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Original Article

Harnessing *Ficus exasperata* Leaf Extract for Sustainable Magnesium Oxide Nanoparticles with Antimicrobial Activity

Lakshmi Tulasi S.[1*], Sumalatha P.[2], Shaheda Niloufer[3], Usha Rani N.[1], Pavani P.[1]

[1]Department of Freshman Engineering, Prasad V. Potluri Siddhartha Institute of Technology, Vijayawada, Andhra Pradesh 520007, India
[2]Department of Basic Sciences and Humanities, Seshadri Rao Gudlavalleru Engineering College, Gudlavalleru, Andhra Pradesh 521356, India
[3]Department of Freshman Engineering, Lakireddy Bali Reddy College of Engineering, Mylavaram, Andhra Pradesh 521230, India

**Corresponding Author's Email: stulasi@pvpsiddhartha.ac.in*

Abstract

Magnesium (Mg) plays a crucial role as a plant nutrient, supporting vital functions such as growth, metabolism, enzyme regulation, and other physiological processes. In the present study, leaf extract from the *Ficus exasperata* plant was utilized to synthesize magnesium nanoparticles (MgNPs). The antioxidant properties and potential for enhancing the growth of *Cicer arietinum* (Bengal gram) plants were evaluated. The stability and morphology of the synthesized nanoparticles were characterized through several techniques, including FTIR, TEM, XRD, and DLS. X-ray diffraction (XRD) measurements were carried out using a Rigaku Ultima III analyzer, with a 2θ scan range from 10° to 80°. Transmission electron microscopy (TEM) revealed that the MgNPs were approximately 25 nm in size. This study proposes the use of magnesium nanoparticles as a Nano-fertilizer, which significantly boosts the growth and yield of *Cicer arietinum* plants in an environmentally friendly manner. The biogenic approach to synthesizing these nanoparticles using plant extracts offers an eco-sustainable method for nutrient delivery in agriculture, advancing green technologies in farming practices.

Keywords: *Antibacterial Activity; Electron Microscopy; Ficus exasperate; Nano Fertilizer; Magnesium Nanoparticles; Transmission*

Introduction

Ficus exasperata, a plant native to tropical and subtropical areas, has been widely acknowledged for its various therapeutic properties, including antimicrobial, anti-inflammatory, and antioxidant effects. These beneficial properties are attributed to its rich array of bioactive substances such as flavonoids, alkaloids, tannins, and other phenolic compounds (Kirubakaran *et al.,* 2024). More recently, the leaf extract of *F. exasperata* has gained significant attention for its potential in the green synthesis of magnesium oxide nanoparticles (MgO NPs) (Ramesh, Anbuvannan & Viruthagiri, 2015). These nanoparticles are of particular interest due to their diverse applications in fields such as medicine, electronics, and environmental sciences. Magnesium oxide nanoparticles are known for their exceptional surface area, biocompatibility, and antibacterial properties. They have shown strong antimicrobial activity against both Gram-positive and Gram-negative bacteria, making them highly suitable for combating bacterial infections (Suresh *et al.*, 2015). However, traditional methods of synthesizing these nanoparticles often involve the use of harmful chemicals, raising concerns regarding environmental sustainability and health safety. As a result, there has been growing interest in

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environmentally friendly approaches to nanoparticle synthesis, with plant-based methods emerging as a viable alternative (Kumar, Senthamil & Govindaraju, 2013).

Green synthesis techniques, using plant extracts such as those from *Ficus exasperata*, offer numerous advantages, including the avoidance of toxic chemicals and the use of renewable, natural resources. In this process, the bioactive components in the plant extract serve as reducing and stabilizing agents for the nanoparticles, enhancing their antimicrobial properties and preventing aggregation (Ramezani *et al.*, 2023). The use of plant extracts in nanoparticle synthesis is a promising approach that is cost-effective, scalable, and environmentally sustainable (Fatiqin, Amrulloh & Simanjuntak, 2021) Research has demonstrated that MgO nanoparticles, particularly those synthesized through green methods using plant extracts like *F. exasperata*, possess enhanced antibacterial activity compared to their chemically synthesized counterparts. The antimicrobial mechanism of these nanoparticles typically involves the disruption of bacterial cell membranes, which results in leakage of cellular contents and ultimately bacterial cell death (Ali *et al.,*2023) This mechanism of action is particularly valuable in the face of increasing antibiotic resistance, which has made conventional treatments less effective (Sharma *et al.*, 2020).

