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Research Article



Sustainable MgO Nanoparticle Synthesis for Photocatalytic Applications in Dye Degradation

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Abstract

The dye degradation is a crucial area of concern for environmental research due to the extensive use of synthetic dyes in industries such as textiles and cosmetics. Dyes often exhibit high stability and resistance to conventional wastewater treatment. The harmful dyes block sunlight, disrupt photosynthesis, and deplete oxygen, thereby causing harmful effects on both human and aquatic organisms. Photocatalytic degradation driven by reactive oxygen species offers a sustainable solution by converting dyes into non-toxic by-products. In the present study, the synthesis of MgO nanoparticles using a Hog Plum leaf extract was carried out. The bio-synthesised nanoparticles were characterised using UV-Visible spectroscopy, Fourier Transform Infrared spectrophotometer, X-ray diffractometer, Scanning Electron Microscope and Energy Dispersive X-ray. The synthesised MgO nanoparticles were confirmed by UV-Visible spectroscopy. The nanoparticles exhibited good photocatalytic degradation, which was enhanced with the nanoparticles loading. The nanoparticles with 100mg loading showed 60% degradation. The degradation efficiency reduced with the increase in concentration of dye, and the optimum pH for maximum degradation efficiency was observed to be 12.

Keywords: MgO nanoparticles, Dye degradation, green synthesis, Hog plum,

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1. Introduction

Organic dyes are widely used in the textile industries, which are carcinogenic and non-biodegradable. The recent developments in the textile industries are associated with environmental contamination, mainly caused by effluents released into aquatic bodies. Nearly 12% of the discarded waste comprises textile dyes, which are toxic and, when released

into water bodies, will increase the chemical oxygen demand, leading to a toxic environment for aquatic organisms and humans [1-4]. To overcome these environmental issues removal of toxic dyes is important. Methods like osmosis, adsorption, and photocatalytic degradation are employed in the removal of harmful dyes from aquatic bodies [5,6]. Heterogeneous photocatalysis is an advanced method used in the decolourisation of dye into nontoxic byproducts like water and carbon dioxide [7-9]. Methylene Blue is an organic cationic dye used in major textile industries. It causes harmful effects like nausea, vomiting, irritation, anaemia, etc, in humans [10].

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Nanoparticles are frequently employed in the removal of dye.

Researchers are driven towards the approach of green synthesis for the synthesis of nanoparticles. Green synthesis is a broadly used method as an alternative to chemical synthesis of nanoparticles, as it is non-toxic, safe, clean, and eco-friendly. Leaves, fruits, bark, roots, stem, and some parts of plants are utilised in the synthesis of metal oxides [11-12]. Many biosynthetic metal oxides, like MgO, NiO, CaO, CoO, CeO₂, and ZnO, are employed in the degradation of dye. [11,13-14].

Magnesium oxide nanoparticles (MgO-NPs) are a type of adsorbent that is cheap, safe, and eco-friendly. They have high porosity, a larger crystalline size associated with a larger surface area, which makes them suitable for various applications. MgO nanoparticles have been synthesised using a variety of physical and processes [15,16]. Numerous chemical synthetic methods like the wet chemical method [17], sol-gel method [18], and precipitation method [19] have been reported for the synthesis of MgO nanoparticles. Likewise, many biogenic methods have also been reported. Magnesium Oxide nanoparticles were synthesised using Musa acuminata Cavendish (banana leaf) [1], Syzygium cumini fruit, Citrullus lanatus fruit, and aloe vera leaves were utilised as a fuel in the synthesis of pure MgO nanoparticles, which were further utilised in the degradation of direct green dye [3]. MgO nanoparticles was synthesized by fungal method by harnessing the metabolites which were secreted by Aspergillus niger strain F1 and was used in the degradation of real textile wastewater [20].

The present study reports the biosynthesis of pure MgO nanoparticles by Hog Plum leaf extract. The synthesised magnesium oxide nanoparticles were characterised by several analytical techniques like UV-Visible, XRD, FT-IR, SEM and EDX. Furthermore, the MgO nanoparticles were employed in the degradation of methylene blue dye.

2. Materials and Methods 2.1. Sample Collection

For the present research work, the reagents and chemicals used were of analytical grade.

