



Comparative Study on Antibacterial Activity of MgO Nanoparticles Synthesized from *Lawsonia inermis* Leaves Extract and Chemical Methods

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Abstract

In this report, *Lawsonia inermis* leaves extract is employed for the first time to synthesize Magnesium Oxide (MgO) nanoparticles (NPs) in a green approach. The green synthesis of MgO NPs with *Lawsonia inermis* leaves extract has extra benefits like eco-friendly, cost-effective, rapid synthesis, safer, and give natural stabilization and capping action. MgO NPs were also prepared by the chemical method for the comparative study of properties. Sodium hydroxide was used as a reducing agent, and magnesium acetate as a precursor in the chemical method whereas in green synthesis leaves extract of *Lawsonia inermis* used. The prepared MgO NPs were characterized using different techniques for their average crystalline size, particle size, morphology, elemental analysis, microstructure and functional groups of the materials. The average crystalline size of 20 nm and 24 nm were observed for green and chemically synthesized MgO NPs. The antibacterial activity of green and chemically synthesized MgO NPs using different concentrations of (20–80 μL) against *B. subtilis*, *S. aureus* gram-positive and *E. coli*, *P. vulgaris* gram-negative bacteria were performed. A large inhibition zone is observed for green synthesized MgO NPs over chemical synthesized MgO NPs confirmed the higher activity for green synthesized MgO NPs. The bio-synthesized MgO NPs showed good antibacterial activity and exhibited maximum inhibition zone at 80 μL concentration. This study presents a rapid, low cost, environmentally friendly green approach for MgO NPs synthesis and obtained MgO NPs can also be used against other microbial species in the future.

Keywords Green method · *Lawsonia inermis* · Chemical method · MgO nanoparticles · Antibacterial activity

1 Introduction

Nanoparticles have attracted a lot of attention from the last two decades due to a huge number of applications in many fields such as antimicrobial applications, bio-sensing, imaging, drug delivery, chemical industry [1–3]. The number of commercial products such as food packaging, cosmetics, personal care and nanomedicine based on nanoparticles were already available in the market [4]. Among all nanoparticles, Magnesium Oxide (MgO) nanoparticles (NPs) find attractive due to their unique properties such as odourless, nontoxicity, and antimicrobial property [5]. MgO NPs were synthesized by different chemical methods such as co-precipitation [6],

sol-gel [7], wet chemical [8], solvent alteration [9], and solution combustion [10]. These chemical methods have their demerits, such as environmental contamination and hazardous by-products produced during their synthesis. To overcome the above challenges, green synthesis methods were developed for the synthesis of MgO nanoparticles. The cost and toxic impact of chemicals during the preparation of NPs can be reduced with the green approach [11, 12].

The green synthesis methods are preferred to prepare nanoparticles for the application in the biomedical field [13]. Three main biological organisms namely bacteria [14], fungi [15], and plants [16] are used in the green synthesis of nanoparticles. The large-scale synthesis of nanoparticles is preferred via bacteria and fungi with minimum usage of toxic chemicals [17]. The usage of bacteria and fungi for nanoparticle production is limited by their prolonged production time [18]. In the green synthesis of MgO NPs, different natural leaf extracts such as *Amaranthus tricolor*, *Amaranthus blitum* and *Andrographis paniculata* [19], *Pisidium guvajava*

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(*P. guvajava*) and *Aloe vera* (*A. vera*) [20], *Trigonella foenum-graecum* leaf extract [21], Orange Fruit Waste [22], *Nephelium lappaceum* L. peels [23], *Kleinia grandiflora* Herba Extract [24] were used.

In this report, *Lawsonia inermis* leaves extract is taken in the green synthesis of MgO NPs, for the first time to the best of our knowledge. The novelty of the manuscript lies in the usage of new leaf extract for the synthesis of MgO nanoparticles. *Lawsonia inermis* is commonly known as Mehndi or Henna. It contains a different variety of bioactive molecules. It is believed to decrease the body temperature in a situation of high fever and also helps the health of hair. The leaves show strong antimicrobial, anticancer, analgesic properties [25]. Recently, *Lawsonia inermis* leaves were used to prepare nanoparticles of gold [26], iron oxide [27], silver [28], Cadmium sulphide [29], Zinc oxide [30] and cerium oxide [31]. These were studied for the antibacterial property against different bacteria. There are no such studies exist on the synthesis of MgO nanoparticles by the green method using *Lawsonia inermis* in the literature. The main advantages of this leaf extract are easily available and can be used for the synthesis of a variety of metal and metal oxide, metal sulphides nanoparticles preparation compare to the other leaf extracts. This plant contains the compounds of Linalool α -terpineol, Etherphenylvinyl A 1,3-indandione, Eugenol, 2-hydroxy-1, 4-naphthoquinone, Oxirane-tetradecyl, Hexadecanoic acid. These compounds present in the *Lawsonia inermis* plant act as a capping as well as the stabilizing agent, which were useful in the formation of MgO nanoparticles. The *Lawsonia inermis* leaves extract is an excellent reduction agent to prepare the MgO NPs with controlled size and morphology [32].

In this work, MgO NPs were prepared using *Lawsonia inermis* leaves extract by green approach. MgO NPs were also prepared by the chemical method to compare the properties. Different characterization techniques were employed for the characterization of obtained MgO NPs. The synthesized nanoparticles were studied for their antibacterial activity against *Bacillus subtilis* (*B. subtilis*) MTCC-441, *Staphylococcus aureus* (*S. aureus*) MTCC-1430, and *Escherichia coli* (*E. coli*) MTCC-433, *Proteus vulgaris* (*P. vulgaris*) MTCC-426, and compared. The present green method is simple, rapid, eco-friendly, non-toxic and useful in pharmaceutical applications.