Beyond their antimicrobial effects, MgO nanoparticles synthesized from *F. exasperata* leaf extract also hold promise in other medical and environmental applications. These include their potential use in cancer therapy, wound healing, and water purification, owing to their non-toxic, ease of functionalization, and biocompatibility (Vijayakumar, Punitha & Parameswari**,** 2022).The plant-based synthesis of these nanoparticles ensures that they are safe for biomedical applications, minimizing concerns about toxicity that are often associated with synthetic chemicals (Mushtaq *et al.*, 2024)..The green synthesis of magnesium oxide nanoparticles using plant materials, especially *F. exasperata*, aligns with the principles of sustainable nanotechnology . This method not only offers a means of producing effective antimicrobial agents but also contributes to reducing the environmental impact associated with traditional nanoparticle production methods. Furthermore, the low cost and ease of scaling up the production of these nanoparticles make them a promising candidate for large-scale use. This review explores the potential of *Ficus exasperata* leaf extract for the environmentally friendly synthesis of magnesium oxide nanoparticles, highlighting their antibacterial properties, potential biomedical applications, and the broader implications of using plant-based resources in nanotechnology. The growing interest in sustainable nanomaterials underscores the importance of advancing green synthesis techniques and exploring new avenues for combating bacterial infections and addressing global health challenges (Ramaprabha *et al.,* 2025).

Materials and Methods

Sampling and Preparation of Leaf Extracts

The green synthesis process begins with the collection of *Ficus exasperata* stems from Rajamundry, East Godavari, Andhra Pradesh, India, identified by plant authentication number SRR-CVR/2020-21/Bot/62. The leaves are cleaned with de-ionized water, air-dried for five days, ground into fine particles, and sieved to a mesh size of 250-300 microns.

50gms of the sieved material is mixed with 250 mL of de-ionized water in a 500 mL beaker, heated to 60°C, and boiled for 15 minutes to extract bioactive compounds. The solution is then filtered through Whatman No. 1 filter paper to remove solid particles. The filtered extract is stored at below 20°C to preserve its bioactivity for future experiments. This process ensures the extract is pure and ready for further analysis.

Green Synthesis of Magnesium Nanoparticles (Mg-NPS)

Magnesium oxide (MgO) nanoparticles were synthesized using an extract from *Ficus exasperata*, which acted as both a stabilizer and a reducing agent due to its hydroxyl and carbonyl groups. The process involved mixing 10 mL of 0.1 M magnesium nitrate [$Mg(NO_3)_2$] with 40 mL of aqueous extract, stirred for 45 minutes. Then, 6.0 mL of 0.2 M sodium hydroxide (NaOH) was added dropwise, causing precipitates to form at 25 ± 3°C. After precipitation, the product was purified with deionized water and calcinated at 873 K for 4 hours. The formation of MgO nanoparticles was confirmed by color change and precipitate appearance. Higher concentrations of magnesium nitrate (1.0 M, 0.1 M) promoted greater yields and stable nucleus formation, while lower concentrations resulted in fewer nucleation sites. Excessive concentrations caused aggregation, leading to larger, non-uniform particles. Optimizing concentration is key to controlling yield and particle size (Amin *et al.,* 2024).

