STM JOURNALS

International Journal of
Advance in Molecular Engineering

Volume 3, Issue 1, 2025
January–June
DOI (Journal): 10.37591/IJAME

https://journals.stmjournals.com/ijame

Review IJAME

Eco-Friendly Synthesis of MgO Nanoparticles and Their Antibacterial Performance

Sapna Chandel[1],*

Abstract

Nanoparticles (<100 nm in size) due to their enhanced surface area and high chemical reactivity have been a boon, ranging from micro to macro level. This has increased its applicability in various fields such as Food, textile, environment, biomedicine etc. Various metal oxides have been employed in Biomedical applications for their antibacterial, antioxidant and anticancerous activities. But MgO NPs have received much attention due to their high stability, non-toxicity and low cost. Because MgO NPs produce reactive oxygen species (ROS) and zone of inhibition (ZOI), they are thought to have exceptional antibacterial action against both gram-positive and gram-negative bacteria. They can be easily synthesized by various methods such as sol gel, hydrothermal, precipitation, green synthesis, microwave assisted, micro emulsion, oxidation and sonochemical methods. Out of these, the most economical method is green synthesis of MgO NPs and is currently discussed here.

Keywords: Magnesium oxide nanoparticles, antibacterial activity, green synthesis, reactive oxygen species, biomedical applications

INDTRODUCTION

Nanotechnology is becoming the base in the field of science and research in the present time. It has evolved into several branches that touch every sphere of human life and nanoparticles behave as a milestone in this field. Nanotechnology acts as an important method in the development of a clean, non-toxic, environment-friendly procedure for the synthesis of the nanoparticle [13]. Nanoparticles range from 1- 100 nm in size, are building blocks for more complex nanostructure [12]. Nanoparticles are not new to the environment, they occur naturally in various forms such as bacteria, minerals, clays. They have been used since ancient times for various purposes like as colorant for metals, but the synthetic design is starting from last few years. In 2017, Rastogi et al. Nanoparticles have gained a lot of attention in a variety of domains, including the industrial, medicinal, and environmental sectors [32]. These days, NPs are created using a green synthetic method, where the biomolecules can function as both reducing and oxidizing agents [21]. Broad approaches available for NP synthesis are bottom-up and top- down. The top-down approach is unrestricted and steady, whereas the bottom-up involves the self- build of atomic size particles to grow nano-size particles [31]. This can be attained by physical and chemical means, green synthesis is eco-friendly, economical, and generate stable NP formation [2]. It is because of their unique properties such as small particle size, large surface area to volume ratio, they are responsible for higher chemical reactivity and results in the formation of reactive oxygen species (ROS). Nanoparticles are usually prepared by various chemical methods such as hydrothermal, precipitation, micelle, pyrolysis, and sol–gel process, etc. [18]. Among all kinds of nanoparticles, metal oxide nanoparticles are indispensable, and because of their distinctive properties, they have wide applications in different fields. These days, self-cleaning coatings, sunscreens, cosmetics, and

***Author for Correspondence**
Sapna Chandel
E-mail: sapna011998@gmail.com

[1]Student, Shoolini University of Biotechnology and Management Sciences, Solan, Himachal Pradesh, India

Received Date: December 16, 2024
Accepted Date: February 07, 2025
Published Date: February 14, 2025

Citation: Sapna Chandel. Eco-Friendly Synthesis of MgO Nanoparticles and Their Antibacterial Performance. International Journal of Advance in Molecular Engineering. 2025; 3(1): 33–41p.

fabrics all make extensive use of them. Additionally, these NPs are widely used as solar cell materials, water treatment agents, and catalytic converters for automobiles [32, 24]. The synthesis and applicability of metal nanoparticles in biomedicine will be influenced by a number of characteristics, including electrical, optical, physical, chemical, and thermal properties. While some of these qualities offer prospects for industrial and environmental applications, others are crucial for medicinal applications. Millions of cases of pathogenic diseases are caused by bacterial contamination, which continues to draw public attention. To address this issue, an efficient antibacterial agent that inhibits bacterial reproduction must be developed immediately. These days, self-cleaning coatings, sunscreens, cosmetics, and fabrics all make extensive use of them. Additionally, these NPs are widely used as solar cell materials, water treatment agents, and catalytic converters for automobiles [28, 33]. The synthesis and applicability of metal nanoparticles in biomedicine will be influenced by a number of characteristics, including electrical, optical, physical, chemical, and thermal properties. While some of these qualities offer prospects for industrial and environmental applications, others are crucial for medicinal applications. Millions of cases of pathogenic diseases are caused by bacterial contamination, which continues to draw public attention. To address this issue, an efficient antibacterial agent that inhibits bacterial reproduction must be developed immediately [14, 6]. Hence we are giving much attention to the inorganic metal oxide nanoparticles.