2 Material and Methods

2.1 Materials

Magnesium Acetate Mg (CH₃COO)₂ and Sodium hydroxide (NaOH) purchased from Merck India Pvt. Ltd. were used without further purification. Fresh leaves of *Lawsonia*

inermis were collected from the greenhouse of NIT- Warangal, Telangana, India.

2.2 Green Synthesis of MgO Nanoparticles

Fresh and healthy collected *Lawsonia inermis* leaves were taken and washed with deionized (DI) water repeatedly. After drying, leaves (15 g) were taken into the 150 mL of DI water in a beaker and kept on a hot plate at 90 °C for 1 h until the colour of the solution changes from colourless to light red colour. The Whatman filter paper was used for the filtration process to separate the *Lawsonia inermis* extract from the leaves. The solution extract of the *Lawsonia inermis* was added to 0.5 M magnesium acetate in a beaker and kept on a hot plate at 80 °C and the heating process was continued till the formation of NPs. The obtained NPs powder was calcinated at 200 °C for 4 h to remove the residual solvents and moisture. A grey colour MgO NPs product was obtained as the final product [33].

2.3 Chemical Synthesis of MgO Nanoparticles

In this process, the Magnesium acetate (0.5 M) was taken into 50 mL of DI water and Sodium hydroxide (0.2 M) solution was added at a slow pace to neutralize the solution. The solution was vigorously stirred to get gel form and the gel was calcinated at 400 °C for 4 h. White colour MgO NPs powder was obtained as a final product [34].

2.4 Characterization of MgO Nanoparticles

Bruker D8 advanced X-Ray diffractometer (XRD) with Cu K α radiation was used to get the XRD patterns of synthesized nanoparticle powders. The Particle size analyzer (PSA) Horiba-SZ-100 was used to find size of the nanoparticles. The morphology of the synthesized powders was investigated by Field Emission Scanning Electron Microscopy (FESEM) (JEOL JSM-7600F). Fourier Transform Infra Red (FTIR) spectrometer (Bruker Alpha) was employed to get FTIR spectra at room temperature using the KBr method. Transmission electron microscopy (TEM) (JEM-Model 100CX II) was used to study the microstructure and size of the nanoparticles.

2.5 Antibacterial Study of MgO Nanoparticles: Disk Diffusion Method

The Gram-negative and Gram-positive bacterial strains were taken for the antibacterial study. The 10⁸ Colony Forming Units (CFU)/mL of the bacterial stock cultures were maintained on Mueller–Hinton agar slants and stored at 4 °C. The disk diffusion method was employed to estimate the antibacterial activities of test compounds [35]. Reactivations of the

bacterial strains were done by transferring stock cultures into Mueller–Hinton broth and incubated at 37 °C for 18 h. The Whatman paper disks (4–8 mm) impregnated with diluted nanoparticles solution were placed on the surface of each plate using a sterile pair of forceps. Then, agar plates are incubated under suitable conditions depending upon the test microorganism. Then the plates were incubated aerobically and the diameter of zone inhibition was measured.

3 Results and Discussions

3.1 Morphological Characterization of the MgO Nanoparticles

The small amount of the obtained MgO NPs powder was taken on a carbon tape for the study of morphology. Fig. 1a and b show the morphology of the green and chemically synthesized powders respectively. The FESEM images confirm the formation of MgO nanoparticles in both synthesis methods. The MgO NPs prepared by green method have a spherical granular structure with high intensity of porosity whereas nanoparticles synthesized by the chemical method have exhibited spherical structure with very less porosity. Fig. 1c and d show the Energy dispersive x-ray spectrums

