

PREPARATION, CHARACTERIZATION, AND ANTIBACTERIAL ACTIVITIES
STUDIES OF MGO ULTRAFINE POWDER PREPARED BY SOL-GEL COMBUSTION
METHODQamar Alzammar^{*1}, Mahmoud Amer¹, Nassim Nasser², Maysaa T. Alloush¹, Maged M. Basuliman³, Salim F. Bamsaoud³¹Department of Chemistry, Faculty of Science, Albaath University, Homs, Syria.²Department of Physics, Higher Institute for Applied Sciences and Technology, Damascus, Syria.³Department of Physics, Faculty of Science Faculty, Hadhramout University, Mukalla, Republic of Yemen.

Article Received: 01 Oct. 2026

Article Revised: 22 Oct. 2026

Article Published: 01 Nov. 2026

***Corresponding Author: Qamar Alzammar**

Department of Chemistry, Faculty of Science, Albaath University, Homs, Syria.

<https://doi.org/10.5281/zenodo.23802273>**How to cite this Article:** Qamar Alzammar^{*1}, Mahmoud Amer¹, Nassim Nasser², Maysaa T. Alloush¹, Maged M. Basuliman³, Salim F. Bamsaoud³. (2026). Preparation, Characterization, And Antibacterial Activities Studies of Mgo Ultrafine Powder Prepared By Sol-Gel Combustion Method. World Journal of Advance Healthcare Research, 10(11), 97–103.

This work is licensed under Creative Commons Attribution 4.0 International license.

ABSTRACT

Magnesium oxide (MgO) nanoparticles were successfully synthesized using a modified sol–gel combustion method with citric acid as a complexing agent. The structural, morphological, and physicochemical characteristics of the products were examined using FT-IR, X-ray diffraction (XRD), scanning electron microscopy (SEM), atomic force microscopy (AFM), and dynamic light scattering (DLS). XRD patterns confirmed the formation of a cubic MgO phase, with crystallite sizes of 34–39.7 nm. SEM images revealed flake-like morphologies with particle sizes ranging between 43 and 48 nm, while AFM analysis showed surface roughness values consistent with ultrafine nanoscale features. DLS measurements indicated a monodisperse suspension with a PDI of 0.384. The antibacterial activity of the MgO nanoparticles was evaluated against *Staphylococcus aureus* and *Escherichia coli* using agar well diffusion. The nanoparticles demonstrated noticeable antibacterial properties, producing inhibition zones of 4–5 mm, although lower than those produced by gentamicin. Interestingly, the inhibitory effect decreased with increasing nanoparticle concentration, suggesting a concentration-dependent interaction with bacterial cells. Overall, the study highlights the potential of MgO nanoparticles synthesized via sol-gel combustion as promising antimicrobial agents with tunable physicochemical features suitable for biomedical and environmental applications.

KEYWORDS: Magnesium oxide; Nanomaterial; Antibacterial activity; Sol-gel method.**1. INTRODUCTION**

The development of antimicrobial materials capable of effectively eliminating both Gram-negative and Gram-positive bacteria, as well as pathogenic fungi, represents a major advancement in microbiology, particularly in combating emerging drug-resistant strains (Xuan et al., 2023). Metal and metal-oxide nanoparticles including silver, gold, copper, and titanium have been widely explored for their potent antimicrobial activity. Their effectiveness is largely attributed to the release of metal ions in aqueous environments, which promotes strong electrostatic interactions with electron-rich biomolecules

such as proteins and DNA, leading to the formation of inhibitory metal–biomolecule complexes (Zhang et al., 2022) (Díez-Pascual, 2018). Despite these promising effects, the molecular and biochemical mechanisms governing the antimicrobial activity of metal-oxide nanoparticles remain insufficiently understood, underscoring the need for continued research in this field (Ma et al., 2025). Compared to their metallic counterparts, metal oxide nanoparticles generally exhibit superior biological performance with reduced toxicity, making them attractive candidates for next-generation antimicrobial materials (Bamsaoud et al., 2021;

Basuliman et al., 2023).