Among the studied inorganic metal oxides, MgO is of particular interest because of their stability under harsh conditions, and also they are regarded as safe material to human beings with strong antibacterial activity, high thermal stability, and low cost [14]. Yipping and coworkers demonstrated that MgO NPs have potent antibacterial activity against important food-borne pathogens and solve the potential mechanism of the harmful effects of MgO NPs on bacteria. Interestingly they have antimicrobial properties without photoactivation, compared with TiO_2 that requires photoactivation [41]. Magnesium can be used in various NMs in the form of MgO and $MgX_2(MgF_2)$. In addition to inducing ROS, magnesium-containing NMs can also directly inhibit essential bacterial enzymes. It was found that MgF_2 can prevent the biofilm formation of *Escherichia coli* and *Staphylococcus aureus*. MgO is an interesting basic oxide with many uses. for example, MgO with ultra-fine, nano-sized particles and high specific surface area has proven to be a destructive adsorbent for toxic chemical reagents. MgO has unique properties optoelectronic, magnetic, thermal, mechanical, and chemical properties [34, 40] MgO is chosen, because it is one of the cheapest and most easily prepared adsorbents amongst the most metal oxide nanoparticles. MgO NPs' actual antibacterial mechanism is yet unknown, however there are a number of potential processes, including the production of reactive oxygen species (ROS), nanoparticle-bacterial interaction, bacterial cell damage, and an alkaline effect [41].

Advantages

The advantages of using NPs for drug delivery is because of their two main properties 1)There small size, which can penetrate through smaller capillaries and are taken up by cells and results in maximum drug accumulation at the target site . 2) use of biodegradable material for Nps preparation allow to assist drug release within the target site over long period .nanoparticles are not only important for drug delivery there are other applications such as in electronic products, nanodiods, quantum computers and so on [20].