The magnesium nitrate hexahydrate Mg (NO₃)₂.6H₂O and methylene blue dye were purchased from Sigma-Aldrich Chemical Pvt. Ltd. and used as received without any further purification. Hog plum leaves were collected from Mysore, Karnataka state, India.

2.2. Preparation of Hog Plum Leaf Extract

Fresh Hog plum leaves were collected, washed several times and dried in sunlight. The dried leaves were finely powdered mechanically using a motor and pestle. 5g of powdered leaves were weighed and mixed with 100ml distilled water, stirred for an hour at 80 °C, cooled to room temperature and filtered. The collected extract was stored for further synthesis.

2.3. Synthesis of MgO Nanoparticles (MgO NPs)

MgO nanoparticles were successfully synthesised by the biogenic method. 1mg of MgNO₃.6H₂O was weighed and dissolved in 90ml distilled water. To this, 10ml of Hog plum leaf extract was added and stirred for 30 minutes. Further, the mixture was heated on a hot plate for 90 minutes at 80 °C. The obtained MgO nanoparticles were filtered, dried in an oven at 60 °C and later calcinated for an hour at 500 °C.

2.4. Characterization

The bio-synthesised MgO nanoparticles were spectroscopic characterised by several methods, including scanning electron microscopy, Fourier-transform infrared spectroscopy, X-ray diffraction, and a UVvisible spectrophotometer. The structural analysis was carried out using a Bruker D8 Advance X-ray diffractometer using Cu Ka radiation ($\lambda = 1.5418$). The surface and elemental analysis were carried out by SEM and EDAX. An FTIR spectrophotometer (Shimadzu 8400S) was used to analyse functional groups in the wavelength range of 400-4000 nm. The optical properties were determined by UV Shimadzu 1900 [21].

2.5. Photocatalytic Degradation

The biosynthesised MgO nanoparticles catalyst was used in the photochemical degradation of methylene blue dye. A known amount of MgO nanoparticles was taken in 20 ml of aqueous

solution of methylene blue, stirred continuously under UV light (40 W) until decolourisation of methylene blue took place. The supernatant was examined using a UV spectrophotometer at regular intervals of time. The degradation efficiency of methylene blue was calculated using Equation 1:

% efficiency
$$(\eta) = \frac{c_0 - c}{c_0} \times 100$$
 ... (1)

Where ' C_0 ' and 'C' are the initial and final concentrations of methylene blue [22].

3. Results and Discussion

3.1. UV-Visible Analysis

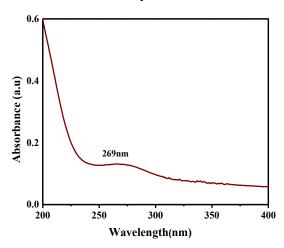


Fig. 1: UV-visible spectrum of synthesised MgO nanoparticle

The bio-synthesised MgO nanoparticles formation was confirmed by using a UV-Visible spectroscopy as shown in Fig. 1 The strong absorption peak was observed at 269 nm, attributed to the formation of MgO nanoparticles [23, 24].

The Tauc's plot of $(\alpha hv)2 \text{ v/s}$ photon energy (E, eV) gives the energy gap of the MgO nanoparticles, where α is absorbance and h is Planck's constant, v is the velocity of light. From Tauc's plot as shown in Fig. 2, the band gap of biosynthesised MgO nanoparticles was found to be 4 eV.

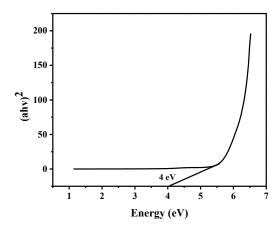


Fig. 2: Tauc's Plot of synthesised MgO nanoparticle.

3.2. X-Ray Diffraction Analysis

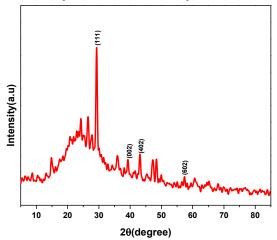


Fig. 3: XRD spectra of synthesised MgO nanoparticles.

