nanoparticles are manufactured in a variety of ways, including chemical, physical, and biological approaches (fig. 2), with the biological method gaining prominence due to its eco-friendliness, low cost, and safety; it is also known as green synthesis of nanoparticles [7]. Research on nanotechnology is currently growing rapidly because it can be widely applied in agriculture, automotive, body care (toothpaste, cosmetics), electronics, the environment, food, medicine, household appliances, petroleum, printing, textiles, and so on [8-10].

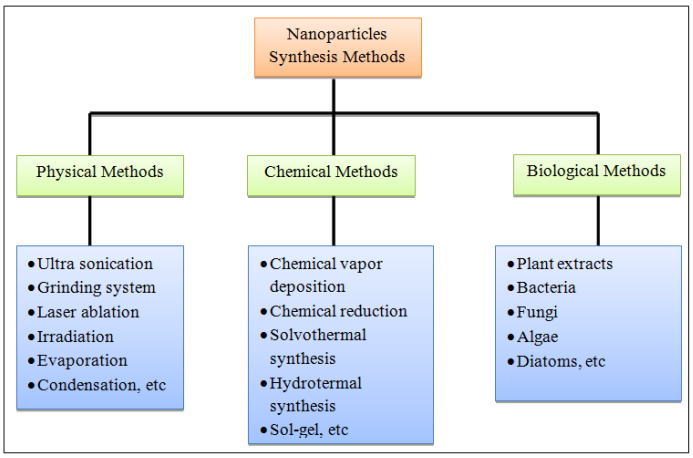

Fig. 2: Summary various methods of nanoparticles (NPs) synthesis [7]

Nanoparticles can be composed of metals, metal oxides, semiconducting materials, polymers, carbon materials, and organic molecules. Due to their unique features, metal and metal oxide nanoparticles are of tremendous importance and have prospective uses in the disciplines of nanotechnology and nanoscience. The numerous physical characteristics that govern the chemical, physical, electrical, and optical properties of nanoscopic materials are size, shape, and surface morphology. Nanomaterials have been utilized in numerous sectors, including photonics, energy storage, drug delivery, catalysis, fuel cells, nanomedicines, etc [11, 12].

Plant-mediated nanoparticles are straightforward to manufacture, easily available, affordable, and simply scaled up. The inclusion of metabolites and phytochemicals such as terpenoids, alkaloids, flavonoids, proteins, peptides, and tannins in plant leaf extracts boosted the biosynthetic production of nanoparticles [13, 14]. The nanoparticles' varied sizes, shapes, and morphologies are determined by the extract's constituents. The utilization of plant components extracts in nanoparticle synthesis is commonly referred to as a green synthesis method approach [15]. The mechanism of nanoparticle formation in plants may be linked to the concept of nanoparticles. As a potential disinfectant of the next generation [16], plant-mediated nanoparticles are being studied for usage in clinical care, consumer goods, and other industrial settings. Nanoparticles with antibacterial, antifungal, anticancer, anti-HIV, anti-diabetic, high catalytic, and photochemical activities have also garnered considerable interest [17, 18].

Metal/metal oxide nanoparticles synthesized via a green route attracted significant interest in a variety of fields, including optics, electronics, biomedicine, and electrochemistry, as opposed to conventional routes, which are currently under scrutiny due to the need for harsh, perishable chemicals in their production. Synthesis often consists of plant elements, such as leaves, flowers, fruits, seeds, roots, and inflorescence, that are eco-friendly and non-detrimental to the environment. In addition, microbes, such as bacteria and viruses, fungus, enzymes, biopolymers, and microwave-assisted heating, can substitute for harmful chemicals [19, 20].

Several metals and metal oxide nanoparticles such as Ag, Au, MgO, ZnO, FeO have been synthesized from *M. oleifera* leaf extract. Ag nanoparticles were synthesized for the first time by reducing the silver ions present in a solution of silver nitrate with an aqueous extract of *M. oleifera* [21]. Ag-NPs have been shown to have significant anticancer activity. This is due to the fact that they selectively disrupt the mitochondrial respiratory chain, resulting in the production of reactive oxygen species (ROS) and the cessation of adenosine triphosphate (ATP), both of which damage the nucleic acid [22]. It was recently discovered that incorporating Ag-NPs into plant extract increased the total phenolic compounds and total flavonoids. As a result, the extract-loaded Ag-NPs' antioxidative and antimicrobial efficiency increased and surpassed that of the plant extract alone or $AgNO_3$ [23].

M. oleifera leaves extracts are used in this review's biosynthesis Ag, Au, Bi, MgO, CuO, ZnO, FeO, and NiO nanoparticles because it's an eco-friendly technique. Researchers and scientists employ *M. oleifera* leaves extract to manufacture metal/metal oxide nanoparticles (M/MO NPs) since it's easily available, safe, and rich in metabolites.

Synthesis of nanoparticles

Many pathways in the *M. oleifera* plant led to the synthesis of metal/metal oxide NPs. The process includes three phases: primary treatment, biosynthesis, and nanomaterial characterization. In order to create the M/MO NPs, a plant extract from the *M. oleifera* tree was used as a reducing/oxidizing agent, capping agent, and stabilizing agent. Table 1 summarizes information gleaned from the literature review about several M/MO NPs, including details on their synthesis and research comparing them to other similar NPs.