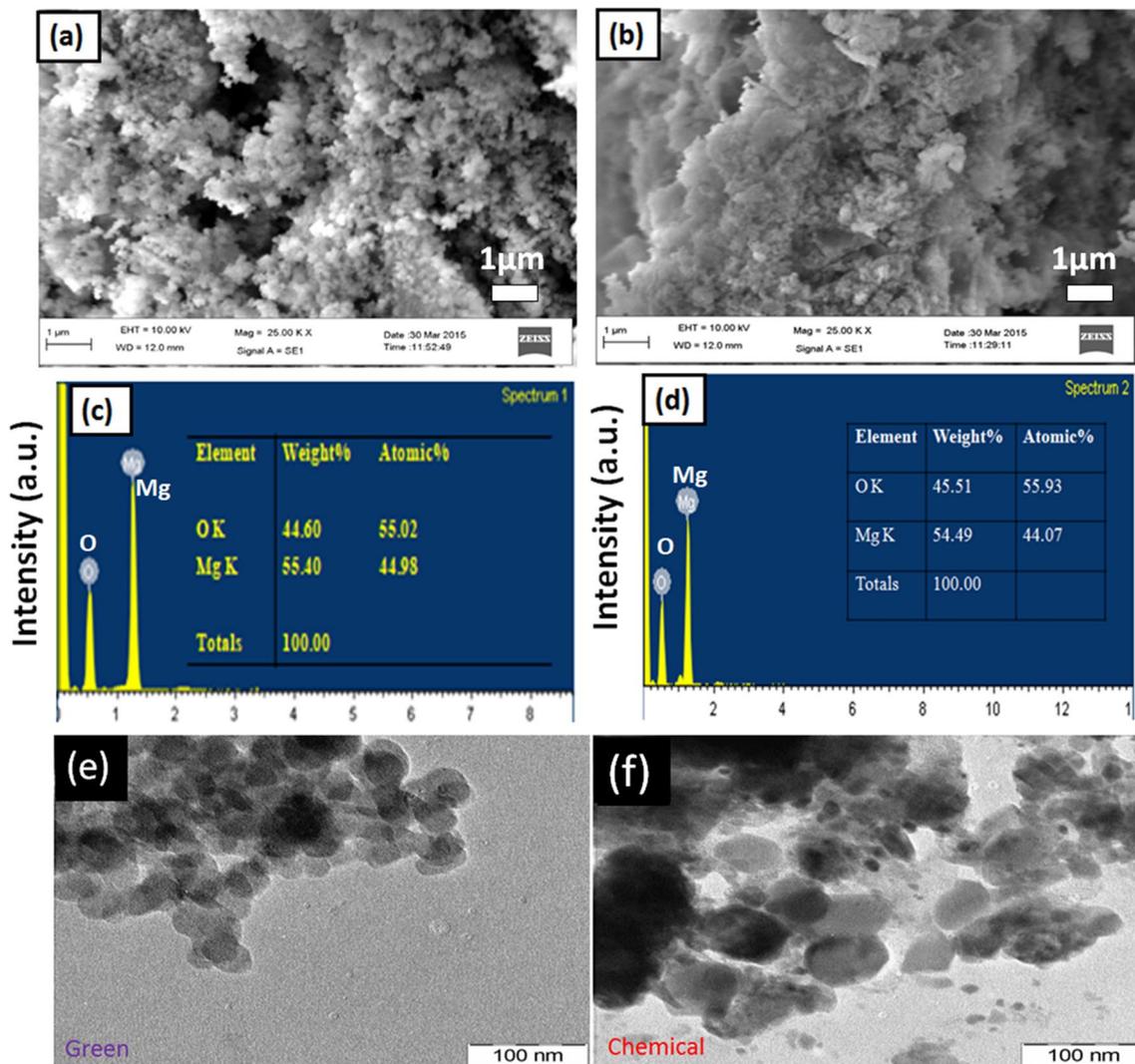


Fig. 1 MgO NPs FESEM images **a** Green synthesis method, **b** Chemical synthesis method; Energy dispersive spectrum of MgO NPs **c** Green synthesis, **d** Chemical synthesis, TEM images of MgO NPs **e** Green synthesis method and **f** Chemical synthesis method

(EDS) of MgO NPs synthesized by green and chemical methods. The EDS of synthesized MgO NPs have shown Magnesium and Oxygen peaks. The weight and atomic percentages of Mg and oxygen represent the MgO phase.

The shape and size of the MgO NPs were characterized by using TEM. The sample for TEM studies was prepared by drop casting of MgO NPs solution on the TEM grid and dried. The TEM images in Fig. 1e and f confirmed that the size of the synthesized MgO NPs was in the range of 10–100 nm. Moreover, the TEM image has shown the spherical structure for both chemical and green synthesized MgO NPs [36].

3.2 X-ray Diffraction (XRD) and Particle Size Analysis (PSA) Studies

The X-ray diffraction patterns of the green and chemical synthesized powders are shown in the Fig. 2a and b. There are four major diffraction peaks observed between 20° and 80° for both the powders. The positions of the diffraction peaks

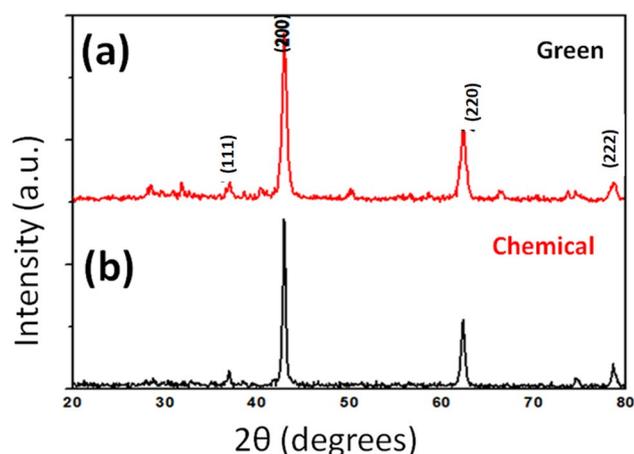
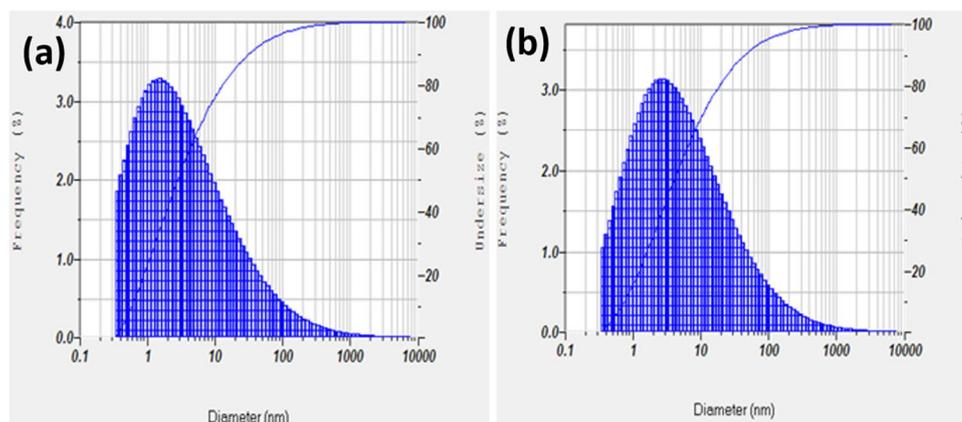