Metal oxides such as SnO_2 , ZnO , TiO_2 , SiO_2 , CuO , and CoO are semiconductor materials valued for their diverse physicochemical and technological applications. When reduced to the nanoscale, these oxides demonstrate unique optical, electrical, chemical, and catalytic properties not observed in their bulk forms, which has driven substantial research interest (Hajra et al., 2024). The morphology and structural features of nanoparticles can be precisely controlled by optimizing synthesis methods and reaction conditions, emphasizing the importance of developing reliable and reproducible fabrication strategies (Andresen et al., 2023). As a result, extensive efforts have been dedicated to designing synthesis techniques that generate nanostructured metal oxides efficiently and consistently. These nanoscale materials are now recognized as key components across multiple advanced fields, including engineering, medicine, chemistry, physics, biosensing, and microbiology (Altammar, 2023; Radulescu et al., 2023). For applications directly related to human health, such as antimicrobial therapy and biomedical devices, it is essential that synthetic processes remain cost-effective, scalable, and environmentally safe.

Magnesium oxide (MgO) nanoparticles have recently gained attention due to their biocompatibility, environmental safety, and ability to interact destructively with a variety of toxic gases. MgO is an essential mineral in human physiology and has demonstrated promising antibacterial potential in several studies, with reports suggesting its ability to reduce bacterial toxicity and inhibit microbial proliferation (Li et al., 2024). However, the literature indicates that research on the antimicrobial properties of MgO nanoparticles remains limited, and the underlying mechanisms by which MgO and other metal-oxide nanoparticles modulate microbial behavior are still not fully elucidated (Kadiyala et al., 2018). Various techniques from advanced approaches such as molecular beam epitaxy and pulsed laser deposition to simpler wet-chemical routes have been employed to synthesize MgO nanoparticles. Notably, the physicochemical properties of the resulting nanomaterials are highly dependent on the synthesis conditions and processing environment (Li et al., 2024).

In this study, MgO nanoparticles were synthesized using a straightforward, reproducible, and high-yield modified sol-gel combustion method. Their antimicrobial activity was systematically evaluated to assess their potential as effective agents against pathogenic microorganisms. The high-yield MgO nanomaterial produced here demonstrates promising applicability in several advanced fields, including antimicrobial agents, catalysis, biosensing, and nanoelectronics. The physicochemical behavior of these nanoparticles is strongly influenced by their particle size, where reduced dimensions lead to altered atomic bonding characteristics and increased surface reactivity. Given the rising demand for new

antimicrobial materials capable of overcoming resistance to conventional antibiotics, MgO nanoparticles and metal-oxide nanomaterials in general represent a promising alternative that continues to attract significant scientific interest.

2. EXPERIMENTAL METHODS

2.1 Materials Preparation

All the chemical precursors were of an analytical grade, and they were used in their original form without any further purification. A modified sol-gel combustion technique was employed to synthesize the material for this study. This approach was derived from the techniques described by (Nassar et al., 2017). A solution containing 0.2 M magnesium sulfate was stirred at 30 °C for 5 min (*Jenway 1000, UK*) to facilitate the release of magnesium ions. At a stirring temperature of 60 °C, a 5 M citric acid aqueous solution was added drop-wise to the stirring magnesium solution to ensure the cohesion of the magnesium ions was maintained. The pH (*Selecta, pH-2005, Spain*) of the resulting solution was adjusted directly to 7 by the addition of ammonium hydroxide solution (30%). The temperature of the reaction was gradually increased to 90°C while maintaining continuous agitation, resulting in the formation of a viscous yellow material. The obtained viscous material was subjected to additional heating in a muffle programmable furnace (*Thermolyne 1300, Netherlands*) at a range of 90–240°C. The burned material was ground and divided into two parts, then calcined for 6 hours at 800°C and 1100°C to produce Magnesia1 and Magnesia2 samples, respectively. Then, the samples were crushed and ground to obtain white ultrafine powders. **Figure 1**, illustrates the sequence of operations employed in the preparation of the materials under investigation through sol-gel combustion.