ANTIBACTERIAL ACTIVITY OF GREEN SYNTHESIZED MAGNESIUM OXIDE NNOPARTICLES

Green synthesized MgONPs exhibited remarkable antibacterial activity against both gram- positive and gram- negative bacterial strains. Several researchers checked the antibacterial activity of green synthesized MgONPs against different pathogenic bacterial strains as depicted in Table 1 and discussed in the following section. In a study, Umaralikhan et al. (2016) reported the antibacterial activity of green synthesized MgONPs (50-90 nm) against *E. coli* (gram-negative) and *S. aureus* (gram-positive) bacteria, which were exposed to different conc [42]. (1, 3 and 5 mg/mL) of MgONPs. The authors observed that MgONPs showed comparatively similar antibacterial activity against both the bacterial strains in conc. dependent manner. They suggested that the possible mechanism behind the antibacterial activity of MgONPs was the generation of ROS and lipid peroxidation. In 2017, Sharma et al. studied the antibacterial effect of MgONPs against different gram-positive (*S. aureus, S. epidermidis*, *B. cereus*) and gram-negative (*E. coli*, *P. vulgaris* and *K. pneumonia*) bacterial strains [36]. The authors observed a significant decrease in the growth of all the pathogenic bacterial strains with an increase in the dose of MgONPs and maximum inhibition was observed at the dose of 40 µl [38]. Further, Palanisamy et al. (2017) synthesized green and chemical based-MgONPs and investigated their antibacterial activity against *P. aerogenosa* and *B. subtilis* [29]. The authors observed an effective antibacterial effect of MgONPs (synthesized from both the methods) against both the pathogenic bacterial strains. However, the green synthesized MgONPs exhibited a more significant zone of inhibition (ZOI) against both the bacterial strains as compared to chemically synthesized MgONPs. Later, researchers also studied the antibacterial effect of biogenic MgONPs against various multi-drug resistant gram-negative (*E. coli*, *P. vulgaris, S. typhimurium*, *S. flexneri*, and *K. pneumonia*) and gram-positive (*S. aureus,* S. pneumonia and *B. cereus*) bacterial strains. From this study, it has been investigated that the biogenic MgONPs significantly inhibited the growth of both gram-negative as well as gram-positive bacterial strains, however, a maximum inhibition zone of 108± 10.53 mm was observed against *S. flexneri*. Moreover, the authors observed that 25 µg/mL of MgONPs (average of MICs) inhibited 90% of the pathogenic bacterial cells as compared with 100 mg/mL solution of ampicilin/ sulbactam that killed 40% of the same tested bacterial cells. In another study, the antibacterial activity of biogenic MgONPs synthesized from the extracellular of *Streptomyces* sp. was checked against B. thuringiensis and B. megaterium bacterial strains. The authors observed significant antibacterial activity against both the phyto-pathogenic bacterial strains in a dose-dependent manner as indicated by ZOI values which were maximum at 20 µg/mL [5]. In the same year, Das et al. prepared MgO nanoflakes (11 nm) from *B. purpurea* leaf extract and demonstrated their antibacterial activity against *S. aureus* by using different conc. of MgO nanoflakes such as 100, 250, 500, 750, and 1000 µg/mL [9]. The minimum inhibitory concentration (MIC) value of the synthesized MgO nanoflakes for showing significant antibacterial effect was found to be 250 µg/mL. Moreover, SEM analysis revealed that the interaction of MgO nanoflakes (250 µg/mL) with the bacterial cells results in damage to the bacterial cell membrane which caused leakage of intracellular components that further leads to bacterial cell death. Besides, cell viability assay demonstrated that the number of dead cells increased with a rise in the conc. of MgO nanoflakes and incubation time. Further, the authors also investigated that treatment of *S. aureus* bacterial strains with MgO nanoflakes results in the generation of ROS in a time and dose-dependent manner which also might be responsible for the significant antibacterial activity of MgO nanoflakes against *S. aureus* [9]. In another study, Vergheese et al. (2018), fabricated MgONPs using the leaf extract of *T. foenum* graecum and evaluated their antibacterial activity against three bacterial strains (*E. coli, S. aureus, and Bacillus*) [43]. The authors determined the MIC values of the as synthesized MgONPs against all the tested bacterial strains using Resazurin Microtitre Assay which were found to be 125 µg for both *E. coli* and *S. aureus* however, towards Bacillus the MIC value was 250 µg. These results demonstrated that *Bacillus* was more resistant towards green synthesized MgONPs as compared to the other two bacterial strains. Later, in 2019, Joghee et al. prepared MgONPs using Pisonia grandis leaf extract and evaluated their antibacterial activity against three gram-negative (*E. coli*, S. paratyphi, and K. pneumonia) and three gram-positive bacteria (*S. aureus, B. subtilis, M. luteus*). The susceptibility of all evaluated bacterial strains, both gram-positive and gram-negative, to biosynthesized MgONPs has been examined. Besides, among different gram-positive bacterial strains, the maximum ZOI was exhibited by *M. luteus* (20 mm) as compared to *S. aureus* (14 mm) and B. subtilis (11 mm). However, when compared various gram-negative bacterial strains *E. coli* (23 mm) showed higher ZOI as compared to *K. pneumonia* (20 mm) and S. paratyphi (15 mm). Hence, the synthesized MgONPs possessed better antibacterial activity against *E. coli* (gram-negative) and *M. luteus* (gram-positive) bacteria [15]. Abdallah et al. (2019) examined the antibacterial potential of MgO nanoflowers (MgONFs) synthesized from Rosmarinus officinalis flower extract against *X. oryzae* (Xoo