Fig. 2 XRD pattern of MgO NPs prepared by **a** Green method and **b** Chemical method

Fig. 3 Particles distribution of MgO NPs prepared by **a** green method and **b** chemical method



observed at 37° , 42° , 62° , and 78° are indexed as (1 1 1), (2 0 0), (2 2 0) and (2 2 2) planes of MgO respectively for both powders. The indexed diffraction patterns exactly matches with standard JCPDS # 89-7746, which confirms the formation of the MgO phase. MgO NPs have the face center cubic structure with lattice parameters $a = b = c = 0.4212$ nm from the standard card.

The variation in the broadness of peaks was observed in the XRD spectrum of the green and chemical methods. The broad diffraction peaks observed in the case of green synthesized NPs confirms the smaller size of the particles compared to the chemical synthesized NPs. The Debye-Scherrer formula was used to measure the average particle size and found as 20 nm and 24 nm for the MgO NPs synthesized by green and chemical synthesis methods, respectively [37].

Further, PSA was used to confirm the average particle size. The MgO NPs were dispersed completely in ethanol using ultrasonication for the PSA analysis. The histograms as shown in Fig. 3 represent the size distribution of the dispersed MgO NPs. The average particle size was obtained from the mean value of the histograms and found 23.9 nm and 29.8 nm for green and chemical methods. These results were in good agreement with the XRD result [38]. The PSA measurements were performed twice and found similar results.

3.3 FTIR Studies

FTIR spectra of the green and chemical synthesized MgO NPs powders were recorded between 500 and 4000 cm^{-1} and the corresponding spectra are shown in Fig. 4a and b. The symmetric, asymmetric stretching was studied to determine the presence of functional groups in the prepared samples. The FTIR spectrum of the stretching bond at 524.6 cm^{-1} indicates the formation of MgO NPs [39]. The O–H stretch appears in the spectrum is very broad band extending from 3429.2 to 3628 cm^{-1} . The band at 2985 cm^{-1} confirms the presence of -OH stretching

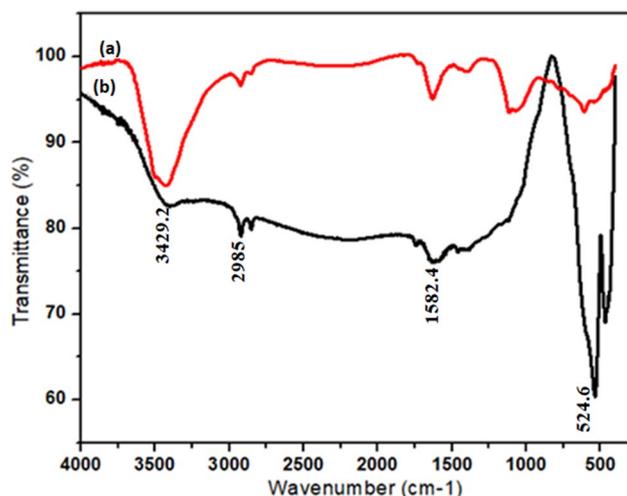


Fig. 4 FTIR spectrum of MgO NPs synthesized by **a** green method and **b** chemical method

vibrations on the surface of the material. The absorption peak at 1582.4 cm^{-1} is attributed to H_2O twisting. The peak located at 1132.5 cm^{-1} is associated with alkoxy stretching vibrations [40].

3.4 Antibacterial Activity by Disk Diffusion Method

The disk diffusion method is used for the study of antibacterial activity. The stock solution with a concentration of 2 mg/mL was prepared from the MgO nanoparticles obtained by green and chemical synthesis methods. The antibacterial study was conducted with different microliter (μL) concentrations ranging from 20 to $80\ \mu\text{L}$ against *B. subtilis*, *S. aureus* gram positive and *E. coli*, *P. vulgaris* gram negative bacteria. The zone of inhibition diameter was measured for each bacteria for different concentrations.

From Fig. 5, it can be observed that the green synthesized nanoparticles have more inhibition zone for *B. subtilis*, *S. aureus* gram positive and *E. coli*, *P. vulgaris* gram negative bacteria as compared to chemically synthesized MgO NPs. It can also observe that inhibition zone increases with an increase in concentration [41–44]. The antibacterial activity of MgO NPs is due to the creation of OH^- and Mg^{2+} ions on surface of MgO NPs. The interaction of MgO NPs with organisms leads to the damaging of the organisms surface, finally cell death was caused by the electrostatic contact between the organism surface and MgO NPs. There were some assumptions MgO NPs to destroy organism's membrane and release OH^- and Mg^{2+} ions [45–47]. The gram-negative bacteria have a thin layer of peptidoglycan, and MgO NPs enters into the cell wall and attaches to the cell membrane, which leads to