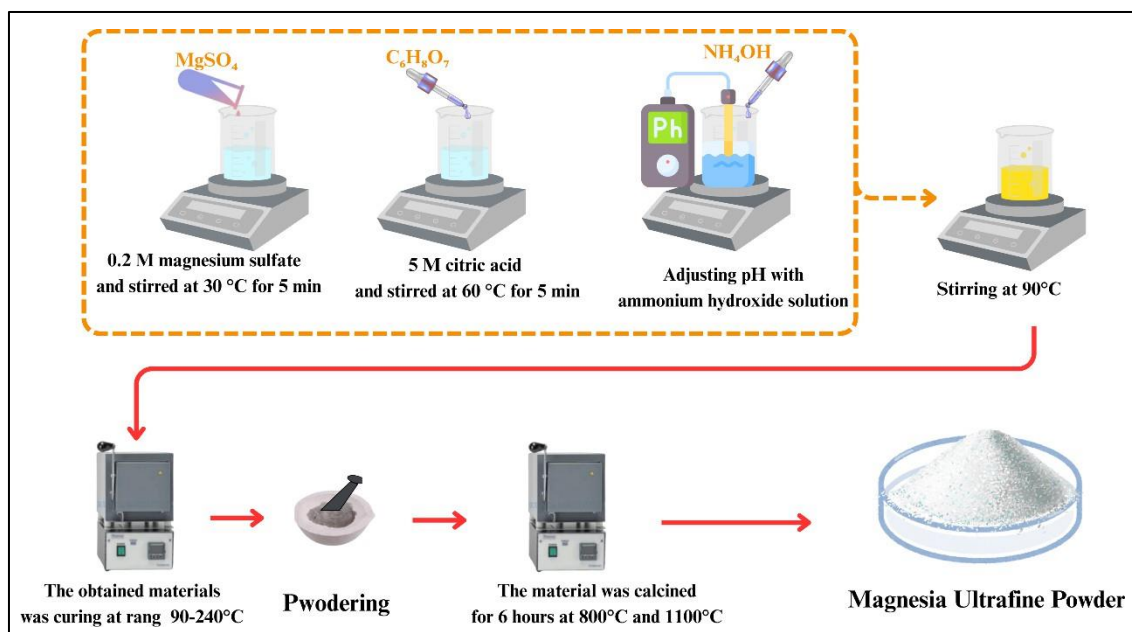


Figure 1: Experimental stages for MgO preparation via the sol-gel combustion.

2.2 Materials Characterizations

Infrared spectroscopy (Jasco, FTIR-4600, Japan), with KBr pellet method compacted at 8 tons in a Perkin-Elmer manual hydraulic press, was used to examine chemical structure and functional groups of the samples at room temperature. The FT-IR spectra of samples were recorded between (400-4000 cm^{-1}) wave number. Sample characterization was carried out by SEM (FEI Quanta 200, Netherlands) and XRD ((Philips PW 1840, The Netherlands). The grain size was estimated from XRD parameters based on Scherer equation ($D = k\lambda / \beta \cos\theta$). Where D is Particle size(nm), $k=0.9$ Scherer constant, Wavelength of X-ray ($\text{CuK}\alpha 1=0.154056 \text{ nm}$), β (FWHM): Full width at half maximum intensity(Rad), θ :Angle of incidence for X-ray /Bragg's angle/ (Rad).

2.3 Antibacterial assay

The agar well diffusion technique was used to evaluate the antibacterial efficacy of the Magnesia samples against *S. aureus* and *E. coli* microorganisms, in comparison to a gentamicin solution (100 $\mu\text{g}/\text{ml}$). A 100 μl of bacterial solutions ($1.5 \times 10^8 \text{ CFU}/\text{ml}$) were

inoculated onto Petri plates with different Mueller Hinton Agar according to (Nazem et al., 2024). The Magnesia samples were dissolved in dimethyl sulfoxide (DMSO) at varying doses of 30, 40, 50, and 100 $\mu\text{g}/\text{ml}$. All plates were incubated at 37 $^{\circ}\text{C}$ for 24 hours in the incubator.

3. RESULTS AND DISCUSSION

3.1 XRD Analysis

All X-ray diffraction (XRD) peaks observed for the magnesia (MgO) samples (Figure 2). The peaks are corresponded to to the cubic phase structure of MgO. The diffraction measurements taken at 2θ ranging from 10° to 90° revealed five distinct peaks at the angles of 36.9° , 42.9° , 62.2° , 74.6° , and 78.5° . These observation distinct peaks indicate that the MgO samples possess a polycrystalline structure. The peak positions are in good agreement with the standard reference patterns provided by the Joint Committee on Powder Diffraction Standards (JCPDS) cards No. 96-900-6458 and No. 96-900-2350 (Darčanova et al., 2016).