Figure1(a) Figure1(b) Figure1(c)

Figure1: *(a-c): change in colour and yield observed with MgONPs solution*

Characterization of (Mg-NPS)

The green synthesis of magnesium oxide nanoparticles (MgONPs) using *Ficus exasperata* leaf extract was thoroughly characterized with several analytical techniques. Functional group analysis was performed using a Bruker IR-II FTIR spectrometer (4000 cm^{-1} to 650 cm^{-1}) to identify the chemical bonds and functional groups in both the leaf extract and the synthesized nanoparticles. Transmission Electron Microscopy (TEM) provided insights into the nanoparticles' morphology, while X-ray Diffraction (XRD) analysis, conducted on a Rigaku Ultima III XRD analyzer (2θ range of 10° to 80°), revealed the structural properties (crystalline or amorphous) of the MgO nanoparticles. Dynamic Light Scattering (DLS) was used to assess the particle size distribution, with measurements taken using a Beckman DelsaNano C series analyzer. Finally, the zeta potential (ZP) was measured to determine the surface charge of the MgO nanoparticles in water. These techniques provided comprehensive data on the nanoparticles' physical, chemical, and structural properties, critical for their potential applications.

Study of anti-oxidant capacity

The antioxidant activity of green-synthesized MgONPs and *Ficus exasperata* leaf extract was evaluated using the DPPH free radical scavenging assay. Solutions of varying concentrations of MgONPs, ascorbic acid, and plant extract were mixed with methanolic DPPH solution and incubated for 30 minutes. Absorbance was measured at 517 nm, with a color change from violet to yellow indicating DPPH reduction. The percentage inhibition was calculated to assess the antioxidant potential of MgONPs and the plant extract compared to ascorbic acid. This experiment highlights the promising antioxidant properties of the synthesized MgONPs and plant extract for various applications

Then the scavenging ability was calculated using the following equation:

$$\% \text{ inhibition} = (A_{blank} - A_{sample}) / A_{blank} \times 100$$

Where A_{blank} is the absorbance of the control reaction (containing all reagents except the test compound) and A_{sample} is the absorbance of the test compound.

Results

FTIR Analysis

The FT-IR spectra of magnesium nanoparticles (MgONPs) revealed distinctive peaks corresponding to various functional groups. Key peaks, such as those at 3743.66 cm^{-1} (Amine N-H stretching), 1540.07 cm^{-1}, and 1518.52 cm^{-1} (C=C stretching), as well as 1073.91 cm^{-1} (C-O stretching), were observed. These vibrations are linked to functional groups like amines, alcohols, carboxylic acids, alkenes, and alkyl halides. The observed peaks suggest that the functional groups in the *Ficus exasperata* leaf extract played a role in reducing, capping, and stabilizing the MgONPs. Variations in wavenumbers may result from factors such as synthesis temperature and the presence of sodium hydroxide, supporting the role of the plant extract in nanoparticle synthesis, as seen in similar plant-mediated studies. (Rajakumar *et al.,* 2024).