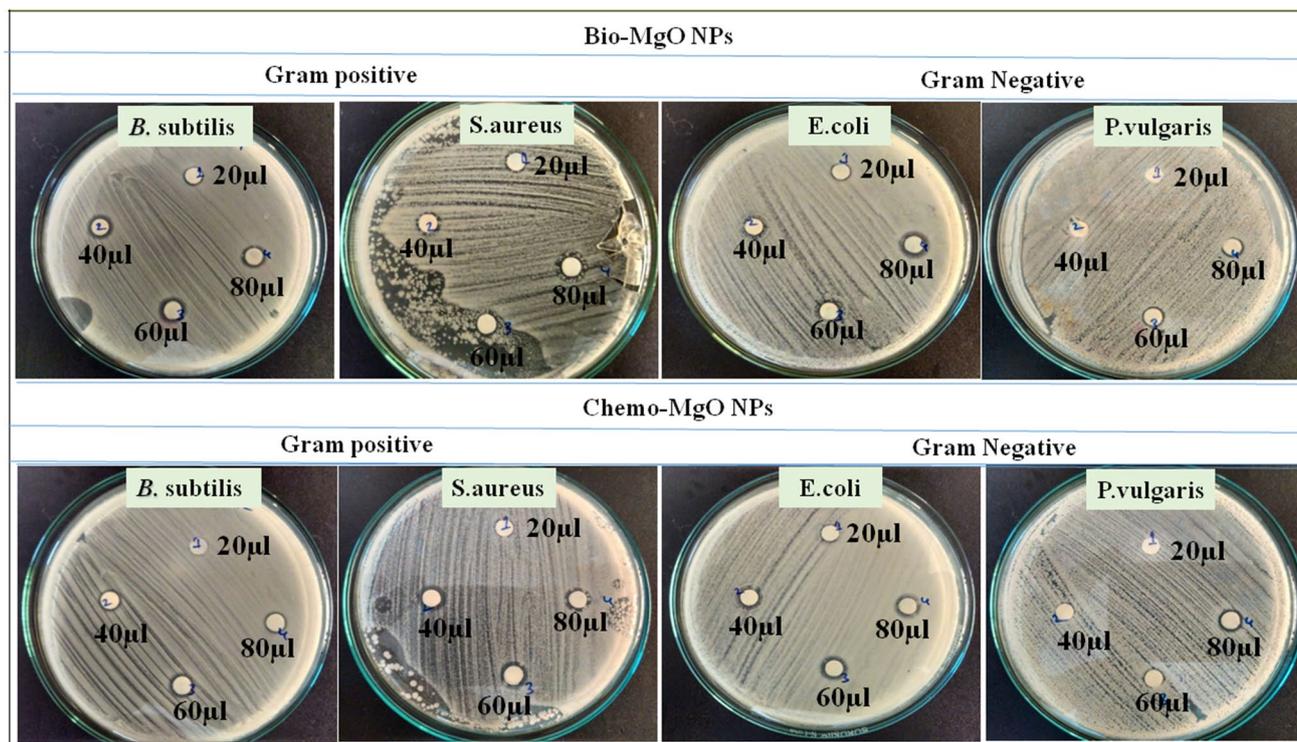


Fig. 5 Antibacterial activity of green synthesized (top panel) and chemically synthesized nanoparticles (bottom panel)

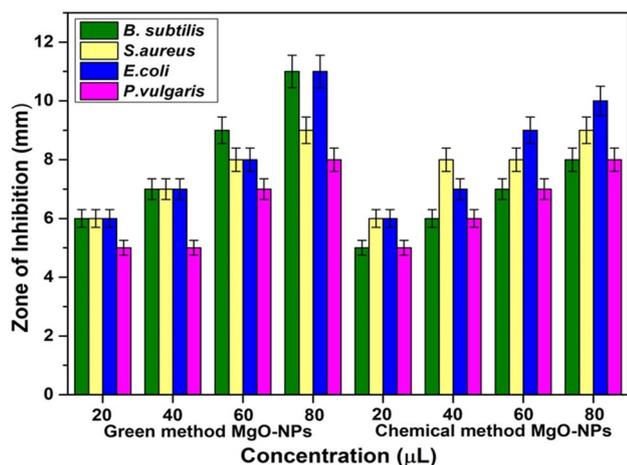


Fig. 6 Antibacterial activity of green synthesized and chemically synthesized nanoparticles against on *B. subtilis*, *S. aureus* gram-positive and *E. coli*, *P. vulgaris* gram-negative bacteria

causing the structure deformation and cell demise [48–50]. Whereas in the gram-positive bacteria the positively charged Mg^{2+} in MgO NPs may bind with the negatively charged teichoic acid end of phosphate groups and finally the bacterial damage occurs [51]. The peptide linkages in gram-negative and gram-positive bacteria and the cell membrane may be teardown by the generation of superoxide ions on the surface of MgO NPs [52]. The MgO NPs can deform and destroy the cell membranes, resulting in the leakage of their intracellular content and eventually death of the bacteria. Hence, it was confirmed due to the interaction of particles and organisms, the MgO NPs exhibited good activity against gram-negative and gram-positive bacteria. The antimicrobial activity of MgO NPs depends on the size, shape and concentration.

The metal oxides, such as TiO_2 , ZnO, CuO, CaO_2 , CeO_2 , Al_2O_3 and MgO can eliminate bacteria through an oxidation reaction. They are strong antimicrobial agents and generate the reactive oxygen species that leads to the death of the bacteria [53]. Whereas, the MgO NPs destroy the cell membrane and cause lipid peroxidation. The lipid peroxidation leads to leakage of intracellular contents, which results in cell death.