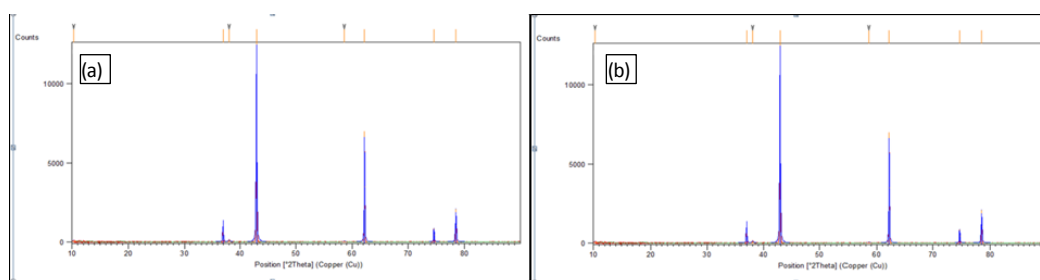


Figure 2: XRD of Magnesia1 (a), and Magnesia2 (b).

A summary of the Magnisa2 XRD-required data is given in Table 1. The results show that the cubic system of MgO crystal particles complies with the values of the

crystal lattice constant as replacement process (Darčanova et al., 2016). The calculated crystallize size was confirmed to be 39.7 nm. The result is slightly smaller than the SEM (43.58nm) because the SEM

analyzer provides a realistic value, whilst the XRD analyzer provides theoretical values (Tomaszewski, 2013). Stated on the JCPDS card. The two sets of values differ somewhat, however, which might be the result of the ion sites.

Table 1 provides an overview of the XRD data for the cubic system of MgO crystal particles that conforms to the crystal lattice constant values as prepared by the present replacement procedure. The estimated crystallite size obtained using the Scherer equation is confirmed to be 34 and 39.7 nm, respectively, for the two samples.

Table 1: XRD data for magnesia2 method with jcpds cards.

Peak Info	(1)	(2)	(3)	(4)	(5)
2θ [deg]	36.920600	42.889260	62.234130	74.598210	78.517870
θ [deg]	18.4603	21.44463	31.117065	37.299105	39.258935
θ [Rad]	0.32202	0.37408	0.542819	0.65066	0.68485
Cos(θ)	0.99998319	0.99997868	0.99995512	0.99993551	0.99992856
Intensity [%]	8.46	100.00	54.83	6.82	16.36
Height [cts]	1078.719000	12757.300000	6994.825000	870.653200	2086.663000
FWHM left [deg]	0.192000	0.168000	0.144000	0.168000	0.192000
FWHM left [Rad]	0.0034933	0.0029306	0.002512	0.0029306	0.0010666
d _{hkl} [Å]for Magnesia2	2.43267	2.16693	1.49055	1.27117	1.21724
d _{hkl} [Å]From JCPDS cards	2.43642	2.11000	1.49200	1.27238	1.21821
Hkl (Miller indices)	111	002	022	113	222

3.1 FT-IR Analysis

The chemical composition of the calcined final products were identified using FT-IR spectra as shown in **Figure 3**. The spectrum of both products was similar and exhibits vibrational absorption at around (424 cm⁻¹) which may be referred to Mg-O stretching vibrational

mode. A sharp vibration band is seen at the wavenumber range (3200-3600 cm⁻¹) due to O-H stretching vibration of absorbed water molecule, that is probably due to the aerial adsorptions of water molecule onto the MgO surface.

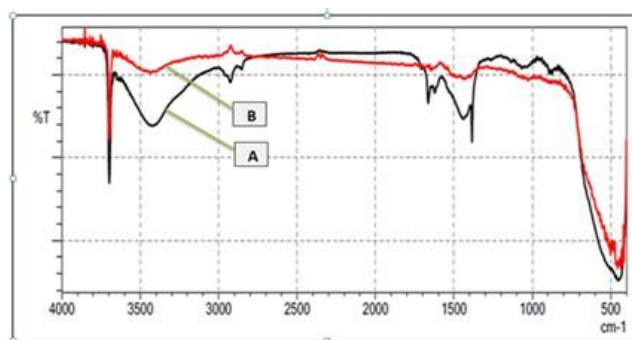


Figure 3: FT-IR spectra of MgO, (A) Magnesia₁, (B) Magnesia₂.