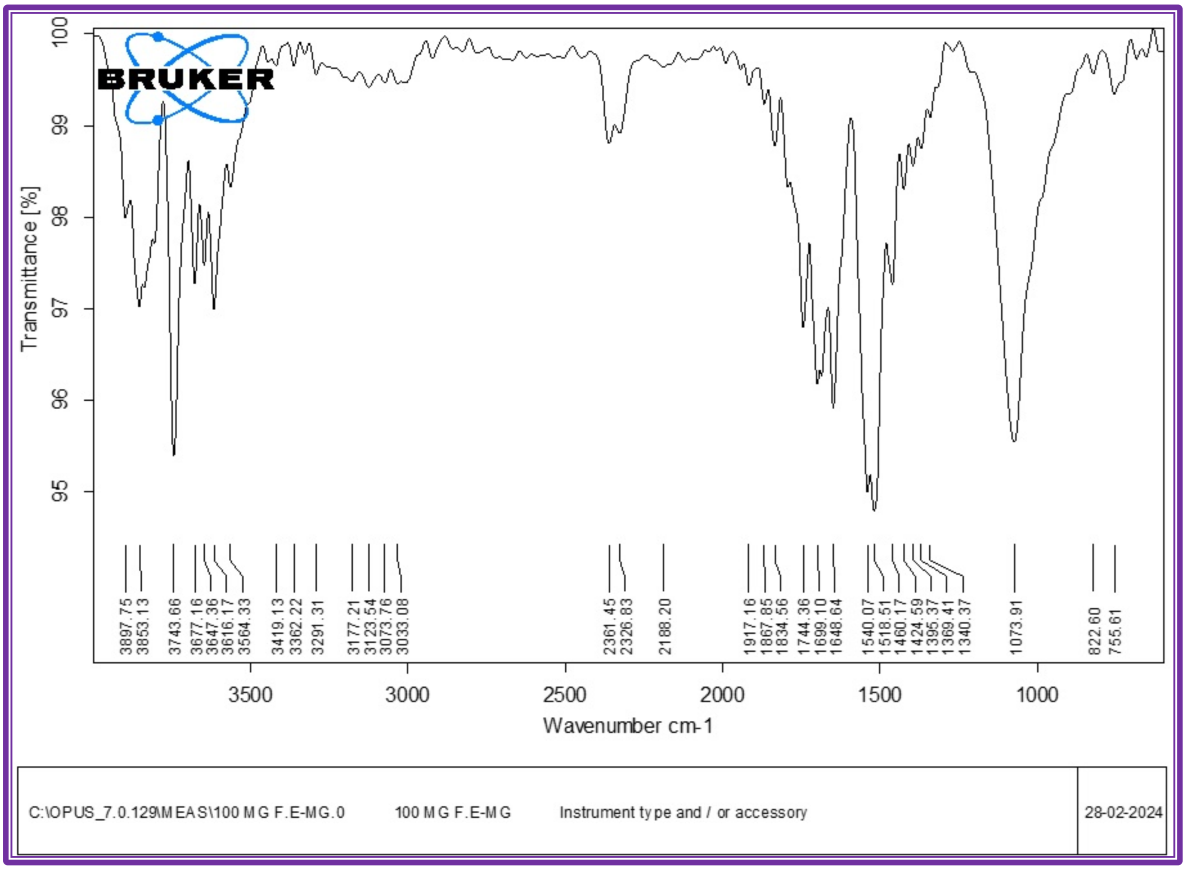

Figure 2: *FT-IR spectra of MgONPs synthesized using Ficus exasperate leaves extract*

Transmission electron microscopy (TEM) analysis of MgONPs:

TEM analysis of the dried magnesium nanoparticles (MgONPs) revealed their morphology and size distribution. The micrograph (Figure 2) shows irregularly shaped nanoparticles with an average diameter of 25 nm, with most particles ranging from 15-30 nm. While some agglomeration was observed, likely due to high surface energy and magnetic interactions, the nanoparticles retained their nano-size characteristics. The results confirm that the powder consists entirely of nano-sized, irregularly shaped particles, supporting their use as nano-fertilizers. These findings highlight the effectiveness of TEM in evaluating the morphology and size distribution of the synthesized nanoparticles (Suseela *et al.,* 2023).