The statistical analysis of the antibacterial activity of green and chemical synthesized MgO NPs is shown in Fig. 6. It is clear from the graphs that the green synthesized MgO NPs exhibited higher antibacterial activity (zone of inhibition) compared to the chemical synthesized MgO NPs. Higher activity of green synthesized MgO NPs is mainly due to the presence of organic biomolecules on the surface of the NPs.

4 Conclusions

The green synthesis has been adopted to prepare the MgO NPs by aqueous extract of *Lawsonia inermis* leaves for the first time. A comparative study was performed with green and chemical synthesized MgO NPs. The formation of MgO NPs and their morphology, composition, size was confirmed by SEM, EDS, TEM, XRD and PSA studies. The green synthesized MgO NPs exhibited good antibacterial activity against *B. subtilis*, *S. aureus* gram-positive bacteria and *E. coli*, *P. vulgaris* gram-negative bacteria compared to the chemical synthesized MgO NPs due to the existence of organic biomolecules on the surface of green synthesized MgO NPs. The present green method is simple, rapid, eco-friendly, non-toxic and useful in pharmaceutical applications.

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Compliance with Ethical Standards

Conflict of interest The author declares that they have no conflict of interest.

References

1. A. Mohamed, E.I. Shafey, Green synthesis of metal and metal oxide nanoparticles from plant leaf extracts and their applications: a review. *Green Process. Synth.* **9**, 304–339 (2020)
2. S.G. Ali, M.A. Ansari, M.A. Alzohairy, M.N. Alomary, M. Jalal, S. AlYahya, S.M. Asiri, H.M. Khan, Effect of biosynthesized ZnO nanoparticles on multi-drug resistant *Pseudomonas aeruginosa*. *Antibiotics* **9**, 260–268 (2020)
3. H. Barabadi, H. Tajani, M. Moradi, M.D. Kamali, R. Meena, S. Honary, M.A. Mahjoub, M. Saravanan, Penicillium family as emerging nanofactory for biosynthesis of green nanomaterials: a journey into the world of microorganisms. *J. Clust. Sci.* **30**, 843–856 (2019)
4. R.G. Saratale, I. Karuppusamy, G.D. Saratale, A. Pugazhendhi, G. Kumar, Y. Park, S.G. Ghodake, R.N. Bhargava, J.R. Banu, H.S. Shin, A comprehensive review on green nanomaterials using biological systems recent perception and their future applications. *Coll. Surf. B.* **170**, 20–35 (2018)
5. L. Uamaralikhani, M.J.M. Jaffar, Green synthesis of MgO nanoparticles and its antibacterial activity. *Iran. J. Sci. Technol. Trans. A Sci.* **42**, 477–485 (2017)
6. A. Khatua, E. Priyadarshini, P. Rajamani, A. Patel, J. Kumar, A. Naik, M. Saravanan, H. Barabadi, A.G. Prasad, B. Paul, R. Meen, Phytosynthesis, characterization and fungicidal potential of emerging gold nanoparticles using pongamia pinnata leave extract: a novel approach in nanoparticle synthesis. *J. Cluster Sci.* **31**, 125–213 (2020)
7. H. Thi, D. Yen, Synthesis of magnesium oxide nanoplates and their application in nitrogen dioxide and sulfur dioxide adsorption. *J. Chem.* **9**, 1–10 (2019)