strain GZ 0005) [1]. The authors compared the antibacterial activities of MgO and biosynthesized MgONFs at three different concentrations (4, 8, and 16 µg/mL) against the Xoo strain. From this study, it has been observed that MgONFs exhibited a superior inhibitory effect against the tested bacterial strain as compared to MgO in a dose-dependent manner. Moreover, the authors reported that the synthesized MgONFs significantly inhibited the growth, swimming motility, and biofilm formation of the tested phytopathogenic Xoo strain. Besides, TEM images of the tested bacterial cells treated with MgONFs (4 µg/mL) showed destruction of bacterial cell wall which further results in leakage of intracellular components that ultimately caused cell death. Hence, this might be considered as the possible mechanism towards the antibacterial activity of MgONFs against Xoo strain [1]. Narendhran et al. (2019) studied and compared the antibacterial activity of *S. trilobatum* and sodium hydroxide mediated MgONPs against *E. coli*, *B. subtilis*, and *S. pyogenes* [22]. They found that MgONPs synthesized from both the techniques showed significant inhibition against all the tested bacterial strains. However, *S. trilobatum* mediated MgONPs were found to be more effective against *E.coli* (ZOI, 16.66 ± 0.66 mm) and *B. subtilis* (ZOI, 16.00 ± 0.88 mm) at the conc. of 100 mg/mL as compared to sodium hydroxide mediated MgONPs and control (streptomycin). In the same year, Ogunyemi et al. examined the antibacterial activity of biosynthesized MgONPs against *A. oryzae* by using different conc. (4, 8 and 16 µg/mL) of MgONPs [26]. The authors observed a strong antibacterial effect against this pathogenic bacterial strain in conc. dependent manner. Moreover, treatment of *A. oryzae* strain with MgONPs results in suppression of its swimming motility and biofilm formation ability. Further, the authors found that small-sized (18.2 nm) MgONPs easily penetrated the bacterial cell membrane and damaged the cell membrane which further caused leakage of cellular contents that ultimately leads to cell death [26]. In 2020, Amina et al. synthesized magnesium oxide nanoparticles (MgONPs) from the root biomasses of two distinct plant types of *S. costus* (Qustal bahri and Qustal hindi) and evaluated their antibacterial activity against bacterial strains of *S. aureus, B. subtilis, E. coli*, and *P. aeruginosa* [4]. The authors observed that Qustal bahri mediated MgONPs exhibited significantly better inhibition against all the tested bacterial strains as compared to Qustal hindi mediated MgONPs in conc. dependent manner. Among all the tested pathogens, the highest antibacterial effect of MgONPs (Qustal bahri) was observed against *E. coli* and *P. aerguinosa* at the conc. of 35 µg/mL. Besides, SEM images demonstrated a change in the morphology of *E. coli* and *P. aerguinosa* after treatment with MgONPs (Qustal bahri). This was probably due to the penetration of NPs into the cell membrane that further causing its damage which consequently results in cell death due to leakage of intracellular contents [4]. Later, Khan et al. (2020) evaluated the antibacterial activity of green synthesized MgONPs against *E. coli* and *R. solanacearum* [17]. It has been observed that the MgONPs having lower Eg value possessed significantly higher antibacterial effect as compared to the MgONPs having higher Eg value. In addition, significant inhibition zones were observed against both the bacterial strains when treated with MgONPs in a dose-dependent manner. However, a superior antibacterial effect was observed against *E. coli* in comparison with *R. solanacearum*. The observed antibacterial effect of MgONPs might be attributed to the production of ROS and lipid peroxidation. In the same year, Siaw et al. studied and compared the antibacterial activity of light-mediated and conventional heat-mediated MgONPs against *E. coli* and *S. aureus* bacterial strains [35]. The authors used different doses of MgONPs (0.0, 0.4, 0.6, 0.8 and 1.0 mL) to check their antibacterial activity. It has been observed that the lethal dose of MgONPs synthesized from both the methods against *S. aureus* was 0.4 mL. However, for *E. coli* the lethal dose of conventional heat-mediated and light-mediated MgONPs was 0.4 and 0.6 mL, respectively. Moreover, MgONPs exhibited larger ZOI towards *S. aureus* in comparison with *E. coli*. Further, the authors observed that increase in the dose of MgONPs above the lethal dose resulted in a decrease in ZOI. This might be due to the fact that at higher doses the conc. of MgONPs increased that further caused agglomeration and increase in the size of NPs, thus making it difficult for the NPs to get penetrated into the bacterial cell membrane. The results demonstrated that MgONPs prepared from both the synthesis approaches exhibited comparatively similar antibacterial potential against both the tested bacterial strains [35]. Recently, Ahmed et al. (2021) fabricated MgONPs using *A. johnsonii* strain and tested their antibacterial activity at three different conc. (5, 10, and 20 µg/mL) against *A. oryzae* strain [3]. These biogenic MgONPs showed remarkable antibacterial potential against *A. oryzae* strain in a dose- dependent manner and maximum inhibition was observed at the conc. of 20 µg/mL. Moreover, SEM and TEM analysis revealed that treatment of *A. oryzae* cells with MgONPs (20 µg/mL) caused damage and change in the morphological structure of the cells which further results in leakage of nucleic material that consequently leads to cell death. Besides, some other researchers [10, 37, 16, 30, 19, 25, 7, 27] have also reported the significant antibacterial activity of green synthesized MgONPs against different pathogenic bacterial strains as illustrated in Table 1.