The sharpness of the band due to decreasing in water molecule number with increasing the calcination temperature, that can be also seen at (1620cm⁻¹) which can be referred to the bending vibrational mode of water molecule, that is confirming the effect of calcination temperature on FT-IR spectra of the prepared oxides (Mandal et al., 2012).

3.2 SEM Analysis

The dimensions and morphology of the synthesized MgO were observed using SEM, as seen in **Figure. 4** for Magnesia₁ and Magnesia₂. SEM data indicate that MgO particles have a flake-like morphology in both samples; however, the Magnesia₂ sample has less agglomeration compared to Magnesia₁. Additionally, the particle size of Magnesia₂ (43.58 nm) is smaller than that of Magnesia₁

(48.5 nm).

The result is slightly smaller than the SEM (43.58 nm) because the SEM analyzer provides a realistic value, whilst the XRD analyzer provides theoretical values (Tomaszewski, 2013), stated on the JCPDS card. The two sets of values differ somewhat, however, which might be the result of the ion sites.

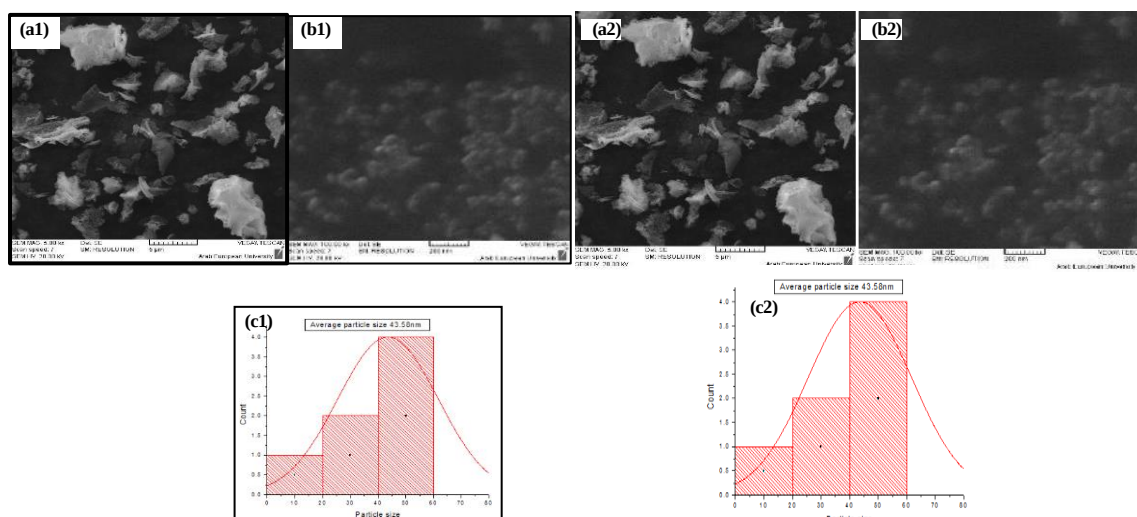


Figure 4: SEM of Magnesia1 (a1), magnified at 5µm, (b1) magnified at 200nm, (c1) Histogram for particle size distribution, and SEM of Magnesia2 (a2), magnified at 5µm, (b2) magnified at 200nm, (c2) Histogram for particle size distribution.

3.3 AFM Analysis

The topography of the external surface for the sample Magnesia2 was studied by AFM as shown in **Figure 5**. The powder was precipitated on a glass sheet using a hydraulic press. From the analysis, there is a good overall picture of different data about the sample, from the histogram it is noticed that there is a large amount of

heights from 22 nm to 58 nm and a very few of heights larger than 60 nm and smaller than 20 nm. From the roughness analysis as seen in **Table 2**, we notice that the root mean square (Sq), typically the most accurate measurement of roughness was 10.1 nm, that confirms the small size of the grains.