The crystalline size of the synthesised MgO nanoparticles was investigated by XRD analysis [25]. Fig. 3 depicts the XRD spectrum MgO nanoparticles. The corresponding to 2θ values 29.1°, 39.4°, 43.4°, 57 with crystal planes of (111), (002), (402), (602) respectively are due to nanoparticles [26,27]. The synthesised MgO nanoparticles were found to have a crystalline nature and a cubic structure based on the XRD pattern [28]. The average crystalline size is calculated using the Debye-Scherrer equation as shown in Eq.2:

$$D = \left(\frac{k\lambda}{\beta \cos \theta}\right)^{-1} \qquad \dots (2)$$

Here, D is the crystallite size (nm), k is the Scherrer constant whose value is 0.9, λ is the wavelength of the X-ray used (=0.1546 nm), β is the full-width at half-maximum (FWHM) of the diffraction peak (in radians), and θ is the Bragg angle (in degrees) [29, 30].

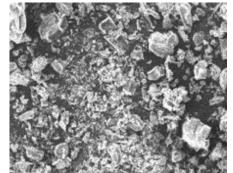
Additional parameters like micro-strain and dislocation constant are calculated using equations 3 and 4, respectively.

$$\varepsilon = \frac{\beta \cos \theta}{4} \qquad \dots (3)$$

$$\delta = \frac{1}{D^2} \qquad \dots (4)$$

The calculated values of biosynthesised MgO nanoparticles are given in Table 1.

Table 1: Calculated Data



Crystallite Size (nm)	Micro strain (ε)	Dislocation constant (δ)
12.68	0.0234	1.469

3.3. Fourier Transform Infrared Analysis

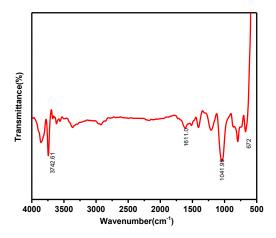


Fig. 4: FTIR spectrum of synthesised MgO nanoparticles.

The spectral behaviour of the bio-synthesized MgO nanoparticles were analysed using FT-IR spectroscopy as shown in Fig. 4 From the FTIR spectrum, the absorption peak obtained at 3748.61 cm⁻¹, 1611.0 cm⁻¹, and 1041.99 cm⁻¹ corresponds to O-H, C=O and C=C stretching confirming the presence of biomolecules on the surface of the nanoparticles, which acts as capping agent to prevent the agglomeration of

nanoparticles. The absorption peaks appeared at 672 nm due to Mg-O stretching vibrations. Thus, the FTIR spectrum of confirms the formation of the MgO nanoparticles successfully [22, 31-33].

3.4. SEM and EDX Spectra

SEM was employed in the analysis of the surface morphology of the synthesised Magnesium oxide nanoparticles. SEM images of MgO nanoparticles are depicted in Fig.5 [34]. From SEM image confirms that the MgO nanoparticles have an irregular shape. EDAX analysis was used to analyse the elemental composition of MgO nanoparticles, indicating the purity of MgO nanoparticles mediated by plants [35]. Furthermore, the EDX profile contains Mg and O. The characteristic peaks confirm the purity of magnesium oxide nanoparticles [36,37].

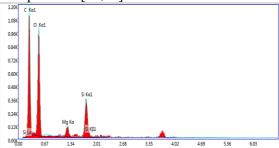


Fig. 5: SEM and EDX spectra of synthesised MgO nanoparticles.

4. Photocatalytic dye Degradation Studies

Methylene blue is an organic dye that exhibits blue colour in its oxidised form and remains colourless in its reduced form. Bio-synthesised MgO nanoparticles are employed in the oxidation of blue colored Methylene Blue. On oxidation, the blue colour of MB dyes fades away by splitting up into simpler molecules like carbon dioxide and water molecules. The synthesised MgO nanoparticle will provide an active site for the degradation of dye. The species responsible for the degradation are OH radical and protons. The UV irradiation time was about 90 minutes with a time interval of 15 minutes. The efficiency of degradation is calculated using equation 1 [38-40].