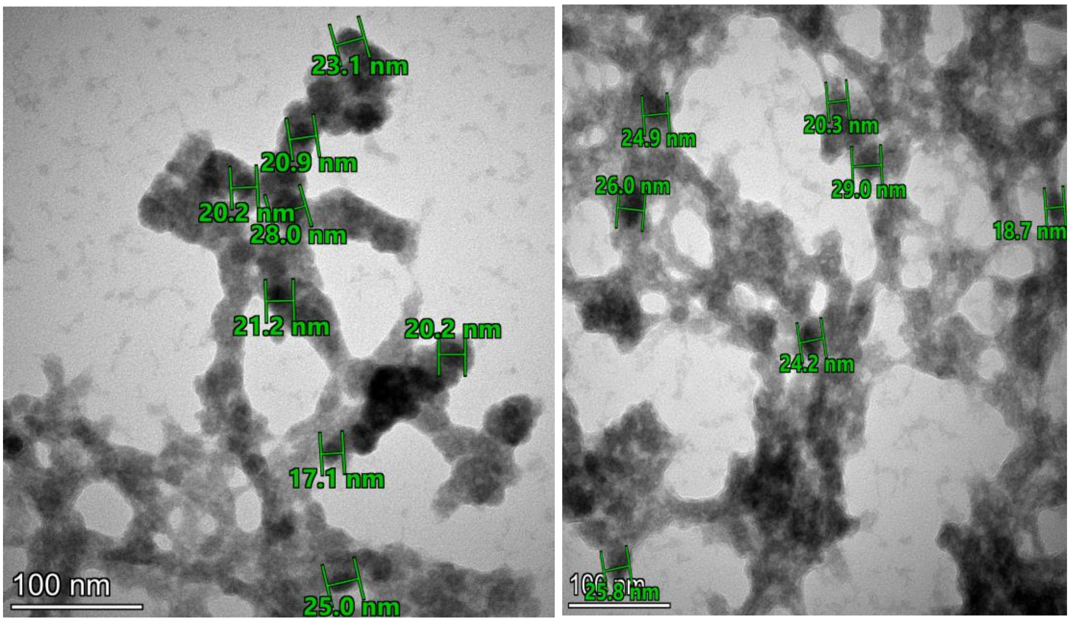

Figure 3: *TEM images of MgONPs (magnesium nanoparticles MgONPs synthesized using Ficus exasperate leaves extract)*

X-ray Diffraction (XRD) analysis

The XRD analysis was employed to examine the crystalline nature and crystallographic structure of the MgO-NPs. As shown, there are 18 prominent peaks at 2θ° of 20.668°, 34.684°, 40.717°, 42.050°, 55.608°, 62.167°, 65.118°, 66.263°, 73.190°, 75.934°, 77.007°, 77.910°, represented by the crystallographic planes (001), (011), (111), (111), (112), (110), (002), (031), (112), (011), (132), (022), (114), (222), (023), (004), (006) and (024) respectively (Figure 3). This reveals that crystalline MgO-NPs were successfully fabricated due to the formation of NPs with a well-defined and ordered crystal structure, as evidenced by the presence of intense and sharp peaks. The presence of extra peaks in XRD could be attributed to the capping agent from the fungal extract, which was confirmed by EDX analysis.

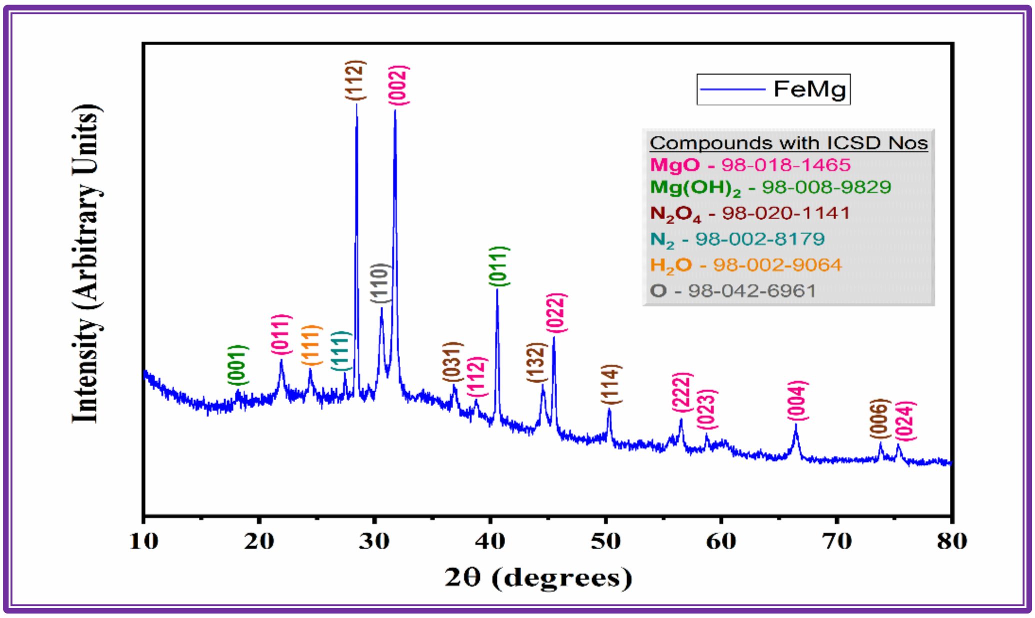

Figure 4: *XRD spectra of MgONPs (magnesium nanoparticles) synthesized using Ficus exasperate leaves extract*