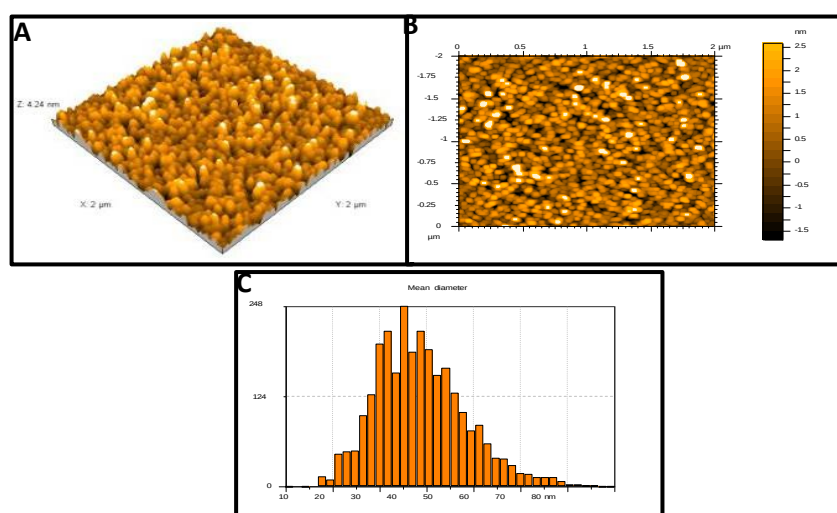


Figure 5: AFM images of Magnesia2, (A) 3D, (B) 2D, (C) histogram for the size distribution.

Table 2: Measurements of magnesia2 surface.

Roughness Average	Root Mean Square	Summit Height	Valley Depth
8.2 nm	10.1 nm	29.7 nm	17.4 nm

3.5 DLS Analysis

The size distribution of suspended Magnesia2 nanoparticles in a solution was determined via DLS analyzer. An aqueous suspension (2%) of Magnesia2 was prepared and ultrasonicated for 24 hours. From the

previous results, it is found that Polydisperse Index (PdI=0.384) with appearance of a single peak (**Figure 7**), both of which indicate that MgO is a monodisperse particle size (Karmakar, 2019).

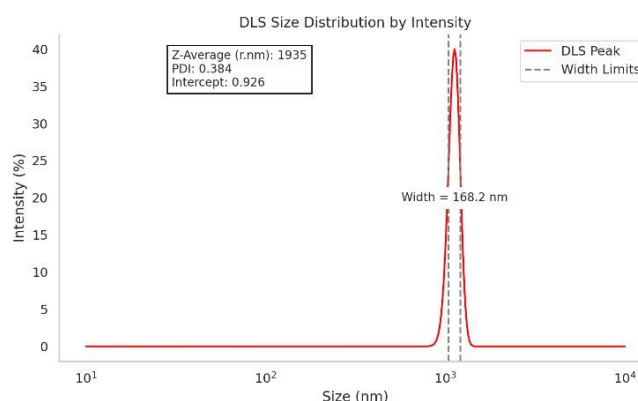


Figure 6: DLS Data of Magnesia 2.

3.6 Antibacterial activity of MgO nanoparticles

Two common and clinically relevant bacteria strains *E. coli* and *S. aureus* were tested to investigate the biological efficacy of the synthesized oxide (Magnesia2)

via agar well diffusion method as shown in **Figure 7**. **Table 3** the antibacterial activities of the prepared Magnesia2 sample against *S. Aureus* and *E. coli* bacteria.

Table 3: Inhibition Zones at Different Concentrations Against *S. Aureus* and *E. Coli* Bacteria.

Well No.	Well content	Sample concentration (µg/ml)	Inhibition zone (mm) <i>S. aureus</i>	Inhibition zone (mm) <i>E. coli</i>
1		30	11	13
2		40	6	5
	Magnesia2			
3		50	5	15
4		100	4	5
5	Gentamicin	100	40	40
6	DMSO	(10%)	-	-

The results indicate that MgO nanoparticles showed effective antibacterial activity against the *S. aureus* and *E. coli* bacteria. The diameter of growth inhibition was 5 mm and 4 mm for *E. coli* and *S. aureus* respectively, compared to 40 mm for gentamycin. The results also showed that the inhibitory effect decreased with the increase in the sample concentration. At higher concentration levels, the increase in concentration had a smaller impact on the radius of the inhibition in agreement with (Campion & Morrissey, 2013). Without a doubt, the deadly effect of microbial cells is due to the liberation of magnesium ions from MgO nanoparticles, which remain in the cell membrane to change its composition, then the cell membrane increases the until cell dies .