Silver (Ag) nanoparticles

Mohammed *et al.* (2020) investigated the antibacterial activity of silver nanoparticles synthesized using *Moringa* stem extract against Gram-negative bacteria such *E. coli* ATCC 8739 [24]. The agar diffusion assay method was used to analyze the comparison between the antibacterial activities of the concentration 100 µg/ml and 80 µg/ml of the biosynthesized silver nanoparticles using *Moringa oleifera* stem extract tested against *E. coli* ATCC 8739. The results showed that the higher the concentration of the silver nanoparticles, the greater the antibacterial activity. FTIR analysis showed that the groups were responsible for the reduction action of *M. oleifera* stem

extract, which led to the formation of silver nanoparticles. TEM shows that *M. oleifera* stem extract spreads nanoparticles over a range of 7.56–23.71–26.13 nm. Synthesized silver nanoparticles with concentrations of 100 µg/ml and 80 µg/ml were proven to be antimicrobial against the *E. coli* ATCC 8739 reference strain by showing a zone of inhibition of 17.5 and 16.5 mm, while *M. oleifera* stem extract solution showed no zone of inhibition.

Moodley *et al.* reported silver nanoparticles (AgNPs) and their antibacterial effects were investigated using extracts from the leaves of *M. oleifera* tree [25]. The synthesis of AgNPs by decreasing Ag^+ was determined using UV-Vis spectroscopy ($AgNO_3$). All of the NP solutions and controls were scanned between 190 and 900 nm on a UV-Vis spectrophotometer. The generation of silver nanoparticles in both fresh and freeze-dried leaf samples was confirmed by surface plasmon resonance at 450 nm and 440 nm. The FTIR spectroscopy method indicates that flavonoids, terpenoids, and polysaccharides play a significant role in the synthesis of Ag NPs, serving both as reducing and capping agents. According to X-ray diffraction analysis, NPs range in size from 9 to 11 nm. Both bacterial and fungal strains demonstrated Ag NPs' antibacterial activity.

In their work, Vasanth *et al.* synthesized colloidal silver nanoparticles (AgNPs) from an extract of the stem bark of *M. oleifera* [26]. Morphology was looked at with electron and pentagon-shaped atomic force microscopy (40 nm). Human cervical cancer cells (HeLa) were used to study the effects of the manufactured AgNPs, and the shape of the cells was looked at with 4, 6-diamidino-2-phenylindole (DAPI). Fluorescence-activated cell sorting (FACS) was used to look into the effectiveness of AgNPs. It was found that they kill HeLa cells by making *reactive oxygen species* (ROS).

Mohammad and El-rahman (2015) reported that silver nanoparticles were synthesized in an environmentally friendly manner using a plant extract that is harmless for the environment [27]. It was discovered that an extract from the leaves of *Moringa oleifera* Lam has the ability to convert silver ions into silver nanoparticles even when the temperature remains constant. The synthesis of AgNPs was performed in this study by making use of an aqueous extract of *M. oleifera.* This extract served as both a reducing and capping agent for the reduction of silver ions. Following an analysis of the synthesized silver nanoparticles using high resolution transmission electron microscopy (HRTEM), UV–visible spectroscopy, and then an investigation into the antimicrobial activity of the particles against phythopathogenic bacteria, the results were presented. Utilizing UV–visible spectroscopy and high-resolution transmission electron microscopy, the produced nanoparticles were characterized. The biogenic silver nanoparticles have antibacterial activity against *Pantoea agglomerans* (27 mm), *Ralstonia solanacearum*, *Erwinia amylovora*, and *Pseudomonas lachrymans* (19.66 mm, 16.66 mm, and 13 mm, respectively), and *Agrobacterium tumefaciens* (13 mm), with no effect on *Erwinia carotovora*. Analysis on the antibacterial activity of produced silver nanoparticles against several phytopathogenic bacteria showed excellent potential as an antibacterial agent in managing various plant illnesses caused by bacteria.

The synthesis of cost-effective, green silver nanoparticles (AgNPs) utilizing *Moringa oleifera seed* (MOS) as a reducing/capping agent is presented, as are its uses in antibacterial and photocatalytic oxidation for water treatment [28]. In the present study, stable silver nanoparticles were synthesized employing MOS using a simple, inexpensive, and green synthesis approach. Specifically, AgNPs with an average size of 9.4 nm were synthesized utilizing MOS and silver nitrate solution by reduction of Ag^+ion and stabilization of silver nanoparticles by MOS secondary metabolites. The MOS phytochemicals served as reductants and capping agents for the silver nanoparticles. The produced MOS-AgNPs displayed good antibacterial activity against both Gram-positive and negative bacteria commonly found in wastewater. MOS-AgNPs shown outstanding antibacterial action against Gram-positive (*Staphylococcus aureus*; 14.6 mm) and Gram-negative (*Escherichia coli*; 30.6 mm, *Salmonella enterica typhimurium* (29 mm), and *Pseudomonas aeruginosa*; 22.8 mm) pathogens. These findings suggest that MOS-AgNPs may be a potent antibacterial agent against water-borne pathogens and a potential and cost-effective solution for the treatment of waste generated by industrial dyeing operations.