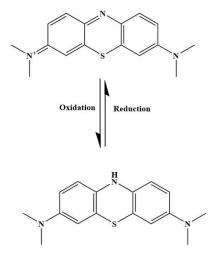


Fig 6: Oxidized and reduced form of methylene blue dye

4.1. Effect of Concentration of Photocatalyst

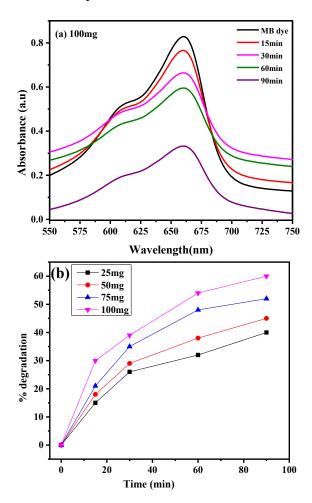


Fig. 7: Photocatalytic dye degradation of MB dye a) 100mg b) variable amounts of photocatalyst

The photocatalytic degradation of Methylene blue was carried out varying the amount of photocatalysts. As the amount of photocatalyst load increases, the degradation efficiency increases as the adsorption sites on nanoparticles increase [22]. The amount of photocatalyst was varied from 25–100mg. The bio-synthesised MgO nanoparticles have a degradation efficiency of 60% with 100 mg loading. The UV spectrum of photocatalytic dye degradation of methylene Blue with maximum loading of biosynthesised MgO nanoparticles, the variation in the amount of photocatalyst is represented in Fig. 7.

4.2. Effect of Concentration of dye

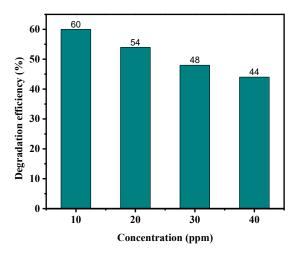


Fig. 8: Degradation efficiency of variable concentration of dye

The degradation efficiency also depends on the concentration of dye. The effect of concentration of dye was measured from 10-40 ppm as shown in Fig. 8 The highest degradation efficiency was observed with the lower concentration of 10ppm. As the concentration of dye increases to 40 ppm, the degradation efficiency drops by 16%. This may be because of the blocking of active sites on the photocatalyst by dye molecules, delaying the rate of breakdown [41-43].

4.3. Effect of pH

pH plays a vital role in the degradation of dye. The charge on MgO nanoparticles photocatalyst will vary with the change in pH. Methylene blue dye is a cationic dye that tends to absorb negative species. The photocatalyst is effective in the presence of OH radical, thus indicating that the efficiency of degradation is higher at basic pH. The surface of the

photocatalyst is free to attract the positive species, which are only cationic dyes in the basic pH range. The optimum pH for the degradation of methylene blue dye is 12, as shown in Fig. 9 [7,23,44].

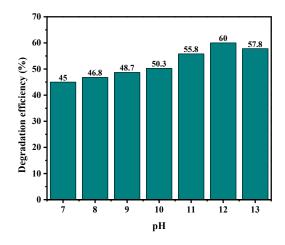


Fig. 9: Degradation efficiency of Methylene blue with variable pH

4.5. Reusability and Scavenger Studies

The bio-synthesised MgO nanoparticle retains its stability up to 4 consecutive cycles. The degradation efficiency was reduced during the fifth cycle, as shown in Fig. 10 (a). From Fig. 10(b), it is observed that the degradation efficiency is reduced in the presence of radical The radical scavengers like scavengers. oxalate ammonium and t-butanol involved, which showed varying amounts of reduced degradation efficiency. The major reduction was observed in the presence of tbutanol, which is a hydroxyl radical scavenger. Thus, it can be concluded that the major degradation is facilitated by hydroxyl radical [16,45,46].