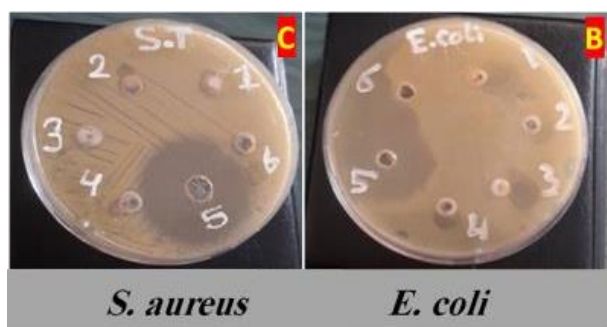


Figure 7: Antibacterial activities for Magnesia2 nanoparticles.

4. CONCLUSION

MgO nanoparticles were successfully synthesized using a modified sol-gel combustion method, yielding ultrafine powders with well-defined structural and morphological characteristics. XRD analysis confirmed the formation of cubic-phase MgO with nanoscale crystallite sizes, while SEM and AFM evaluations revealed flake-like morphologies and low surface roughness, consistent with the expected features of nanostructured MgO. DLS measurements further supported the production of a monodisperse nanoparticle suspension. The antibacterial assessment demonstrated that the synthesized MgO nanoparticles possess measurable inhibitory activity against *S. aureus* and *E. coli*, confirming their ability to interact with and suppress microbial growth. Although the inhibition zones were smaller than those of gentamicin, the results verify the intrinsic antimicrobial potential of MgO. The observed decrease in activity at higher nanoparticle concentrations suggests a complex interaction mechanism between MgO surface chemistry and bacterial cell structures. Overall, this study provides a straightforward and reproducible method for producing MgO nanoparticles with desirable physicochemical and antimicrobial properties. These findings support the further exploration of MgO nanomaterials for applications in antibacterial formulations, catalysts, sensors, and other fields where stable and biocompatible nanostructures are required.

ACKNOWLEDGMENT

The authors wish to extend their appreciation to Hadhramout University and Albaath University for their assistance and collaboration throughout this study.

