RJC

RASĀYAN *J. Chem.*
Vol. 18 | No. 1 |14-21| January - March | 2025
ISSN: 0974-1496 | e-ISSN: 0976-0083 | CODEN: RJCABP
http://www.rasayanjournal.com
http://www.rasayanjournal.co.in

GRAPE SEED EXTRACT AS A GREEN ROUTE FOR MgO NANOPARTICLE SYNTHESIS: ANTIBACTERIAL INSIGHTS

V. Senthilkumar[1] and K. K. Ilavenil[2,✉]

[1]Department of Mechanical Engineering, SRM TRP Engineering College, Irungalur (PO), Tiruchirappalli-621 105, Tamilnadu, India.

[2]Department of Chemistry, School of Engineering and Technology, Dhanalakshmi Srinivasan University, Samayapuram, Tiruchirappalli - 621112, Tamilnadu, India.

✉Corresponding author: ilavenilkk.set@dsuniversity.ac.in

ABSTRACT

The study outlines the synthesis and characterization process of magnesium oxide nanoparticles (MONPs) sourced from *Vitis vinifera* seeds. Extraction of seed powder, treatment with a magnesium nitrate precursor, and subsequent analysis using UV-Vis spectrophotometry, FTIR, DLS, SEM, and XRD methods were conducted. FTIR identified surface functional groups, UV absorbance revealed optical properties, and DLS provided a PDI of 0.347 with an average diameter of 94.3 nm. SEM and XRD confirmed morphology and cubic structure. Additionally, antimicrobial assays demonstrated MONPs' potency against various pathogens, highlighting potential biomedical applications. The study signifies the significance of MONPs derived from *Vitis vinifera* seeds by elucidating their synthesis, characterization, and antimicrobial efficacy.

Keywords: Magnesium Oxide Nanoparticles, *Vitis Vinifera* Seeds, Synthesis, Characterization, UV-Vis Spectrophotometry.

RASĀYAN *J. Chem.*, Vol. 18, No. 1, 2025

INTRODUCTION

Over the past few years, there has been a noticeable surge in both the study and practical application of nanomaterials. This trend is attributed to the distinct characteristics that nano-sized objects exhibit compared to their bulk counterparts. These disparities arise due to alterations in the surface-to-volume ratio of the materials at the nanoscale. This particular aspect imparts unique properties to nanomaterials, setting them apart from their larger counterparts. As a result, these nanomaterials have found diverse applications across various industries. The myriad of potential uses stems from their exceptional properties and behaviors, making them a valuable asset in fields ranging from electronics to medicine, and from energy to materials science. This increasing adoption and exploration of nanomaterials signify the ongoing efforts to harness their potential and revolutionize multiple industries.[1] Nanotechnology is a cutting-edge scientific discipline that leverages diverse methodologies to produce nanoparticles characterized by their small size and large surface area, resulting in distinctive properties and behavior. In recent times, nanotechnology has made substantial contributions to an array of fields such as automotive technology, bioengineering, pharmaceuticals, agriculture, electronics, cosmetics, eco-friendly chemistry, medicine, and packaging.[2,3] A study by Maduraiveeran *et al.*[4] emphasized these advancements. In the realm of biotechnology, nanomaterials have been ingeniously employed for a multitude of purposes. They played a pivotal role in bio-imaging, facilitating the visualization of biological structures at the nanoscale. Additionally, they were integral in diagnostic applications, providing sensitive and precise detection methods. The utilization of nanomaterials extended to bio-sensing, where their unique properties enabled the creation of highly responsive and accurate sensing platforms.[3] Their application in anticancer medications showcased groundbreaking potential in delivering therapies with enhanced precision and reduced side effects.[5] The emergence of metallic nanoparticles in nanotechnology has opened up a fascinating new avenue, distinguished by its unique attributes compared to other types of nanoparticles. Notably, extensive research has been conducted on gold and silver nanoparticles, finding applications in diverse fields such as agriculture, electronics, and biomedicine[6], where they serve as innovative drug delivery systems, potent antimicrobial agents[7,8] and promising anti-cancer agents[9], and dye degradation.[10] Within the food industry,