Applications in Enhancing Fertilizer Efficiency

DLS analysis and zeta potential analysis

DLS analysis provides insights into nanoparticle (NP) uniformity, distinguishing between polydisperse NPs, which vary in size, and monodisperse NPs, which are uniform and also helps detect NP aggregation, which affects stability, reactivity, and performance. Smaller NPs offer higher stability in suspension, reduced aggregation, and enhanced catalytic activity due to a higher surface area-to-volume ratio. For the green-synthesized MgO-NPs, a zeta potential of -17.5mV indicates good stability within the colloidal system.

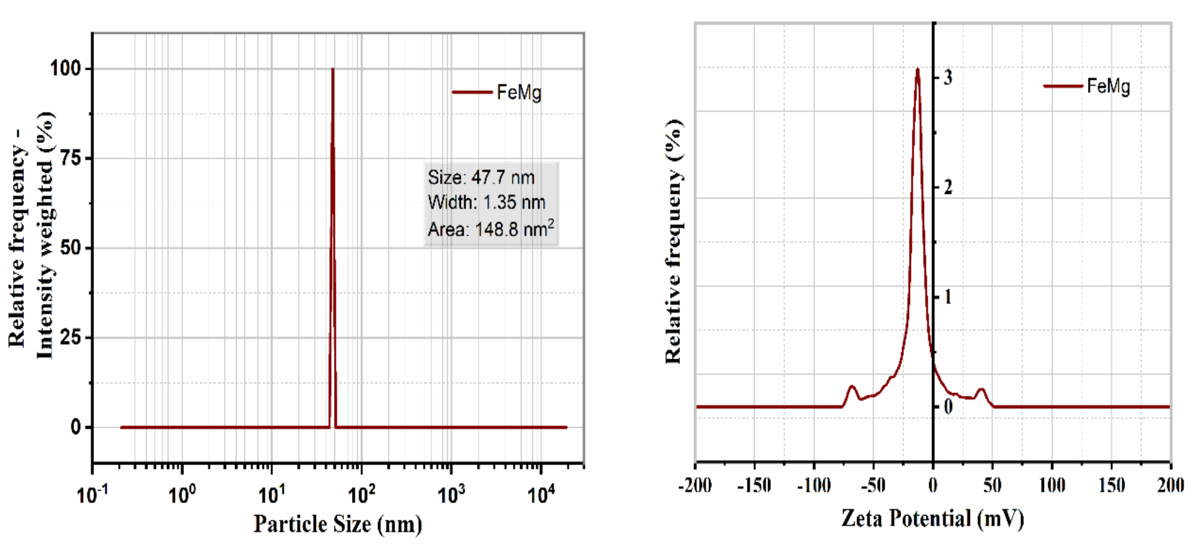

Figure:5(a) Figure:5(b)

Figure 5: *The DLS analysis that shows the average particle size of MgO-NPs in colloidal solution, and (b) the zeta potential value, which shows the surface charge of –17.5 mV*

Zeta potential helps in reducing the tendency of nano-MgO fertilizers to settle out of suspension or adhere to containers during storage, ensuring that the fertilizer remains active and usable until application. This can reduce waste and enhance the efficiency of magnesium delivery to crops. MgO nanoparticles with an optimized zeta potential can improve their interaction with soil particles and increase the availability of magnesium in the soil, which is vital for plant growth. This can lead to better growth rates, higher yields, and improved crop quality.