Gold (Au) nanoparticles

Kiran *et al.* investigated green synthesis of AuNPs using *M. oleifera* aqueous leaves extract [34]. The AuNPs produced with this approach supplied nontoxic carrier for many applications. This study revealed the eco-friendly, cost-effective synthesis of AuNPs from M. oleifera leaves extract, which had antioxidant, anti-diabetic, and anti-cancer properties. Analytical techniques comprising UV–vis absorption spectroscopy was utilized to confirm the AuNPs in the solution, crystalline structure of AuNPs were validated by X-ray diffraction (XRD) pattern. Energy dispersive spectroscopy (EDS) results confirmed the presence of elemental AuNPs. High-resolution transmission electron microscopy (HR-TEM) and scanning electron microscopy (SEM) were employed to identify size and morphology. The MO-AuNPs revealed dose-dependent antioxidant potential completed with DPPH, antidiabetic investigation indicated the effective reduction of the activity of digesting enzyme α-Amylase as compared to the conventional metformin. Further cytotoxicity study on MCF-7 cell lines revealed significant reduction in the cell viability with increase in concentrations exhibiting its anticancer potential. Thus, the MO-AuNPs can be anticipated as a strong contender for biomedicinal applications and environmental biological remediation.

Anand *et al.* investigate the *M. oleifera* flower-mediated *in vitro* one-step transformation of AuNPs, as well as their cytotoxic effects on the A549 human lung cancer cell line and normal healthy human peripheral lymphocytes [35]. Synthesized AuNP using 1M chloroauric acid and *M. oleifera* (MO) aqueous floral extract. The XRD, TEM, and DLS were used to characterise the AuNPs, and the FTIR and ^{1}H-NMR spectroscopies were used to determine the type of natural capping agens. The AuNPs were well-dispersed triangular, hexagonal, and nearly spherical AuNPs with a diameter of less than 5 nm. Catalytic activity was demonstrated by the AuNPs, as evidenced by the fast reduction of 4-nitrophenol and 4-nitroaniline. In addition, AuNPs generate considerable cytotoxicity in A549 cells but do not have the same effect on normal healthy PL cells.

Boruah *et al.* (2021) reported that a comprehensive study was conducted to determine the physiochemical and biological activity of gold nanoparticles stabilised by conventional citrate and those stabilised by *M. oleifera* plant leaves extract [36]. The prepared nanoparticles were tested for their biological properties, such as their antioxidant, antibacterial, and blood cytotoxic activity, in order to evaluate their potential for further application in therapeutic techniques. A comparison was made between the properties and activities of green gold nanoparticles and those of ordinary citrate-stabilized gold nanoparticles. In a study utilising an animal model, it was found that green gold nanoparticles that were generated using *M. oleifera* showed less cytotoxicity and helped in the regeneration of neural cells. In animal model research, the green manufacturing of gold nanoparticles employing *M. oleifera* demonstrates less cytotoxicity and aids in the regeneration of neural cells. Fig. 3 shows the preparation process of *M. oleifera* leaves extract in methanol followed by the production of green gold nanoparticles reduced and stabilized by the extract. The reported actions are a result of the high medicinal value of the biomolecules contained in the methanolic fraction of this plant's leaves. In addition, gold nanoparticles stabilized by *M. oleifera* extract have enhanced photocatalytic capabilities for MB breakdown. This may result from the presence of polyphenolic chemicals with an electron-rich environment in the extract. Therefore, this approach of synthesizing gold nanoparticles will open a new door for the creation of physiologically active gold nanoparticles.

Bismuth (Bi) nanoparticles

Edwin *et al.* reported green production of bismuth nanoparticles using a hydroalcoholic extract of *M. oleifera* leaves and physical characterisation using several methods [38]. They tested M. oleifera leaves extract and synthesised phytochemical encapsulated bismuth nanoparticles for antioxidant, antibacterial, and antifungal activity against various bacteria and fungi. The amount of total phenolic content in the *M. oleifera* leaves extract that was utilized was 23.0±0.3 mg gallic acid equivalent per gram of powdered *M. oleifera*

leaves. According to the findings of the SEM, the nanoparticles of synthesized bismuth have a form that is amorphous and range in size from 40.4 to 57.8 nm. The DPPH and phosphomolybdenum assays demonstrated that the *M. oleifera* leaf extract and the bismuth nanoparticles that were generated both exhibit a significant amount of antioxidant activity. On the other hand, the antioxidant capacity of the manufactured bismuth nanoparticles is significantly lower than that of the *M. oleifera* leaf extract. The nanoparticles may have lost some phenolic components. Both the *M. oleifera* leaves extract and the synthesized bismuth nanoparticles have a strong antibacterial effect on *E. coli, K. pneumoniae, S. aureus, and E. faecalis* (MIC values for the extract: 500, 250, 250, and 250 µg/ml; MIC values for the nanoparticles: 500, 500, 500, and 250 µg/ml). The nanoparticles also have relatively stronger anti-fungal activity against.