http://doi.org/10.31788/RJC.2025.1819012

nanotechnology has revolutionized food packaging, preservation, and safety. Nano-based materials can create impermeable barriers that extend the shelf life of perishable products and prevent contamination. In the realm of biomedicine, nanotechnology has unleashed transformative advancements. The myriad metallic nanoparticles utilized across various research domains, magnesium oxide nanoparticles (MONPs) have garnered significant attention. This heightened interest can be attributed to their non-toxic characteristics and cost-effectiveness, positioning MONPs as a highly appealing choice for a wide spectrum of applications. Magnesium oxide nanoparticles (MONPs) have received a green light from the Food and Drug Administration (FDA) as safe materials, leading to a surge in recent research efforts due to their broad applications in the medical field. MONPs have highlighted their impressive ability to exterminate bacteria, including *Staphylococcus aureus* and *E. coli*[8], as well as their effectiveness in combatting aggressive plant pathogens.[11] Diverse techniques exist for the synthesis of MONPs, encompassing the sol-gel process[12], co-precipitation[13], microwave and hydrothermal methods, and sonochemical approaches.[14] These various methods offer flexibility and adaptability in tailoring MONPs for a wide range of applications. Currently, there is a significant focus on the eco-friendly and cost-effective approach of green synthesis of metal nanoparticles using plant extracts.[15,16] The literature on green synthesis of magnesium oxide nanoparticles (MONPs) is somewhat limited, with only a few studies documenting the use of environmentally friendly methods. These include the utilization of plant sources such as *Dalbergia sissoo* leaf extract[15], *Artemisia abrotanum* herba extract[16], *Camellia sinensis*[17], *Mariposa christia vespertilionis* leaves extract[18], *Terminalia bellirica*[19], *Ficus racemosa* leaf extract[20], *Caccinia macranthera* extract[21], and Rubber seed shell.[22] This study explores the novel synthesis of magnesium oxide nanoparticles (MONPs) using grape seed extract, known for its medicinal properties due to its high antioxidant content. The nanoparticles were thoroughly characterized using techniques such as UV-Vis spectroscopy, Dynamic Light Scattering, XRD, and FTIR analysis. It presents an eco-friendly approach to nanoparticle synthesis with promising implications for nanotechnology and materials science.

EXPERIMENTAL

Chemicals

Hi-Media supplied analytical-grade chemicals, including TPTZ (2, 4, 6-tripyridyl-s-triazine), DPPH (2, 2-diphenyl-1-picrylhydrazyl), magnesium nitrate, fluconazole, ferric chloride, and potato dextrose agar.

Green Synthesis of MONPs using *Vitis vinifera* Seed Extract

Fresh *Vitis vinifera* seeds were gathered from Samayapuram, Trichy district, Tamil Nadu, and the leaves were rinsed with tap water, air-dried in the shade, and finely powdered. Following this, 1 g of the seed powder was combined with 100 mL of distilled water and subjected to a 1-hour treatment in a water bath[23] at 70°C.

Fig.-1: Synthesized Metal Oxide Nanoparticles

The mixture underwent magnetic stirring for approximately 60 minutes, and the extract was obtained by filtration using Whatman paper. A solution of 1 mM Mg (NO3)2 precursor was then mixed with the seed extract at a 2:1 ratio in basic media, and the resulting mixture was allowed to incubate at room temperature for the complete synthesis of MONPs. The formation of MONPs was monitored by measuring the absorbance across the wavelength range of 200–700 nm using a UV–Vis spectrophotometer (Perkin Elmer) at regular intervals. Once the synthesis of MONPs was finalized, the solution underwent centrifugation at

6000 rpm for 15 minutes, followed by drying at 80°C, and subsequent storage (Fig.-1)for further analysis.[24] The reaction is shown below,

$$Mg(NO_3)_2.\ 6\ H_2O) + 2\ NaOH \rightarrow Mg\ (OH)_2$$

$$Mg\ (OH)_2 \rightarrow MgO + H_2O$$

Characterization of Nanoparticles

FTIR Studies

The FTIR spectrum of magnesium oxide nanoparticles exhibits (Fig.-2) distinct peaks at specific wavenumbers, providing valuable information about the sample's composition and structure. The peak observed at 3445.30 cm^{-1} suggests the presence of hydroxyl (OH) groups or adsorbed water molecules on the nanoparticle surface, as it corresponds to the stretching vibration of OH bonds. Another notable peak at 2071.02 cm^{-1} may indicate the adsorption of carbon dioxide (CO_2) on the nanoparticle surface. The peak at 1634.78 cm^{-1} is likely associated with the bending vibration of water molecules or the presence of carbonate species (CO_3^{2-}) absorbed onto the nanoparticle surface. Additionally, the peak observed at 1114.98 cm^{-1} is characteristic of the stretching vibration of metal-oxygen (M-O) bonds within the magnesium oxide lattice structure, while the peak at 687.55 cm^{-1} corresponds to the stretching vibration of magnesium-oxygen (Mg-O) bonds. These FTIR peaks collectively suggest the presence of surface functional groups, adsorbed species, and the characteristic vibrations of the magnesium oxide lattice structure in the nanoparticles.