Table 1. Activity of synthesiszed nanoparticles against different bacterial strains.

S.N.	**Size (nm) / Morphology**	**Bacterial Strains**	**Dose / Concentration**	**Observation**	**References**
1	50-90 nm / Cubic	*E. coli*, *S. aureus*	1, 3, and 5 mg/mL	Significant antibacterial activity against both bacterial strains	[17]
2	<20 nm / Spherical	*S. aureus* , *S. epidermidis*, *B. cereus*, *E. coli*, *P. vulgaris*, *K. pneumonia*	10, 20, 30, and 40 µL	Effective antibacterial activity observed against all pathogenic strains	[38]
3	<10 nm / Spherical	*E. coli*, *P. aeruginosa*, *S. aureus* , *S. faecalis*	-	More effective against gram-positive bacteria compared to gram-negative bacteria	[12]
4	-	*P. aeruginosa*, *B. subtilis*	20, 40, 60, and 80 µg/µL	Naturally synthesized MgONPs showed higher ZOI compared to chemically synthesized MgONPs	[29]
5	25 nm / Spherical, Ellipsoidal	*E. coli*, *P. vulgaris*, *S. typhimurium*, *S. flexneri*, *K. pneumonia*, *S. aureus* , *S. pneumonia*, *B. cereus*	5-55 µg/µL	Strong antibacterial activity against gram-negative and gram-positive multidrug-resistant pathogens	[11]
6	25 nm / Spherical	*B. thuringiensis*, *B. megaterium*	5, 10, 15, and 20 µg/mL	Remarkable antibacterial effect against both phyto-pathogenic strains	[5]
7	10.28 nm / Round	*S. aureus* , *S. epidermidis*, *A. baumannii*, *E. coli*, *E. faecalis*, *E. cloacae*, *B. subtilis*, *K. pneumonia*, *P. aeruginosa*	250 µg/mL	Promising antibacterial activity, especially against *E. faecalis* (22 mm ZOI) and *K. pneumonia* (20 mm ZOI)	[10]
8	11 nm / Flake-shaped	*S. aureus*	100-1000 µg/mL	Potent antibacterial effect in a dose- and time-dependent manner	[9]
9	13 nm / Spherical	*E. coli*, *S. aureus* , *Bacillus*	3.9-500 µg	Superior antibacterial effect against *E. coli* and *S. aureus* compared to *Bacillus*	[8]
10	50 nm / Hexagonal	*S. aureus* , *B. subtilis*, *E. coli*, *S. paratyphi*	-	Greater inhibition against *S. paratyphi* and *B. subtilis*	[37]
11	60-80 nm / Ball-shaped	*S. aureus* , *B. subtilis*, *M. luteus*, *E. coli*, *S. paratyphi*, *K. pneumonia*	100 µg/disc	Higher activity against *M. luteus* (20 mm ZOI) and *E. coli* (23 mm ZOI)	[15]
12	23-24 nm / -	*S. aureus* , *S. mutants*, *E. coli*, *Pseudomonas sp.*	50 mg/mL (10 mg/well)	Significant antibacterial effect, with bigger ZOI observed around *SA10*	[16]
13	68.02 nm / Flower-shaped	*S. pneumonia*, *MRSA*, *E. coli*, *P. aeruginosa*, *A. baumannii*	10-30 µg/mL	Strong bactericidal activity in a dose-dependent manner	[30]
14	<20 nm / Round	*X. oryzae*	4, 8, and 16 µg/mL	Higher inhibitory effect in a concentration-dependent manner	[1]
15	29 nm / Rod-	*E. coli*, *S. typhi*, *P.*	200-500 mg/mL	Highest antibacterial	[19]

	shaped	*aeruginosa*		effect at 500 mg/mL against *E. coli* (21.75 mm ZOI), *S. typhi* (22.75 mm ZOI)	
16	30 nm / Spherical	*E. coli, B. subtilis, S. pyogenes*	25-100 mg/mL	Excellent activity against *E. coli* and *B. subtilis*	[22]
17	4-8 nm / Flower, Spherical, Flake	*S. aureus* , *E. coli, K. pneumonia, P. aeruginosa*	0.0025-25 µg/mL	Stronger effect against *S. aureus* and *K. pneumonia*	[25]
18	18.2 nm / Disc-shaped	*A. oryzae*	4, 8, and 16 µg/mL	Potent antibacterial effect causing bacterial cell death by membrane damage	[26]
19	70 nm / Rod-shaped	*E. coli, S. aureus*	10-40 µL	Significant inhibition against both strains	[7]
20	20-50 nm / Hexagonal, Spherical	*S. aureus* , *S. pneumoniae, E. coli, S. typhi*	10-100 µL	Potent activity against gram-positive and gram-negative strains	[27]
21	30-34 nm / Cubic	*S. aureus* , *B. subtilis, E. coli, P. aeruginosa*	15-35 µg/mL	Higher inhibition in dose-dependent manner	[4]
22	<50 nm / Spherical	*E. coli, R. solanacearum*	1-3 mg/mL	Excellent antibacterial potential for lower *Eg* values	[17]
23	74.6 nm / Spherical	*E. coli, S. aureus*	0.4-1.0 mL	Significant potential in light- and heat-mediated synthesis	[35]
24	18-45 nm / Spherical	*A. oryzae*	5-20 µg/mL	Substantial effect (35.2 mm ZOI) at 20 µg/mL	[3]