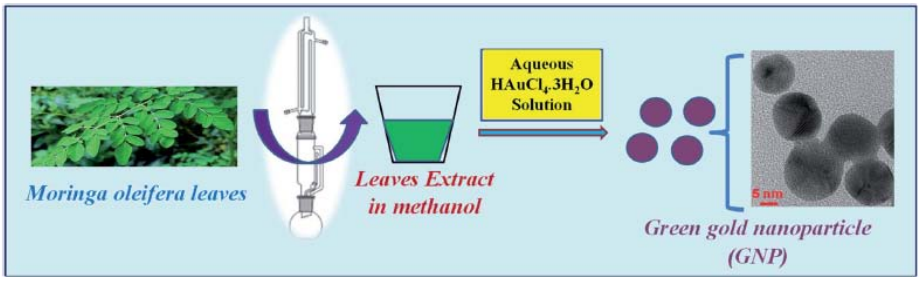

Fig. 3: Preparation of *Moringa oleifera* leaves extract in methanol followed by production of green gold nanoparticles reduced and stabilized by the extract [36]

Magnesium oxide (MgO) nanoparticles

The present effort, as reported by Fatiqin *et al.* [39], centered on the synthesis of nano-sized MgO utilizing water-soluble chemicals isolated from various parts of the *M. oleifera* plant. These portions included woody vascular, the bark of woody, twigs, and leaves. The production of green synthetic magnesium oxide nanoparticles, also known as MgO NPs, was accomplished by combining magnesium chloride solution with extracts of *M. oleifera* leaves. After combining the aqueous extracts with a solution of magnesium chloride, which was followed by the addition of a solution of sodium hydroxide, in order to produce a precipitate of magnesium hydroxide, the efficacy of the extracts as a reducing agent and a stabilizing agent was evaluated. The utilization of characterisation strategies has provided evidence that indicates the development of MgO as a nanomaterial, with the particle size falling somewhere in the region of 40 to 100 nm. The fact that this study was able to achieve success in producing nano-sized MgO suggests that the M. oleifera plant is a potential source of environmentally friendly agents that may be used in the creation of nano-sized materials.

Hanif *et al.* [40] showed the bioactivities of nano-scale magnesium oxide that had been synthesized utilizing an aqueous extract of *Moringa oleifera* leaves as the green agent. Nano-size magnesium oxide (NS-MgO) was produced in this study by starting with a solution of magnesium chloride ($MgCl_2$) and then adding a green agent in the form of an aqueous extract of the leaves of *Moringa oleifera* (AEMOL). The information that was provided by the many different characterisation techniques that were utilized served to verify the production of NS-MgO. It was determined through characterization using the XRD technique that NS-MgO exists as a crystalline material. The information concerning the particle size that was provided by SEM, TEM, and PSA reveals that the particle sizes are in the region of 40–70 nm. According to the maximum inhibition concentration (MIC), it was discovered that the NS-MgO possesses good antibacterial activity against *S. aureus*, *E. faecalis, E. coli*, and *S. dysenteriae bacteria* (MIC values: 250–500 µg ml^{-1}), and much stronger antifungal activity against *A. flavus*, *A. niger*, and *C. albican* (MIC values: 62.5–125 µg ml^{-1}). According to these findings, there is a potential for NS-MgO to be synthesized as a therapeutic candidate for the treatment of candidiasis.

In the phytochemical-mediated synthesis of MgO NP fabrication, the extract of Moringa oleifera leaf extract (a capping and stabilizing agent) was added to the aqueous solution of $MgCl_2.6H_2O$ and stirred vigorously at room temperature. After this, a few drops of NaOH are added under stirring for the purpose of maintaining an appropriate PH, which could be acted upon as a precipitating agent. The mixture is then allowed to remain at room temperature. A yellowish hue was introduced into the previously clear solution. After six hours, the stirring process was finished, and precipitation was achieved. The precipitation was of a yellowish tint and consisted of colloidal particles that were found near the bottom of the flash. This implies that $Mg(OH)_2$ was formed. The dried samples of $Mg(OH)_2$ were put into a mortar and mashed down using a pestle and a mortar. The ground samples were calcinated in a muffle furnace at different temperatures at 500, 600, and 700 °Celsius for three hours to remove the moisture, the impurities were eliminated, and the final product was white MgO nanoparticles. The mechanism of synthesis of MgO nanoparticles is illustrated in fig. 4.

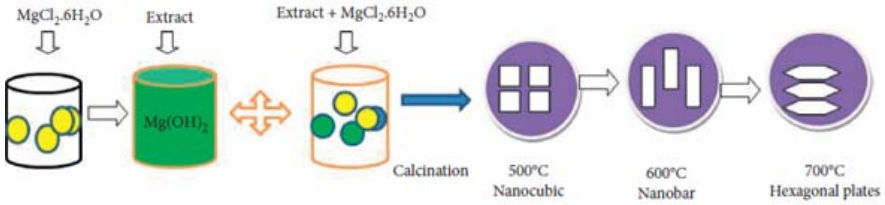

Fig. 4: Mechanism of synthesis of MgO nanoparticles [43]

Copper oxide (CuO) nanoparticles

The hierarchical CuO microspheres were generated by the leaf extract of *M. oleifera*, as shown by Kalaiyan *et al.* [44]. The bactericidal tendency of these hierarchical CuO microspheres was tested against a variety of pathogenic bacterial strains. It was considered that the primary phytochemicals, which included phenolic acids, flavonoids, and vitamins, and which were found in the *M. oleifera* leaf extract, played important roles as reducing agents as well as capping agents. Fig. 5 shows the process of hierarchical CuO microspheres synthesis by *M. oleifera* leaves extract.