Application Study of antioxidant capacity % DPPH Activity:

The antioxidant activity of MgONPs synthesized from *Ficus exasperata* was assessed using the DPPH assay, with ascorbic acid as the standard. The assay measures the reduction of DPPH radicals, indicated by decolorization. Ascorbic acid showed the lowest IC_{50} value at 118.56 µg/mL, indicating strong antioxidant activity. The IC50 values for MgONPs were 125 µg/mL for 1.0 M, 198.85 µg/mL for 0.1 M, and 202.1 µg/mL for 0.01 M, while the plant extract had an IC_{50} of 241.9 µg/mL. MgONPs synthesized with 1.0 M magnesium showed the strongest antioxidant activity, outperforming other concentrations and the plant extract. These results suggest that MgONPs, particularly those synthesized with 1.0 M magnesium, possess significant antioxidant properties, comparable to ascorbic acid.

Table1: DPPH Inhibition activity study for Magnesium nanoparticels using Ficus exasperata extract

S No	Concentration in µg/ml	Ascorbic acid	1.0M CuO NP	0.1 M CuO NP	0.01 M CuO NP	Plant extract
1	25	13.22	13.07	12.58	12.70	10.38
2	50	24.96	19.53	20.85	21.29	22.5
3	75	33.48	32.31	49.86	27.24	27.5
4	100	42.51	37.81	34.58	33.04	31.21
5	125	52.72	50.00	39.72	36.51	36.74
6	150	63.22	60.67	45.08	45.15	39.92
7	200	78.41	71.95	50.29	49.49	46.34
8	250	87.05	80.52	55.80	56.27	51.67

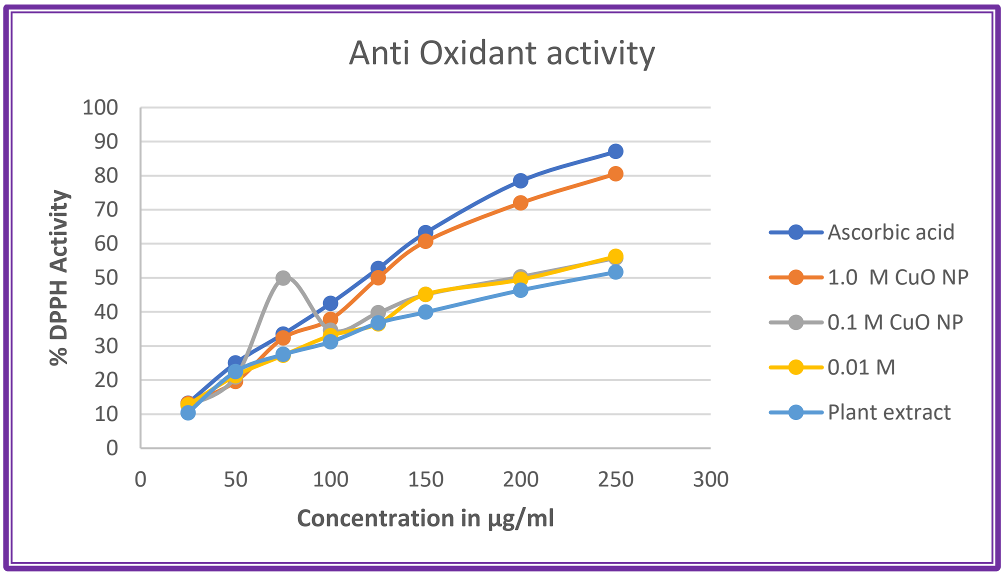

Figure 6: Comparative antioxidant activity of MgONPs at different concentration)10 M, 0.1 M and).01 M) and aqueous extract of Ficus exasperate plant

Discussion

The green synthesis of magnesium oxide nanoparticles (MgONPs) using *Ficus exasperata* leaf extract has garnered significant attention due to its eco-friendly approach and the multifunctional properties of the resulting nanoparticles. Recent studies have provided deeper insights into the synthesis mechanisms, structural characteristics, and potential applications of these nanoparticles.