REFERENCES

- Altammar, K. A. A review on nanoparticles: characteristics, synthesis, applications, and challenges. In *Frontiers in Microbiology*, 2023; 14. Frontiers Media S.A. <https://doi.org/10.3389/fmicb.2023.1155622>
- Andresen, E., Islam, F., Prinz, C., Gehrmann, P., Licha, K., Roik, J., Recknagel, S., & Resch-Genger, U. Assessing the reproducibility and up-scaling of the synthesis of Er, Yb-doped NaYF₄-based upconverting nanoparticles and control of size, morphology, and optical properties. *Scientific Reports*, 2023; 13(1). <https://doi.org/10.1038/s41598-023-28875-8>
- Bamsaoud, S. F., Basuliman, M. M., Bin-Hameed, E. A., Balakhm, S. M., & Alkalali, A. S. The effect of volume and concentration of AgNO₃ aqueous solutions on silver nanoparticles synthesized using Ziziphus Spina-Christi leaf extract and their antibacterial activity. *Journal of Physics: Conference Series*, 2021; 1900(1). <https://doi.org/10.1088/1742-6596/1900/1/012005>
- Basuliman, M. M., Bamahel, A. S., Al-Kathiri, D. G., & Al-Suhily, A. M. The Effect of Various Concentrations of AgNO₃ Aqueous Solutions on Silver Nanoparticles Biosynthesis Using Tarchonanthus Camphoratus Leaf Extract and Their Antibacterial Activity. *Moroccan Journal of Chemistry*, 2023; 11(2): 361–370. <https://doi.org/10.48317/IMIST.PRSM/morjchem-v11i1.33269>
- Campion, E. W., & Morrissey, S. A Different Model — Medical Care in Cuba. *New England Journal of Medicine*, 2013; 368(4): 297–299. <https://doi.org/10.1056/nejmp1215226>
- Darčanova, O., Tamutè, M., Beganskienė, A., & Kareiva, A. Synthesis of magnesium oxide nanoparticles via sol-gel method and hydrolysis and application for paper deacidification treatment. In *chemija*, 2016; 27: 3.
- Díez-Pascual, A. M. Antibacterial activity of nanomaterials. In *Nanomaterials*, 2018; 8(6). MDPI AG. <https://doi.org/10.3390/nano8060359>
- Hajra, K., Maity, D., & Saha, S. Recent Advancements of Metal Oxide Nanoparticles and their Potential Applications: A Review. *Advanced Materials Letters*, 2024; 15(1): 2401–1740. <https://doi.org/10.5185/amlett.2024.011740>
- Kadiyala, U., Kotov, N. A., & VanEpps, J. S. Antibacterial Metal Oxide Nanoparticles: Challenges in Interpreting the Literature. *Current Pharmaceutical Design*, 2018; 24(8): 896–903. <https://doi.org/10.2174/1381612824666180219130659>
- Karmakar, S. (2019). *Particle size distribution and zeta potential based on dynamic light scattering: Techniques to characterize stability and surface charge distribution of charged colloids*. <https://www.researchgate.net/publication/328577330>
- Li, X., Liu, H., He, Y., Li, Z., Zhan, F., Li, Y., & Zhao, J. Enhanced antibacterial effect with MgO nanoplates: Role of oxygen vacancy and alkalinity. *Ceramics International*, 2024; 50(21): 42877–42885. <https://doi.org/10.1016/j.ceramint.2024.08.133>
- Ma, J. X., Chen, X. L., & Huang, M. X. (2025). Understanding the antibacterial mechanism of metal surfaces. *Acta Biomaterialia*, 192: 501–512. <https://doi.org/10.1016/j.actbio.2024.12.001>
- Mandal, S., Patil, V. S., & Mayadevi, S. Alginate and hydrotalcite-like anionic clay composite systems: Synthesis, characterization and application studies. *Microporous and Mesoporous Materials*, 2012; 158: 241–246. <https://doi.org/10.1016/j.micromeso.2012.03.046>
- Nassar, M. Y., Mohamed, T. Y., Ahmed, I. S., & Samir, I. MgO nanostructure via a sol-gel combustion synthesis method using different fuels: An efficient nano-adsorbent for the removal of some anionic textile dyes. *Journal of Molecular Liquids*, 2017; 225: 730–740. <https://doi.org/10.1016/j.molliq.2016.10.135>
- Nazem, A. M., Abo Shaala, E. K., & Awad, S. A. Application of some inorganic metal oxide nanoparticles to control E. coli in raw milk. *Open Veterinary Journal*, 2024; 14(1): 545–552. <https://doi.org/10.5455/OVJ.2024.v14.i1.49>
- Radulescu, D. M., Surdu, V. A., Fica, A., Fica, D., Grumezescu, A. M., & Andronescu, E. Green Synthesis of Metal and Metal Oxide Nanoparticles: A Review of the Principles and Biomedical Applications. In *International Journal of Molecular Sciences*, 2023; 24: 20. Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/ijms242015397>
- Tomaszewski, P. E. The uncertainty in the grain size calculation from X-ray diffraction data. *Phase Transitions*, 2013; 86(2–3): 260–266.
- Xuan, J., Feng, W., Wang, J., Wang, R., Zhang, B., Bo, L., Chen, Z. S., Yang, H., & Sun, L. Antimicrobial peptides for combating drug-resistant bacterial infections. In *Drug Resistance Updates*, 2023; 68. Churchill Livingstone. <https://doi.org/10.1016/j.drup.2023.100954>
- Zhang, S., Lin, L., Huang, X., Lu, Y. G., Zheng, D. L., & Feng, Y. Antimicrobial Properties of Metal Nanoparticles and Their Oxide Materials and Their Applications in Oral Biology. In *Journal of Nanomaterials*, 2022. Hindawi Limited. <https://doi.org/10.1155/2022/2063265>