CONCLUSION

Nanoparticle are become the center of attraction in the field of research nowadays , because of their enhanced properties and their applications in various fields. In this review, MgO NPs are studied for different biomedical applications such as antibacterial, antifungal, and anticancer. MgO NPs' antibacterial properties exhibit a highly notable concentration-dependent inhibition. We can conclude that MgO NPs can exhibit outstanding antibacterial properties against plant infections as well as human life. Both gram-positive and gram-negative types of bacteria have been found to be significantly inhibited by MgO NPs. It was proposed that the production of reactive oxygen species (ROS), such as superoxide anion (O^{2-}), may be the cause of the antibacterial action of magnesium oxide nanoparticles, with the increase in surface area of MgO NPs leads to an increase in $o2^{-}$ concentration and thus results in more effective destruction of cell wall of the bacteria which eventually results to cell death. The advantage of MgO NPs is that they are nontoxic and relatively easy to obtain. Additionally, MgO NPs exhibit antibacterial properties against plant pathogenic bacteria, making them a viable substitute for chemical pesticides in crop protection. MgO NPs have the advantage of not been genotoxic and cytotoxic to humans, it has great potential for controlling plant diseases in future.

REFERENCES

1. Abdallah Y, Ogunyemi SO, Abdelazez A, Zhang M, Hong X, Ibrahim E, Hossain A, Fouad H, Li B, Chen J. The green synthesis of MgO nano-flowers using Rosmarinus officinalis L.(Rosemary) and the antibacterial activities against Xanthomonas oryzae pv. oryzae. BioMed research international. 2019 Oct;2019.
2. Ahmad S, Munir S, Zeb N, Ullah A, Khan B, Ali J, Bilal M, Omer M, Alamzeb M, Salman SM, Ali S. Green nanotechnology: A review on green synthesis of silver nanoparticles—An ecofriendly approach. International journal of nanomedicine. 2019;14:5087.