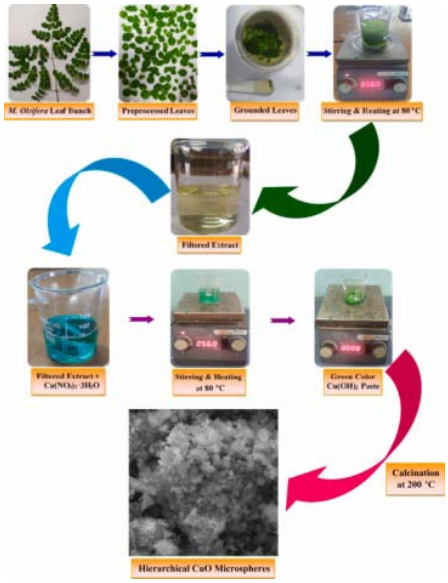

Fig. 5: Process of hierarchical CuO microspheres synthesis by *M. oleifera* leaves extract [44]

As the solution was stirred, the color of the solution changed from bluish to dark green, which is evidence that Cu $(NO_3)_2 3H_2O$ was converted into Cu^{2+}ions during the process. The stirring was sustained till the solution was changed to green color paste that indicated the formation of hierarchical $Cu(OH)_2$ microspheres. The XRD pattern demonstrated the development of monoclinic CuO crystals, which is evidence that phytochemicals present in the MO leaves extract were responsible for the conversion of Cu $(NO_3)_2 3H_2O$ to Cu^{2+}ions. Hierarchical CuO microspheres come to mind while looking at the cluster-like formations displayed in the SEM micrographs. The asymmetric stretching deformation vibration bands seen in the FTIR spectrum can be attributed to Cu–O bonding. These links were essential in the production of monoclinic unit crystals, and the nanoparticles that resulted from their utilization are more effective at killing bacterial populations. In comparison to the commonly used antibiotic (tetracycline), the hierarchical CuO microspheres demonstrated superior antibacterial activity against a variety of Gram-positive and Gram-negative bacterial strains. The order of effectiveness was as follows: S. *aureus*>*K. pneumoniae*>E. coli>B. cereus. Based on these results, pompon-like hierarchical CuO microspheres with sponge-like morphology are appropriate for antibacterial action *against Gram-positive* and *Gram-negative* bacteria.

Ben Amor *et al.* investigated the biosynthesis of cupric oxide (CuO) and cuprous oxide (Cu_2O) nanoparticles using an aqueous extract of *M. oleifera* leaves [46]. The utilization of an aqueous extract of *Moringa oleifera* leaves both as a capping and reducing agent for the production of CuO/Cu_2O nanoparticles is a novel aspect of this research. In addition, the purpose of this research is to produce irresistible and long-lasting CuO/Cu_2O nanoparticles from aqueous $CuSO_4.5H_2O$ by employing an extract of *Moringa oleifera* leaves. We looked into how the pH affected the production of CuO/Cu_2O nanoparticles as well as their *in vitro* antioxidant activity. In order to evaluate the bioactive components (capping agent), the produced CuO/Cu_2O NPs were examined using scanning electron microscopy (SEM), infrared spectroscopy (FTIR), and ultraviolet-visible spectroscopy (UV-Vis). Copper oxide with a direct bandgap of 2.59–2.65 eV and an indirect band gap of 1.74–1.84 eV exhibited a UV-vis absorption peak at 275 nm with a significant absorption. FTIR measurement revealed two unique absorption bands at 511 and 528 cm^{-1}, indicating that copper oxide nanoparticles were successfully manufactured. The synthesized CuO/Cu_2O NPs were found to be crystalline spheroids with an average particle size of 18.5–25.4 nm. CuO/Cu_2O NPs samples' *in vitro* antiradical activity was investigated using two tests: ABTS radical scavenging assay and DPPH. Free radical elimination. It was shown that CuO/Cu_2O NPs are great antiradical and can function as powerful and dependable antioxidants to preserve human health.

Zinc oxide (ZnO) nanoparticles

Elumalai *et al.* investigate the antibacterial and antifungal properties of ZnO nanoparticles synthesized from *M. oleifera* leaf using a green method, which is a low–cost, straightforward, and environmentally–friendly procedure [49]. The results of antimicrobial activities revealed the maximum zone of inhibition against *S. aureus* (23.8±0.76) and fungal at a concentration of 200 µg/ml of ZnO NPs.

Pal *et al.* synthesis of ZnO nanoparticles using Moringa Oleifera (Drumstick) leaves as natural precursor via precipitation method [50]. The nanoparticles that were synthesized have an average crystal size of 52 nm and a hexagonal wurtzite structure. The synthesized ZnO nanoparticles were used as a photocatalytic agent to degrade the organic pigment Titan yellow under visible light after one hour of exposure to visible light. Nanoparticles of ZnO degraded nearly 96% of the titan yellow pigment. In this study, antibacterial activity was also demonstrated, and it was discovered that synthesized ZnO nanoparticles have potential applications in antibacterial activity.