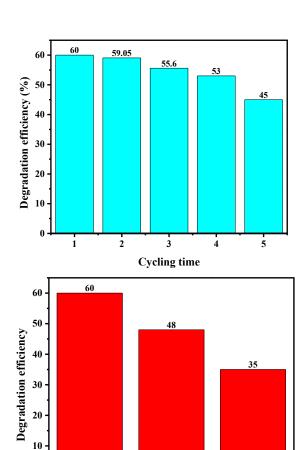


Fig. 10 (a): Reusability of MgO nanoparticles and (b) Degradation efficiency of methylene blue using different scavengers

No Scavenger

Ammonium oxalate

Type of Scavneger

t-butanol

4.6. Mechanism of dye Degradation and Kinetics

The MgO photocatalyst present in the aqueous solution of methylene blue dye will adhere the dye molecules which induce the electronic transition from HOMO to LUMO. When exposed to UV light, the electronic transition gives rise to electron holes and an equal number of free electrons. The excited electron of biosynthesised MgO nanoparticles transferred from the valence band to the conduction band of MgO nanoparticles. The electron holes generated will react with water to release hydrogen protons and Hydroxyl radicals, the important species responsible for the decolourisation of methylene blue dye [7, 47]. From Fig.11, it is evident that as the exposure time increases, the intensity of the absorbance peak decreases, enhanced degradation efficiency. Kinetic studies have been conducted to study the photocatalytic activity of bio-synthesised MgO nanoparticles. Fig.11 shows the first-order kinetics evaluated in the time range of 15 – 90 min with 100mg of MgO nanoparticles and 10ppm of Methylene Blue dye. The rate constant was found to be 0.0103 min⁻¹ and has the corresponding correlation coefficient (R²) of 0.840.

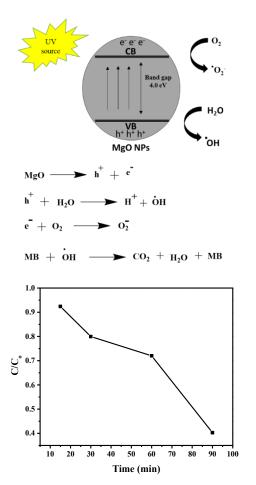
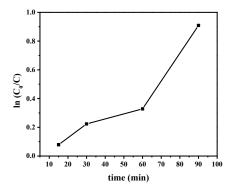


Fig. 11 (a): C/C_0 vs irradiation time curves and (b) Natural logarithm C_0/C vs irradiation time



5. Conclusion

The MgO nanoparticles were synthesized by employing the green synthesis method by using Hog-Plum leaf extract. The formation of MgO nanoparticles was confirmed by UV-Visible spectroscopy. The functional group analysis was carried out by FT-IR. The crystal size, dislocation constant and micro strain were calculated using XRD Analysis. The shape and elemental composition were confirmed by employing SEM and EDAX. The biosynthesised MgO nanoparticles were employed as a photocatalyst in the degradation of methylene blue dye. From the photocatalytic degradation data, it was observed that the degradation efficiency increased with the nanoparticles concentration, and decreased with dye concentration. At an optimum pH of 12, the MgO nanoparticles showed the highest degradation efficiency towards methylene blue dye. The scavenger study reveals that the degradation is mainly due to the presence of hydroxyl radicals. The reusable stability of MgO nanoparticles was seen up to 4 consecutive cycles. It is also evident that the degradation of methylene blue dye using the bio-synthesised MgO follows first-order kinetics.

References

- Munjal S, Singh A, Kumar V. Synthesis and characterization of MgO nanoparticles by orange fruit waste through green method. *Int J Adv Res Comput Sci.* 2017;4(9):36-42. http://dx.doi.org/10.20431/2349-0403.0409005
- Fernandes M, Singh KR, Sarkar T, Singh P, Singh RP. Recent applications of magnesium oxide (MgO) nanoparticles in various domains. Adv Mater Lett. 2020;11(8):1-10. doi:10.5185/amlett.2020.081543
- 3. Ealia SAM, Saravanakumar MP. A review on the classification, characterisation, synthesis of nanoparticles and their application. *IOP Conf Ser Mater Sci Eng.* 2017;263(3):032019. doi:10.1088/1757-899X/263/3/032019
- 4. Cho EJ, Holback H, Liu KC, Abouelmagd SA, Park J, Yeo Y. Nanoparticle characterization: state of the art, challenges, and emerging technologies. *Mol Pharm.* 2013;10(6):2093-2110. https://doi.org/10.1021/mp300697h
- Allahveran S, Mehrizad A. Polyaniline/ZnS nanocomposite as a novel photocatalyst for removal of Rhodamine 6G from aqueous