3. Ahmed T, Noman M, Shahid M, Shahid MS, Li B. Antibacterial potential of green magnesium oxide nanoparticles against rice pathogen Acidovorax oryzae. Materials Letters. 2021 Jan;282:128839.
4. Amina M, Al Musayeib NM, Alarfaj NA, El-Tohamy MF, Oraby HF, Al Hamoud GA, Bukhari SI, Moubayed NM. Biogenic green synthesis of MgO nanoparticles using Saussurea costus biomasses for a comprehensive detection of their antimicrobial, cytotoxicity against MCF-7 breast cancer cells and photocatalysis potentials. Plos one. 2020 Aug 14;15(8):e0237567.
5. Balraj B, Senthilkumar N, Potheher IV, Arulmozhi M. Characterization, antibacterial, anti-arthritic and in-vitro cytotoxic potentials of biosynthesized Magnesium Oxide nanomaterial. Materials Science and Engineering: B. 2018 May 1;231:121–7.
6. Beyth N, Houri-Haddad Y, Domb A, Khan W, Hazan R. Alternative antimicrobial approach: nano-antimicrobial materials. Evidence-based complementary and alternative medicine. 2015 Oct;2015.
7. Bodade AB, Wankhade AS, Kale PD, Chaudhari GN. Preparation and Characterization of Nanocrystaline Magnesium Oxide Using Datura Stramonium Leaves and Its Antibacterial Activity.
8. Camtakan Z, Erenturk S, Yusan S. Magnesium oxide nanoparticles: preparation, characterization, and uranium sorption properties. Environmental Progress & Sustainable Energy. 2012 Dec;31(4):536–43.
9. Das B, Moumita S, Ghosh S, Khan MI, Indira D, Jayabalan R, Tripathy SK, Mishra A, Balasubramanian P. Biosynthesis of magnesium oxide (MgO) nanoflakes by using leaf extract of Bauhinia purpurea and evaluation of its antibacterial property against Staphylococcus aureus. Materials Science and Engineering: C. 2018 Oct 1;91:436–44.
10. El-Sayyad GS, Mosallam FM, El-Batal AI. One-pot green synthesis of magnesium oxide nanoparticles using Penicillium chrysogenum melanin pigment and gamma rays with antimicrobial activity against multidrug-resistant microbes. Advanced Powder Technology. 2018 Nov 1;29(11):2616–25.
11. El Shafey AM. Green synthesis of metal and metal oxide nanoparticles from plant leaf extracts and their applications: A review. Green Processing and Synthesis. 2020 Jun 18;9(1):304–39.
12. Fard JK, Jafari S, Eghbal MA. A review of molecular mechanisms involved in toxicity of nanoparticles. Advanced pharmaceutical bulletin. 2015 Nov;5(4):447.
13. Honary S, Barabadi H, Gharaei-Fathabad E, Naghibi F. Green synthesis of copper oxide nanoparticles using Penicillium aurantiogriseum, Penicillium citrinum and Penicillium waksmanii. Dig J Nanomater Bios. 2012 Jul 1;7(3):999–1005.
14. He Y, Ingudam S, Reed S, Gehring A, Strobaugh TP, Irwin P. Study on the mechanism of antibacterial action of magnesium oxide nanoparticles against foodborne pathogens. Journal of nanobiotechnology. 2016 Dec;14(1):1–9.
15. Joghee S, Ganeshan P, Vincent A, Hong SI. Ecofriendly biosynthesis of zinc oxide and magnesium oxide particles from medicinal plant Pisonia grandis R. Br. leaf extract and their antimicrobial activity. BioNanoScience. 2019 Mar;9(1):141–54.
16. Kandiah K, Jeevanantham T, Ramasamy B. Reliability of antioxidant potential and in vivo compatibility with extremophilic actinobacterial-mediated magnesium oxide nanoparticle synthesis. Artificial cells, nanomedicine, and biotechnology. 2019 Dec 4;47(1):862–72.
17. Khan MI, Akhtar MN, Ashraf N, Najeeb J, Munir H, Awan TI, Tahir MB, Kabli MR. Green synthesis of magnesium oxide nanoparticles using Dalbergia sissoo extract for photocatalytic activity and antibacterial efficacy. Applied Nanoscience. 2020 Jul;10(7):2351–64.
18. Kumar PP, Bhatlu ML, Sukanya K, Karthikeyan S, Jayan N. Synthesis of magnesium oxide nanoparticle by eco friendly method (green synthesis)–A review. Materials Today: Proceedings. 2020 Oct 14.
19. Maishera HA, Kuta FA, Tijani JO, Adabara NU, Adedeji AS, Bala JD. Biosynthesis and antibacterial potential of tectona grandis mediated magnesium oxide nanorods. Journal of Bio-Science. 2019 Dec 26;27:109–20.
20. Mohanraj VJ, Chen Y. Nanoparticles-a review. Tropical journal of pharmaceutical research. 2006;5(1):561–73.