Rhamdiyah *et al.* synthesized ZnO nanoparticles from an aqueous extract of *M. oleifera* for use as an antibacterial and photocatalyst [51]. Using water extract of *Moringa leaf* (*Moringa oleifera L.*) as a reducing agent, stabilizer, and capping agent, ZnO nanoparticles were effectively synthesized via the biosynthesis method. The purpose of this research was to characterize ZnO nanoparticles and their applications as antibacterial and photocatalyst. Biosynthesis ZnO nanoparticles feature a hexagonal wurtzite phase with an average crystal size of 16.97 nm and 78.49% crystallinity. The biosynthetic ZnO nanoparticles showed antibacterial activity against pathogenic *S. aureus* (gram positive) and *E. coli* (gram negative) as well as good photodegradation ability. The greater the concentration of ZnO nanoparticles, the larger the diameter of the inhibition zone. The result of photodegradation of methylene blue is greatest with mass variation of ZnO nanoparticles and the concentration of methylene blue is 95% with a nanoparticle mass of 120 mg, a concentration of methylene blue of 10 ppm, and an irradiation time of 150 min.

Abel *et al.* investigates the technique of biosynthesis of nanoparticles of zinc oxide from the extraction of moringa leaves [53]. The biosynthesis approach adopted is modest and easily biodegradable and conducted in a short duration. The showed yellow tint suggests the preparation of zinc oxide NPs, which further established the reduction of Zn ions into ZnO nanoparticles by employing ultraviolet-visible spectroscopy. The UV spectroscopic absorption peak is at 350 nanometers. XRD and SEM studies show that the particle property created was polycrystalline and had no void and flower-like shape. The result of medicinal value demonstrates significant antibacterial activity in contrast to the type of pathogenic bacteria *Escherichia coli* and *Staphylococcus aureus*. From the XRD data, there are no further peaks that match to contaminants that are detected, confirming the excellent purity of the supplied results.

Iron oxide (FeO) nanoparticles

Aisida *et al.* reported the synthesis of iron oxide nanorods (FeO-NRs) from FeCl3 capped using an aqueous extract of Moringa oleifera (MO) plant with a green and enviromentally friendly approach [56]. Dark-brown-capped MO-FeO NPs were synthesized using *M. oleifera* leaf powder extract and $FeCl_3$ solution. FeO NPs confirmed the color change from orange to dark brown, indicating the presence of FeO NPs. Fig. 6 shows schematic representation the synthesis of MO-FeO.

SEM and TEM images revealed that NPs have rod-like morphologies with an average particle size of 15 nm. Regarding antibacterial efficacy, biosynthesized FeO NPs suppressed microbial growth more effectively than chemical FeO NPs. The created FeO-NRs suppress the development of six human pathogens with a stronger efficacy at lower concentrations. It is interesting that the bacterial strains demonstrate high and effective susceptibility to the manufactured FeO-NRs at lower concentrations compared to the standard antibacterial medicines.

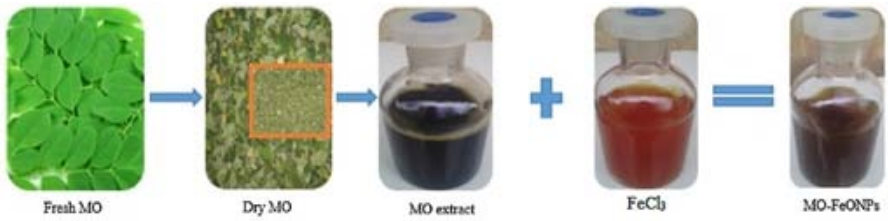

Fig. 6: Schematic representation the synthesis of MO-FeO [56]

Tovar *et al.* report the biogenic one-pot synthesizing of iron oxide nanoparticles using *M. oleifera leaves* and chitosan [57]. A beneficial effect of the combination of *Moringa* and *chitosan* on the index-seed germination and growth parameters of corn plants has been observed. The results suggest that the index-speed germination enhance the speed response for the photosynthetic capacity and the root and stem length was increased with the presence of the nanoparticles.

Jegadeesan *et al.* synthesized FeNPs from aqueous extracts of *Moringa oleifera* fruit (MOF) and *Moringa oleifera* leaves (MOL) and claim that it may be employed as an antioxidant and antibacterial agent [58]. TEM and SEM images reveal irregular shaped MOF-Fe and MOL-Fe (particle size of 45 nm). XRD examination indicated that the Fe NPs were predominantly Fe_2O_3 and FeOOH, with crystallite size of 35–40 nm. The antioxidant activity of the aqueous extracts was higher than that of the biogenic Fe NPs, the extract the highest among all, given its higher phenolic content. The antibacterial activity of Fe-NPs was greater than the extract alone, with MOL-Fe the most powerful towards *S. aureus* and *B. subtilis*.