- media: Optimization of influential parameters by response surface methodology and kinetic modeling. J Mol Liq. 2017;225:339-346. https://doi.org/10.1016/j.molliq.2016.11.051
- Abdalla AM, Ali AM, Al-Jarallah Characterization and radiation detection application of ZnS (Ag) nanoparticles. Phys B 2018;550:235-243. Condens Matter. https://doi.org/10.1016/j.physb.2018.09.024
- 7. Ashraf M, Iqbal T, Masood A, Masood N, Abdella FI, El-Sofany WI, et al. Experimental and theoretical verification of WO3-based nanocomposites for their application as efficient photocatalyst for treatment of industrial wastewater. J Inorg Organomet Polym Mater. 2023;33(8):2537-2551.
 - https://doi.org/10.1007/s10904-023-02705-w
- 8. Khan KS, Khan I. Nanoparticles: Properties, applications and toxicities. Arab J Chem. 2017;12(7):908-931. https://doi.org/10.1016/j.arabjc.2017.05.011
- 9. Alfryyan N, Boukhris I, Parveen S, Albarkaty KS, Alrowaili ZA, Al-Buriahi MS, et al. Iron and vanadium co-doped WO3 nanomaterial and their composites for wastewater applications. Results Phys. 2023;55:107142. https://doi.org/10.1016/j.rinp.2023.107142
- 10. Khan I, Saeed K, Zekker I, Zhang B, Hendi AH, Ahmad A, et al. Review on methylene blue: Its properties, uses, toxicity and photodegradation. Water. 2022:14(2):242. https://doi.org/10.3390/w14020242
- 11. 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;9(1):141-154.
 - https://doi.org/10.1007/s12668-018-0573-9
- 12. 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. Biocatal Agric 2019;18:100991. Biotechnol. https://doi.org/10.1016/j.bcab.2019.01.029
- 13. Manzoor S, Yasmin G, Raza N, Fernandez J, Atiq R, Chohan S, et al. Synthesis of polyaniline coated magnesium and cobalt oxide nanoparticles through eco-friendly approach and their application as antifungal agents. 2021;13(16):2669. https://doi.org/10.3390/polym13162669
- 14. Jadoun S, Arif R, Jangid NK, Meena RK. Green synthesis of nanoparticles using plant extracts: A review. Environ Chem Lett. 2021;19(1):355-374. https://doi.org/10.1007/s10311-020-01074-x
- 15. Fouda A, Hassan SED, Saied E, Hamza MF. Photocatalytic degradation of real textile and

- tannery effluent using biosynthesized magnesium oxide nanoparticles (MgO-NPs), heavy metal adsorption, phytotoxicity, and antimicrobial activity. J Environ Chem Eng. 2021;9(4):105346. https://doi.org/10.1016/j.jece.2021.105346
- 16. Panda BS, Ahemad MA, Mishra LN. Green synthesized nanoparticles & an approach towards antibacterial & antimicrobial activities: A review. Int J ChemTech Res. 2021;14(1):16
 - http://dx.doi.org/10.20902/IJCTR.2021.14010
- 17. Singh RP, Shukla VK, Yadav RS, Sharma PK, Singh PK, Pandey AC. Biological approach of zinc oxide nanoparticles formation and its characterization. AdvMater 2011;2(4):313-317.
- 18. Shukla VK, Singh RP, Pandey AC. Black pepper synthesis assisted biomimetic of silver nanoparticles. Alloys Compd. 2010;507(1):L13-L16. https://doi.org/10.1016/j.jallcom.2010.07.156
- 19. Fedorov PP, Tkachenko EA, Kuznetsov SV, Voronov VV, Lavrishchev SV. Preparation of MgO nanoparticles. Inorg Mater. 2007;43:502
 - https://doi.org/10.1134/S0020168507050111
- 20. Rotti RB, Sunitha DV, Manjunath R, Roy A, Mayegowda SB, Gnanaprakash AP, et al. Green synthesis of MgO nanoparticles and its antibacterial properties. Front Chem. 2023;11:1143614.
 - https://doi.org/10.3389/fchem.2023.1143614
- 21. Shubhada HC, Rajeshwari KM, Bindya S, Hemavathi AB, Veena MG, Supreetha M, et al. PVA/PEG/PANI@WO3 Flexible polymer nanocomposite film for EMI shielding studies. J Inorg Organomet Polym Mater. 2025:1-14. https://doi.org/10.1007/s10904-025-03597-8
- 22. Rajeshwari KM, Suhasini MR, Bindya S, Hemavathi AB, Ali N, Amachawadi RG, et al. Photocatalytic efficacy of magnesium oxide nanoparticles in dye degradation: A sustainable one-pot synthesis utilizing Syzygium samarangense L. extract. Results Chem. 2023;6:101193.
 - https://doi.org/10.1016/j.rechem.2023.101193
- 23. Rahmani-Nezhad S, Dianat S, Saeedi M, Hadjiakhoondi A. Synthesis, characterization and catalytic activity of plant-mediated MgO nanoparticles using Mucuna pruriens L. seed extract and their biological evaluation. J Nanoanal. 2017;500(1):0. (Note: Page number seems incorrect or placeholder; please verify.)
- 24. Umaralikhan L, Jamal Mohamed Jaffar M. Green synthesis of MgO nanoparticles and its antibacterial activity. Iran J Sci Technol Trans A 2018;42:477-485. https://doi.org/10.1007/s40995-016-0041-8