21. Muthuvinothini A, Stella S. Green synthesis of metal oxide nanoparticles and their catalytic activity for the reduction of aldehydes. Process Biochemistry. 2019 Feb 1;77:48–56.
22. Narendhran S, Manikandan M, Shakila PB. Antibacterial, antioxidant properties of Solanum trilobatum and sodium hydroxide-mediated magnesium oxide nanoparticles: a green chemistry approach. Bulletin of Materials Science. 2019 Jun;42(3):1–8.
23. Nguyen NH, Padil VV, Slaveykova VI, Černík M, Ševců A. Green synthesis of metal and metal oxide nanoparticles and their effect on the unicellular alga Chlamydomonas reinhardtii. Nanoscale research letters. 2018 Dec;13(1):1–3.
24. Nguyen NY, Grelling N, Wetteland CL, Rosario R, Liu H. Antimicrobial activities and mechanisms of magnesium oxide nanoparticles (nMgO) against pathogenic bacteria, yeasts, and biofilms. Scientific reports. 2018 Nov 2;8(1):1–23.
25. Nijalingappa TB, Veeraiah MK, Basavaraj RB, Darshan GP, Sharma SC, Nagabhushana H. Antimicrobial properties of green synthesis of MgO micro architectures via Limonia acidissima fruit extract. Biocatalysis and Agricultural Biotechnology. 2019 Mar 1;18:100991.
26. Ogunyemi SO, Zhang F, Abdallah Y, Zhang M, Wang Y, Sun G, Qiu W, Li B. Biosynthesis and characterization of magnesium oxide and manganese dioxide nanoparticles using Matricaria chamomilla L. extract and its inhibitory effect on Acidovorax oryzae strain RS-2. Artificial cells, nanomedicine, and biotechnology. 2019 Dec 4;47(1):2230–9.
27. Prasanth R, Kumar SD, Jayalakshmi A, Singaravelu G, Govindaraju K, Kumar VG. Green synthesis of magnesium oxide nanoparticles and their antibacterial activity.
28. Parveen K, Banse V, Ledwani L. Green synthesis of nanoparticles: their advantages and disadvantages. InAIP conference proceedings 2016 Apr 13 (Vol. 1724, No. 1, p. 020048). AIP Publishing LLC.
29. Palanisamy G, Pazhanivel T. Green synthesis of MgO nanoparticles for antibacterial activity. International research journal of engineering and technology. 2017 Aug 4;4(9):137–41.
30. Pugazhendhi A, Prabhu R, Muruganantham K, Shanmuganathan R, Natarajan S. Anticancer, antimicrobial and photocatalytic activities of green synthesized magnesium oxide nanoparticles (MgONPs) using aqueous extract of Sargassum wightii. Journal of Photochemistry and Photobiology B: Biology. 2019 Jan 1;190:86–97.
31. Pillai AM, Sivasankarapillai VS, Rahdar A, Joseph J, Sadeghfar F, Rajesh K, Kyzas GZ. Green synthesis and characterization of zinc oxide nanoparticles with antibacterial and antifungal activity. Journal of Molecular Structure. 2020 Jul 5;1211:128107.
32. Rastogi A, Zivcak M, Sytar O, Kalaji HM, He X, Mbarki S, Brestic M. Impact of metal and metal oxide nanoparticles on plant: a critical review. Frontiers in chemistry. 2017 Oct 12;5:78.
33. Rao KG, Ashok CH, Rao KV, Chakra CS, Rajendar V. Synthesis of TiO2 nanoparticles from orange fruit waste. Synthesis. 2015;2(1):1.
34. Sánchez-López E, Gomes D, Esteruelas G, Bonilla L, Lopez-Machado AL, Galindo R, Cano A, Espina M, Ettcheto M, Camins A, Silva AM. Metal-based nanoparticles as antimicrobial agents: an overview. Nanomaterials. 2020 Feb;10(2):292.
35. Siaw YM, Jeevanandam J, Hii YS, San Chan Y. Photo-irradiation coupled biosynthesis of magnesium oxide nanoparticles for antibacterial application. Naunyn-Schmiedeberg's archives of pharmacology. 2020 Dec;393(12):2253–64.
36. Sharma G, Soni R, Jasuja ND. Phytoassisted synthesis of magnesium oxide nanoparticles with Swertia chirayaita. Journal of Taibah University for Science. 2017 May 1;11(3):471–7.
37. Suresh J, Pradheesh G, Alexramani V, Sundrarajan M, Hong SI. 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. Advanced Powder Technology. 2018 Jul 1;29(7):1685–9.
38. Sharma G, Soni R, Jasuja ND. Phytoassisted synthesis of magnesium oxide nanoparticles with Swertia chirayaita. Journal of Taibah University for Science. 2017 May 1;11(3):471–7.
39. Sharma A, Singh S. Green synthesis of magnesium oxide nanoparticles and their antibacterial properties. Materials Today: Proceedings. 2020 Aug 28.

40. Sundararajan V, Rajendra D, Shanmugam C, Manoharan S, Sathish M. Green synthesis of magnesium oxide nanoparticles from an edible plant (Moringa oleifera) and their antibacterial activity. Journal of Environmental Chemical Engineering. 2016 Mar 1;4(1):1180–4.
41. Tang ZX, Lv BF. MgO nanoparticles as antibacterial agent: preparation and activity. Brazilian Journal of Chemical Engineering. 2014 Sep;31(3):591–601.
42. Umaralikhan L, Jaffar MJ. Green synthesis of MgO nanoparticles and it antibacterial activity. Iranian Journal of Science and Technology, Transactions A: Science. 2018 Jun;42(2):477– 85.
43. Vergheese M, Vishal SK. Green synthesis of magnesium oxide nanoparticles using Trigonella foenum-graecum leaf extract and its antibacterial activity. J Pharmacogn Phytochem. 2018;7(3):1193–200