Nickel oxide (NiO) nanoparticles

Ezhilarasi *et al.* [60] reported that a green approach has been described to synthesize nickel oxide nanoparticles using *Moringa oleifera* plant extract as fuel. Additionally, their cytotoxic efficacy against human cancer cells and their antibacterial activity against bacterial pathogens have been investigated. The NiO NMps were single crystals with a face-centered cubic phase and two strong PL at 305.46 nm and 410 nm. XRD and FTIR showed that a pure NiO phase had formed (average size 9.69 nm). HR-TEM proved that nano and microstructures were made (agglomerated spherical shape). Different doses of NiO NPs made from an extract of the *M. oleifera* plant were used to test their cytotoxicity and ability to kill bacteria in a test tube. The MTT assay measurements on cell vialbility and morphological studies showed that the synthesized NiO nanoparticles possess cytotoxic activity against human cancer cells. Additionally, the various zones of inhibition (mm), obtained revealed the effective antibacterial activity of NiO nanoparticles against various Gram-positive and Gram-negative bacterial pathogens.

Ngom *et al.* describe the production of nickel oxide nanoparticles (NiO-NPs) using an extract of *M. oleifera* leaves [61]. The structural investigation demonstrates the development of cubic NiO-NPs with a mean crystallite size of 17.80 nm. The band gaps were calculated to be 4.28 eV using diffuse reflectance analysis. Due to the optical properties deduced from diffuse reflectance and photoluminescence studies, these semiconductors will be employed in the development of inexpensive nanomaterials for electronic applications.

Suresh *et al.* reported nanosized nickel oxide nanoparticles synthesized using Moringa leaf extract via a green method [62]. The NiO nanoparticles synthesized from *Moringa oleifera* plant extract demonstrated good cytotoxic action against HT-29 (colon cancer cell lines). The results were corroborated by the morphological study of treated and controls cells. Normal and regular morphology was detected in untreated cells, however, aberrant cell morphology was demonstrated by the cells treated with NiO nanoparticles. The active creation of the ROS has led to the degradation of the cell protein, DNA and cell membrane resulting in cell death, accounting for the superior antibacterial activity of the NiO nanoparticles. The average crystallite size of NiO nanoparticles is 12 nm, which is consistent with the particle size determined by TEM micrographs. The spherical nanoparticles with uniform dispersion are readily visible in the FESEM and HRTEM micrographs. NiO nanoparticles' multifunctional applications, such as anticorrosive, photocatalytic, and antibacterial properties, are also investigated [63, 64]. Green synthesis had a greater impact on the antibacterial properties of NiO nanoparticles against *Staphylococcus aureus* and *Escherichia coli*.

Table 1: Summary of parameters and conditions for biosynthesized nanoparticles using the *Moringa oleifera* plant

NPs	Precursor	MO extract conc. (g/ml)	Reaction Temp/Time	Morphology size (nm)	Activity	References
Ag	1 mmol AgNO3	10 g/90 ml	90 °C for 1 h	7.56-23.71-26.13 nm	Antibacterial	[24]
Ag	1 mmol $AgNO_3$	10 g reducing agent	-	9-11 nm agglomerated	Antimicrobial	[25]
Ag	1 mmol $AgNO_3$	5 g reducing agent	60 °C	40 nm, spherical shape	Anticancer	[25]
Ag	2 mmol AgNO3	10 g/100 ml	Room temperature	5-50 nm, spherical shape	Antibacterial	[27]
Ag	0.5 mmol AgNO3	10 mg/90 ml	60 °C	Average 4 nm, spherical	Antimicrobial and Photocatalytic	[28]
Ag	1 mmol $AgNO_3$	0.2 g thick extract	80 °C for 30 min	82.9 nm	Antioxidant	[29]
Ag	1 mmol $AgNO_3$	Reducing agent	37 °C for 24 h	Uniform sized	Antibacterial	[30]
Ag	1 mmol $AgNO_3$	10 g reducing agent	60-80 °C for 20 min	57 nm, spherical shape	Antimicrobial	[31]
Ag	1 mmol $AgNO_3$	10 g/50 ml	25 °C for 48 h	15.22-29.45 nm, spherical shape	Antioxidant and Antibacterial	[32]
Ag	1 mmol $AgNO_3$	20 g reducing agent	-	8 nm monodispered spcherical shape	Antimicrobial	[33]
Au	1 mmol $HAuCl_4.3H_2O$	20 g bioreduction	-	15.2 nm spherical, oval, and hexagonal shape	Antioxidant, Anticancer, and Antidiabetic	[34]
Au	1 mmol ($HAuCl_43H_2O$, ACS reagent)	20 g capping and reducing agent	-	100 nm triangular, hexagonal, and spherical	Anticancer and Catalytic	[35]
Au	$HAuCl_4.3H_2O$	30 g, stabilizing agent	75 °C	15-20 nm	Photocatalytic	[36]
Au	1 mmol $HAuCl_4.3H_2O$	5 g bioreduction	-	10–20 nm spherically shape	Anticancer	[37]
Bi	1 g $Bi(NO_3)_3.5H_2O$	10 g/100 ml	60 °C for 3 h	40.4–57.8 nm	Antioxidant and Antimicrobial	[38]
MgO	1 mmol $MgCl_2.6H_2O$	4 g reducing agent	600 °C for 5 h	20-50 nm spherical shape	Antibacterial	[39]
MgO	1 mmol $MgCl_2.6H_2O$	4 g green agent	600 °C for 5 h	40-70 nm spherical shape	Antibacterial, Antioxidant, and Antifungal	[40]