- 25. Khan AU, Khan M, Khan AA, Parveen A, Ansari S, Alam M. Effect of phyto-assisted synthesis of magnesium oxide nanoparticles (MgO-NPs) on bacteria and the root-knot nematode. *Bioinorg Chem Appl.* 2022;2022(1):3973841. https://doi.org/10.1155/2022/3973841
- 26. Khan MI, Akhtar MN, Ashraf N, Najeeb J, Munir H, Awan TI, et al. Green synthesis of magnesium oxide nanoparticles using *Dalbergia sissoo* extract for photocatalytic activity and antibacterial efficacy. *Appl Nanosci*. 2020;10:2351-2364. https://doi.org/10.1007/s13204-020-01414-x
- 27. Amina M, Al Musayeib NM, Alarfaj NA, El-Tohamy MF, Oraby HF, Al Hamoud GA, et al. 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;15(8):e0237567. https://doi.org/10.1371/journal.pone.0237567
- 28. Dobrucka R. Synthesis of MgO nanoparticles using *Artemisia abrotanum* herba extract and their antioxidant and photocatalytic properties. *Iran J Sci Technol Trans A Sci*. 2018;42:547-555. https://doi.org/10.1007/s40995-016-0076-x
- 29. 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):1193-1200.
- 30. Verma S, Rao BT, Jayabalan J, Rai SK, Phase DM, Srivastava AK, et al. Studies on growth of Au cube-ZnO core-shell nanoparticles for photocatalytic degradation of methylene blue and methyl orange dyes in aqueous media and in presence of different scavengers. *J Environ Chem Eng.* 2019;7(4):103209. https://doi.org/10.1016/j.jece.2019.103209
- 31. Palanisamy G, Pazhanivel T. Green synthesis of MgO nanoparticles for antibacterial activity. *Int Res J Eng Technol*. 2017;4(9):137-141.
- 32. Esmaeili H, Foroutan R, Jafari D, Rezaei MA. Effect of interfering ions on phosphate removal from aqueous media using magnesium oxide@ferric molybdate nanocomposite. *Korean J Chem Eng.* 2020;37(5):804-814. https://doi.org/10.1007/s11814-020-0493-6
- 33. Arasu MV, Arokiyaraj S, Viayaraghavan P, Kumar TSJ, Duraipandiyan V, Al-Dhabi NA, et al. One step green synthesis of larvicidal, and azo dye degrading antibacterial nanoparticles by response surface methodology. *J Photochem Photobiol B*. 2019;190:154-162. https://doi.org/10.1016/j.jphotobiol.2018.11.020
- 34. Fatiqin A, Amrulloh H, Simanjuntak W. Green synthesis of MgO nanoparticles using *Moringa oleifera* leaf aqueous extract for antibacterial