8. J. Suresh, R.G. Raivgandhi, S. Selvam, M. Sundraraja, Synthesis of magnesium oxide nanoparticles by wet chemical method and its antibacterial activity. *Adv. Mater. Res.* **678**(297), 300 (2013)
9. P. Bhattacharya, S. Swain, G. Lopamudra, N. Sudarsan, Fabrication of magnesium oxide nanoparticles by solvent alteration and their bactericidal applications. *J. Mater. Chem. B.* **7**, 4141–4148 (2019)
10. L.I. Songnan, Combustion synthesis of porous MgO and its adsorption properties. *Int. J. Ind. Chem.* **9**, 1089–1096 (2019)
11. J. Jeevanandam, Y.S. Chan, M.K. Danquah, Evaluating the antibacterial activity of MgO nanoparticles synthesized from aqueous leaf extract. *Nanopart. Med.* **5**, 1–18 (2019)
12. R. Prasanth, S.D. Kumar, A. Jayalakshmi, G. Singaravelu, K. Govindaraju, V.G. Kumar, Green synthesis of magnesium oxide nanoparticles and their antibacterial activity. *Indian J Geo-Marine Sci.* **48**, 1210–1215 (2019)
13. J. Jeevanandam, S.C. Yen, M.K. Danquah, Evaluating the antibacterial activity of MgO nanoparticles synthesized from aqueous leaf extract. *Med One.* **4**, 1–15 (2019)
14. K. Kalimuthu, B.S. Cha, S. Kim, K.S. Park, Eco-friendly synthesis and biomedical applications of gold nanoparticles: a review. *Microchem. J.* **152**, 104296–1042105 (2020)
15. P. Clarence, B. Luvankar, J. Sales, A. Khusro, P. Agastian, J.K. Tack, M. Manal, Al.H. KhulaifiAL-Shwaima, A.M. Elgorban, A. Syed, Green synthesis and characterization of gold nanoparticles using endophytic fungi *Fusarium solani* and its in-vitro anticancer and biomedical applications. *Saudi J. Biol. Sci.* **27**, 706–712 (2020)
16. M. Vergeheese, S.K. Vishal, Green synthesis of magnesium oxide nanoparticles using *Trigonella foenum-graecum* leaf extract and its antibacterial activity. *J. Pharmacogn. Phytochem.* **7**, 1193–1200 (2018)
17. G. Geeta, A.R. Choudhury, A review on the biosynthesis of metal and metal salt nanoparticles by microbes. *RSC Adv.* **9**, 12944–12968 (2019)
18. C. Mohanasrinivasan, C.S. Devi, M. Avani, P. Suman, A. Aditi, E. Selvarajan, S.J. Naine, Biosynthesis of MgO nanoparticles using *Lactobacillus* sp. and its activity against human leukemia cell lines HL-60. *BioNanoScience* **8**, 1–6 (2017)
19. M.L. Khan, M.N. Akhtar, N. Ashraf, J. Najeeb, H. Munir, T.I. Awan, M.B. Tahir, M.R. Kabli, Green synthesis of magnesium oxide nanoparticles using *Dalbergia sissoo* extract for photocatalytic activity and antibacterial efficacy. *Appl. Nanosci.* **10**, 2351–2364 (2019)
20. V. Mary, S.K. Vishal, Green synthesis of magnesium oxide nanoparticles using *Trigonella foenum-graecum* leaf extract and its antibacterial activity. *J. Pharmacogn. Phytochem.* **7**, 1193–1200 (2018)
21. M. Shikha, S. Aakash, K. Vipin, Synthesis and characterization of MgO nanoparticles by orange fruit waste through green method. *Int. J. Adv. Res. Chem. Sci.* **4**, 36–42 (2017)
22. J. Suresh, R. Yuvakkumar, M. Sundrarajan, S.I. Hong, Green synthesis of magnesium oxide nanoparticles. *Adv. Mater. Res.* **952**, 141–144 (2014)
23. D. Renata, Synthesis of MgO nanoparticles using *Artemisia abrotanum* herba extract and their antioxidant and photocatalytic properties. *Iran J. Sci. Technol. Trans. Sci.* **42**, 547–555 (2018)
24. K. Kanagamani, P. Muthukrishnan, K. Shankar, A. Kathiresan, H. Barabadi, M. Saravanan, Antimicrobial, cytotoxicity and photocatalytic degradation of norfloxacin using *Kleimia grandiflora* mediated silver nanoparticles. *J. Clust. Sci.* **30**, 1415–1424 (2019)
25. J.K.K. Al-rubiay, N.N. Jaber, L.K. Alrubaiy, Antimicrobial efficacy of henna extracts. *Oman Med. J.* **23**, 253–256 (2008)
26. J. Kasthuri, S. Veerapandian, N. Rajendiran, Biological synthesis of silver and gold nanoparticles using apiin as reducing agent. *Coll. Surf. B* **68**, 55–60 (2009)
27. L.T. Dama, Green synthesis of silver nanoparticles using leaf extract of *Lawsonia inermis* and *Psidium guajava* and evaluation of their antibacterial activity. *Sci. Res. Rep.* **6**, 89–95 (2016)
28. S. Chauhan, D.N. Kumar, L.S.B. Upadhyay, Facile synthesis of iron oxide nanoparticles using *Lawsonia inermis* extract and its application in decolorization of dye. *BioNanoScience* **9**, 789–798 (2019)
29. J. Vijaya, Investigation on preferably oriented abnormal growth of CdSe nanorods along (0002) plane synthesized by henna leaf extract-mediated green synthesis. *R. Soc. Open Sci.* **5**, 1–9 (2018)
30. H. Upadhyaya, S. Shome, R. Sarma, S. Tewari, M.K. Bhattacharya, S.K. Panda, Green synthesis, characterization and antibacterial activity of ZnO nanoparticles. *Am. J. Plant Sci.* **9**, 1279–1291 (2018)
31. K. Shanker, N. Jayarambabu, G.K. Mohan, S.M.N.R. Basria, M. Ramamohan, V. Gupta, A Novel Pharmacological approach of herbal mediated cerium oxide and silver nanoparticles with improved biomedical activity in comparison with *Lawsonia inermis*. *Coll. Surf. B.* **174**, 199–206 (2018)
32. K. Jhansi, N. Jayarambabu, K.P. Reddy, N.M. Reddy, Biosynthesis of MgO nanoparticles using mushroom extract : effect on peanut (*Arachis hypogaea* L.) seed germination. *3 Biotech* **7**, 1–11 (2017)
33. N. Jayarambabu, K.V. Rao, V. Rajendar, Biogenic synthesis, characterization, acute oral toxicity studies of synthesized Ag and ZnO nanoparticles using aqueous extract of *Lawsonia inermis*. *Mater. Lett.* **211**, 43–47 (2018)
34. A.G. El-Shamy, Synthesis of new magnesium peroxide (MgO₂) nano-rods for pollutant dye removal and antibacterial applications. *Mater. Chem. Phys.* **243**, 122640–122649 (2020)
35. J. Suresh, G. Pradheesh, V. Alexramani, M. Sundrarajan, S. Hong, Green synthesis and characterization of hexagonal shaped MgO nanoparticles using insulin plant (*Costus pictus* D. Don) leave extract and its antimicrobial as well as anticancer activity. *Adv. Powder Technol.* **29**, 1685–1694 (2018)
36. S. Ogunyemi, F. Zhang, Y. Abdallah, Y. Zhang, Y. Wang, G. Sun, W. Qiu, Biosynthesis and characterization of magnesiumoxide and manganese dioxide nanoparticles using *Matricaria chamomilla* L. extract and its inhibitory effect on *Acidovorax oryzae* strain RS-2, Artificial Cells. *Nanomed. Biotechnol.* **47**(2230), 2239 (2019)
37. E.R. Essien, V.N. Atasie, O.A. Okefor, D.O. Nwude, Biogenic synthesis of magnesium oxide nanoparticles using *Manihot esculenta* (Crantz) leaf extract. *Int. Nano Lett.* **10**, 43–48 (2020)
38. L. Cai, J. Chen, Z. Liu, H. Wang, H. Yang, W. Ding, Magnesium oxide nanoparticles: effective agricultural antibacterial agent against *Ralstonia solanacearum*. *Front. Microbiol.* **9**, 790–809 (2018)
39. E.R. Essien, V.N. Atasie, O.T.O.A. Okefor, T.O. Oyebanji, D.O. Nwude, Biomimetic synthesis of magnesium oxide nanoparticles using *Chromolaena odorata* (L.) leaf extract. *Chem. Pap.* **74**, 2101–2109 (2020)
40. S. Priyadarshini, M. Azizah, S. Faridah, Y. Rosiyah, A. Abdullah, A.A. Alyousef, A. Mohammed, Biosynthesis of TiO₂ nanoparticles and their superior antibacterial effect against human nosocomial bacterial pathogens. *Res. Chem. Intermed.* **46**, 1077–1089 (2020)
41. G. Karli, S. Buford, K. Mark, K.G. Akhilesh, Antimicrobial activity of metal and metal-oxide based nanoparticles. *Adv. Ther.* **9**, 1700033–1700048 (2018)
42. M.R. Bindhu, M. Umadevi, M.K. Micheal, M.V. Arasu, A. Al-Dhabi, Structural, morphological and optical properties of MgO nanoparticles for antibacterial applications. *Mater. Lett.* **166**, 19–22 (2016)
43. M.S.R. Rajoka, Antibacterial and antioxidant activity of exopolysaccharide mediated silver nanoparticle synthesized by *Lactobacillus brevis* isolated from Chinese koumiss. *Coll. Surf. B.* **186**, 110734–110746 (2020)