Fourier Transform Infrared Spectroscopy (FT-IR) analysis has identified key functional groups such as amines, alkenes, and hydroxyl or carboxylic acids in MgONPs synthesized with *Ficus exasperata* leaf extract. These functional groups underscore the pivotal role of phytochemicals in both reducing and stabilizing the nanoparticles. Variations in synthesis parameters, including temperature and sodium hydroxide concentration, have been observed to influence shifts in absorption peaks, indicating the sensitivity of phytochemical interactions to reaction conditions. This aligns with findings from (Orlu, Ollor & Ebor, 2024), who reported that plant extracts rich in bioactive compounds significantly affect nanoparticle formation and stability.

Transmission Electron Microscopy (TEM) analyses have revealed that MgONPs typically exhibit irregular morphologies with average particle sizes around 25 nanometers. Some degree of particle clustering is noted, attributed to elevated surface energy and magnetic interactions between particles. Despite this clustering, the nanoparticles maintain nanoscale dimensions, enhancing their surface activity. Similar observations were made by (Muhaymin *et al.,* 2024 and kumar *et al.*,2013), who synthesized MgONPs using *Hyphaene thebaica* fruit extract and reported quasi-spherical particles with sizes ranging from 20 to 60 nm

X-ray Diffraction (XRD) analysis confirms the crystalline structure of MgONPs, displaying distinct peaks corresponding to specific crystal planes indicative of well-formed nanoparticles. The presence of additional minor peaks suggests residual organic compounds from the plant extract, potentially serving as stabilizing or capping agents. This interpretation is further supported by Energy Dispersive X-ray Spectroscopy (EDX), which detects elemental signals consistent with the presence of such phytochemicals. Mohammed *et al.*, (2024) noted similar findings in their study on bimetallic Ni-Zn nanoparticles synthesized using *Ficus exasperata* leaf extract.

Dynamic Light Scattering (DLS) measurements indicate that the zeta potential of MgONPs is around -17.5 mV, suggesting moderate colloidal stability. This level of surface charge prevents excessive aggregation, ensuring better dispersion in aqueous systems. Such dispersion is advantageous for soil applications, as it enhances the availability of magnesium to plants, improves nutrient absorption by roots, and promotes higher crop productivity and plant development. demonstrated that MgONPs synthesized using *Moringa oleifera* extracts exhibited similar stability profiles, making them suitable for agricultural applications

The antioxidant potential of MgONPs has been assessed using the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay. Nanoparticles synthesized with a 1.0 M magnesium precursor demonstrate notable free radical scavenging capacity, achieving an IC_{50} value of 125 µg/mL, comparable to that of standard ascorbic acid (IC_{50} = 118.56 µg/mL). The enhanced antioxidant activity observed at higher magnesium concentrations may be due to increased surface area and reactivity with free radicals. These results highlight the multifunctional potential of MgONPs, positioning them as both effective nano-fertilizers and valuable antioxidant agents in agriculture and biomedical fields. provided a comprehensive review on the bio-mediated green synthesis and multiple applications of MgONPs, emphasizing their antioxidant properties

Limitation

This work did not investigate the long-term effects or environmental stability of the synthesized nanoparticles. Additionally, the study did not isolate or identify the specific compounds in the extract responsible for nanoparticle formation.

Future Scope

Further studies could focus on understanding the exact antimicrobial mechanisms of MgONPs and optimizing their formulation. There is also potential for incorporating these nanoparticles into antimicrobial coatings or drug delivery systems.

Conclusion

The use of *Ficus exasperata* leaf extract for the green synthesis of magnesium oxide nanoparticles (MgONPs) presents an eco-friendly and sustainable approach for nanoparticle production. The synthesized MgONPs exhibit notable antibacterial activity, demonstrating their potential as effective antimicrobial agents. Additionally, the environmentally friendly nature of the synthesis process, utilizing plant-derived materials, aligns with the growing demand for sustainable and green technologies. The ability of these nanoparticles to perform effectively against bacteria, combined with their biocompatibility, suggests promising applications in various fields, including medicine, agriculture, and environmental protection.

Conflicts of Interest

The authors declare they have no conflict of interest.

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