- activity. *Bull Chem Soc Ethiop*. 2021;35(1):161-170. https://doi.org/10.4314/bcse.v35i1.14
- 35. Vijayakumar S, Punitha VN, Parameswari N. Phytonanosynthesis of MgO nanoparticles: green synthesis, characterization and antimicrobial evaluation. *Arab J Sci Eng.* 2022;47(6):6729-6734. https://doi.org/10.1007/s13369-021-06107-3
- 36. Hassan SED, Fouda A, Saied E, Farag MM, Eid AM, Barghoth MG, et al. *Rhizopus oryzae*-mediated green synthesis of magnesium oxide nanoparticles (MgO-NPs): A promising tool for antimicrobial, mosquitocidal action, and tanning effluent treatment. *J Fungi*. 2021;7(5):372. https://doi.org/10.3390/jof7050372
- 37. Kumar D, Yadav LR, Lingaraju K, Manjunath K, Suresh D, Prasad D, et al. Combustion synthesis of MgO nanoparticles using plant extract: structural characterization and photoluminescence studies. *AIP Conf Proc.* 2015;1665(1):050145. https://doi.org/10.1063/1.4917786
 - 38. Khan I, Saeed K, Zekker I, Zhang B, Hendi AH, Ahmad A, et al. Review on methylene blue: its properties, uses, toxicity and photodegradation. *Water*. 2022;14(2):242. https://doi.org/10.3390/w14020242
 - 39. Adeleke JT, Theivasanthi T, Thiruppathi M, Swaminathan M, Akomolafe T, Alabi AB. Photocatalytic degradation of methylene blue by ZnO/NiFe₂O₄ nanoparticles. *Appl Surf Sci.* 2018;455:195-200.
 - https://doi.org/10.1016/j.apsusc.2018.05.184
- 40. Ravichandran K, Mohan R, Sakthivel B, Varadharajaperumal S, Devendran P, Alagesan T, et al. Enhancing the photocatalytic efficiency of sprayed ZnO thin films through double doping (Sn+F) and annealing under different ambiences. *Appl Surf Sci.* 2014;321:310-317. https://doi.org/10.1016/j.apsusc.2014.10.023
- 41. Xu C, Rangaiah GP, Zhao XS. Photocatalytic degradation of methylene blue by titanium dioxide: experimental and modeling study. *Ind Eng Chem Res.* 2014;53(38):14641-14649. https://doi.org/10.1021/ie502367x
- 42. Chowdhury PR, Bhattacharyya KG. Retracted Article: Ni/Ti layered double hydroxide: synthesis, characterization and application as a photocatalyst for visible light degradation of aqueous methylene blue. *Dalton Trans*. 2015;44(15):6809-6824. https://doi.org/10.1039/C5DT00257E
- 43. Abdellah MH, Nosier SA, El-Shazly AH, Mubarak AA. Photocatalytic decolorization of methylene blue using TiO₂/UV system enhanced by air sparging. *Alex Eng J.* 2018;57(4):3727-3735. https://doi.org/10.1016/j.aej.2018.07.018

- 44. Singh RK, Behera SS, Singh KR, Mishra S, Panigrahi B, Sahoo TR, et al. Biosynthesized gold nanoparticles as photocatalysts for selective degradation of cationic dye and their antimicrobial activity. *J Photochem Photobiol A Chem.* 2020;400:112704. https://doi.org/10.1016/j.jphotochem.2020.112704
- 45. Rahmani-Nezhad S, Dianat S, Saeedi M, Hadjiakhoondi A. Synthesis, characterization and catalytic activity of plant-mediated MgO nanoparticles using *Mucuna pruriens* L. seed extract and their biological evaluation. *J Nanoanal*. 2017;500(1):0.
- 46. Qiu M, Sun P, Shen L, Wang K, Song S, Yu X, et al. WO₃ nanoflowers with excellent pseudocapacitive performance and the capacitance contribution analysis. *J Mater Chem A*. 2016;4(19):7266-7273. https://doi.org/10.1039/C6TA00237D
- 47. Roshdy AA, Mady AH, Khalil MM, Abo-EL-Enein SA, Elfadly AM, Lee YI, et al. Novel polyaniline/tungsten trioxide@ metal-organic framework nanocomposites for enhancing photodegradation of 4-nitrophenol. *Environ Technol Innov*. 2021;22:101404. https://doi.org/10.1016/j.eti.2021.101404