NPs	Precursor	MO extract conc. (g/ml)	Reaction Temp/Time	Morphology size (nm)	Activity	References
MgO	1 mmol $MgCl_2.6H_2O$	4 g biocapping and bioreducing agent	600 °C	60-100 nm spherical shape	Antioxidant and Antibacterial	[41]
MgO	1 mmol $MgCl_2.6H_2O$	4 g/100 ml reducing and stabilizing agent	600 °C for 5 h	40-100 nm cubic shape	-	[42]
MgO	1 mmol $MgCl_2.6H_2O$	capping and stabilizing agent	500, 600, and 700 °C for 3 h	cubic, nanobar, and hexagonal shape	-	[43]
CuO	1 g $Cu(NO_3)_2.6H_2O$	5 g, reducing and stabilizing agent	200 °C for 1 h	45.30 nm, cluster-like	Bacterial activity	[44]
CuO	1 g $CuSO_4.5H_2O$	80 ml *M. oleifera* leaves extract	60 °C for 3 h	35.8-49.2 nm aggregates	Antioxidant and Antimicrobial	[45]
CuO	1 mmol $CuSO_4.5H_2O$	10 g/100 ml	100 °C for 24 h	Average 18.5–25.4 nm	Antioxidant	[46]
CuO	2g/20 ml Copper acetate tetrahydrate	20 g/100 ml, reducing and capping agent	400 °C for 2 h	Average 12 nm aggregates	Antioxidant and Anticancer	[47]
CuO	3g/10 ml copper (II) nitrate	3 g biocapping agent	100 °C for 1 h	12 and 18 nm spherical shape	Antimicrobial	[48]
ZnO	2g $Zn(NO_3)_2.6H_2O$	20 g, stabilizing agent	400 °C for 2 h	16-20 nm spherical and agglomerated particles	Antimicrobial	[49]
ZnO	2.1 g zinc acetate	5 g, stabilizing and accelerating agents	350 °C for 5 h	52 nm spherical shape	Photocatalytic and Antibacterial	[50]
ZnO	$Zn(NO_3)_2.6H_2O$	30 g reducing agent	500 °C for 1 h	12.27 and 30.51 nm	Electrochemical	[51]
ZnO	90 ml $Zn(CH_3COO)_2.2H_2O$	20 g/100 ml, reducing, stabilizing, and capping agent	60 °C for 10 min	16.97 nm hexagonal shape	Antibacterial and photocatalytic	[52]
ZnO	0.2 M ($Zn(NO_3)_2{\cdot}6H_2O$)	10 g/90 ml	300-350 °C for 1 h	50 nm	Antibacterial	[53]
ZnO	3 g ($Zn(CH_3COO)_2.2H_2O$)	10 g/200 ml	80 °C for 5 h	19.20-40.05 nm	Photocatalytic	[54]
ZnO	1 g $Zn(NO_3)_2.6H_2O$	0.5 g/100 ml	400 °C for 4 h	60 nm	Antibacterial	[55]
FeO	0,5 M $FeCl_3$	10 g, capping agent	100 °C for 24 h	15:01±6:03 nm rod like	Antibacterial	[56]
FeO	1.6 g $FeCl_3.6H_2O$	2 g, reducing agent	250 °C for 15 h	66±20 nm agglomeration	-	[57]
FeO	0,5 M $FeCl_3$	10 g/100 ml, reductant	100 °C, 24 h	76±2:0 nonuniform rod like	Photocatalytic and Antibacterial	[58]
FeO	0.5M $FeCl_2.7H_2O$	Reducing power	-	45 nm irregular shape	Antioxidant and antibacterial	[58]
NiO	0.1 mmol $Ni(NO_3)_2$	20 g/100 ml	400 °C for 9 h	9.69 nm agglomerated spherical shape	Antibacterial and Cytotoxicity	[60]
NiO	3 g $Ni(NO_3)_2.6H_2O$	9 g/300 ml, chelating reduction/oxidizing agent	500 °C for 2 h	Average size 17.80 nm	-	[61]
NiO	1.82 g $Ni(NO_3)_2$	2 g/200 ml, reducing agent and capping agent	500 °C for 3 min	Average size 12 nm, spherical shape	Photocatalytic and Antimicrobial	[62]

CONCLUSION

This review summarized that Ag, Au, Bi, MgO, CuO, ZnO, FeO, and NiO nanoparticles have been made from the *M. oleifera* plant, which is thought to be a center for medicine. It has been confirmed that *M. oleifera* biomolecules are responsible for reducing and stabilizing the synthesized nanoparticle agents. Several approaches were looked at, and it was found that *M. oleifera* plants can easily biosynthesize different types of metal and metal oxides nanoparticles. In terms of antioxidant properties, biosynthesized CuO was better than other nanoparticles, while ZnO and AgNP were better at antibacterial activity. But not all articles talk about the size and shape of nanoparticles made when *M. oleifera* plant extracts are concentrated. During the biosynthesis process, the size of the nanoparticles was determined by the concentration of plant extracts, the temperature, and the length of time for the reaction.

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AUTHORS CONTRIBUTIONS

All the authors have contributed equally.

CONFLICT OF INTERESTS

The authors declared no conflict of interest

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