44. P. Raju, P.M. Kavitha, S. Rajasree, N. Suganthi, Anticancer, antimicrobial and photocatalytic activities of green synthesized magnesium oxide nanoparticles (MgONPs) using aqueous extract of sargassum wightii. *J. Photochem. Photobiol. B* **190**, 86–97 (2019)
45. P. Bhuyar, M.H. Rahim, S. Sundararaju, P.R.G. Maniam, N. Govindan, Synthesis of silver nanoparticles using marine macroalgae *Padina* sp. and its antibacterial activity towards pathogenic bacteria. *J. Basic Appl. Sci.* **9**, 1–15 (2020)
46. N.-Y. Nguyen, N. Grelling, C.L. Wetteland, R. Rosario, H. Liu, Antimicrobial activities and mechanisms of magnesium oxide nanoparticles (nmgo) against pathogenic bacteria, yeasts, and biofilms. *Sci. Rep.* **16260**, 1–24 (2018)
47. N. Pauzi, N.M. Zain, R.V. Kutty, H. Ramli, Antibacterial and antibiofilm properties of ZnO nanoparticles synthesis using gum arabic as a potential new generation antibacterial agent. *Mater. Today* (2020). <https://doi.org/10.1016/j.matpr.2020.06.359>
48. F. Ding, Z. Nie, H. Deng, L. Xiao, Y. Du, X. Shi, Antibacterial hydrogel coating by electrophoretic co-deposition of chitosan/alkynyl chitosan. *Carbohydr. Polym.* **98**, 1547–1552 (2013)
49. R. Song, J. Yan, Xu. Shasha, Y. Wang, T. Ye, J. Chang, H. Deng, Bin Li Silver ions/ovalbumin films layer-by-layer self-assembled polyacrylonitrile nanofibrous mats and their antibacterial activity. *Coll. Surf. B.* **6**, 322–328 (2013)
50. B. Janani, A. Syed, L. Raju, F.H. Al-Harathi, A.M. Thomas, A. Das, S.S. Khan, Synthesis of carbon stabilized zinc oxide nanoparticles and evaluation of its photocatalytic antibacterial and anti-biofilm activities. *J. Inorg. Organomet. Polym. Mater.* **30**, 2279–2288 (2020)
51. P. Suvaita, S. Selvam, G. Shree Chinnadurai, D. Ganesan, P. Perumal, V. Kandan, Cadmium oxide-zinc oxide nanocomposites synthesized using waste eggshell membrane and its in-vitro assessments of the antimicrobial activities and minimum inhibitory concentration. *J. Inorg. Organomet. Polym. Mater.* (2020). <https://doi.org/10.1007/s10904-020-01688-2>
52. F. Zahir Oghani, K. Tahvildaril, M. Nozari, Novel antibacterial food packaging based on chitosan loaded ZnO nanoparticles prepared by green synthesis from nettle leaf extract. *J. Inorg. Organomet. Polym. Mater.* (2020). <https://doi.org/10.1007/s10904-020-01621-7>
53. S. Pavithra, B. Mohana, M. Mani, P.E. Saranya, R. Jayavel, D. Prabu, S. Kumaresan, Bioengineered 2D ultrathin sharp-edged MgO nanosheets using *Achyranthes aspera* Leaf extract for antimicrobial applications. *J. Inorg. Organomet. Polym. Mater.* (2020). <https://doi.org/10.1007/s10904-020-01772-7>

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