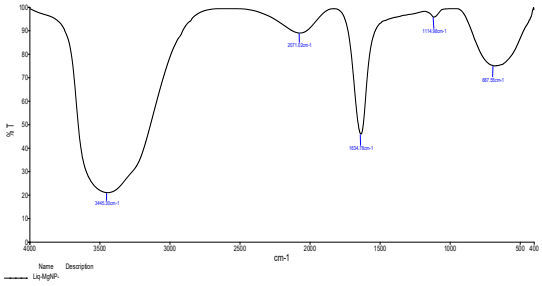


Fig.-2: FTIR Spectrum of Magnesium Oxide Nanoparticles

UV Absorption Spectra

The UV absorbance measurements of magnesium oxide nanoparticles (MgONP) reveal distinct peaks at 398.80 nm and 416.25 nm with corresponding absorbance values of 0.344 AU and 0.360 AU, respectively (Fig.-3). These peaks signify the sample's absorption of light at these specific wavelengths. The absorption at 398.80 nm suggests the presence of electronic transitions or surface functional groups within the nanoparticles, contributing to their optical properties. Similarly, the absorption peak at 416.25 nm indicates another wavelength at which the MgONP sample absorbs light, possibly related to different electronic transitions[25] or surface phenomena.

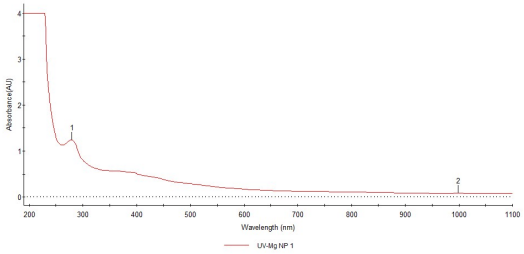
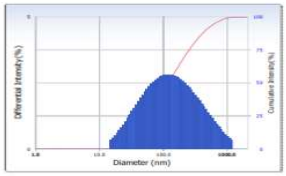


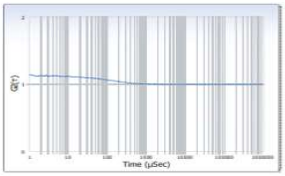
Fig.-3: UV Absorbance Peak of MgONPs

Nanoparticle Hydrodynamic Size Measurement

Dynamic light scattering (DLS) analysis provides valuable information about the size distribution and polydispersity of nanoparticles (Fig.-4). In the case of magnesium oxide nanoparticles (MgONPs), the average distribution peak is measured at 207.4 nm, indicating that the majority of nanoparticles in the sample have a size close to this value. This peak represents the most frequently occurring size within the

nanoparticle population. The polydispersity index (PDI) of 0.347 suggests that the size distribution of MgONPs is relatively narrow. A PDI value close to zero indicates a uniform size distribution, while higher values suggest a broader distribution. In this case, a PDI of 0.347 indicates a moderate degree of size variation among the MgONPs, suggesting some heterogeneity in their size distribution. The diameter of the MgONPs is reported as 94.3 nm. This value represents the average size of the nanoparticles in the sample. It is important to note that DLS provides an intensity-weighted average size, which may be influenced by larger particles contributing more to the scattering signal. Therefore, the reported diameter of 94.3 nm represents the average hydrodynamic diameter of the MgONPs in solution, considering their Brownian motion.[26]





Distribution Results (Contin)

Peak	Diameter (nm)	Std. Dev.
1	207.4	215.7
2	0.0	0.0
3	0.0	0.0
4	0.0	0.0
5	0.0	0.0
Average	207.4	215.7
Residual :	2.669e-003	(O.K)

Cumulants Results

Diameter	(d)	: 94.3	(nm)
Polydispersity Index	(P.I.)	: 0.347	
Diffusion Const.	(D)	: 5.216e-008	(cm²/sec)

Measurement Condition

Temperature	: 25.0	(°C)
Diluent Name	: WATER	
Refractive Index	: 1.3328	
Viscosity	: 0.8878	(cP)
Scattering Intensity	: 32910	(cps)
Attenuator 1	: 11.3	(%)

Fig.-4: DLS of MgONPs

Electrokinetic Potential

The zeta potential (ζ) reflects the electric charge on nanoparticles in a liquid dispersion, dictating their repulsion or attraction. High values maintain dispersion stability by preventing aggregation, while low values indicate potential aggregation. The zeta potential (ζ) measurement of -30.24 mV for plant-synthesized MgO-NPs indicates a highly stable dispersion. The negative sign signifies a net-negative charge on the nanoparticles' surfaces, suggesting strong electrostatic repulsion between particles. This robust repulsion mechanism effectively hinders aggregation, ensuring the stability of the dispersion.[27]

SEM Imaging Analysis

SEM (Scanning Electron Microscopy) analysis of magnesium nanoparticles (MgNP) involves imaging the morphology and size of particles (Fig.-5). For both 1 µm and 2 µm MgNP samples, SEM parameters include an accelerating voltage of 10.00 kV and a working distance (WD) of 11.0 mm. The spherical shape of the MgNP is considered during imaging, ensuring that the SEM images accurately reflect the inherent round or spherical structure of the nanoparticles.[28] A magnification of 20,000 times (20.00 kX) is applied to visualize the details of the larger nanoparticles while maintaining consistency with imaging conditions.

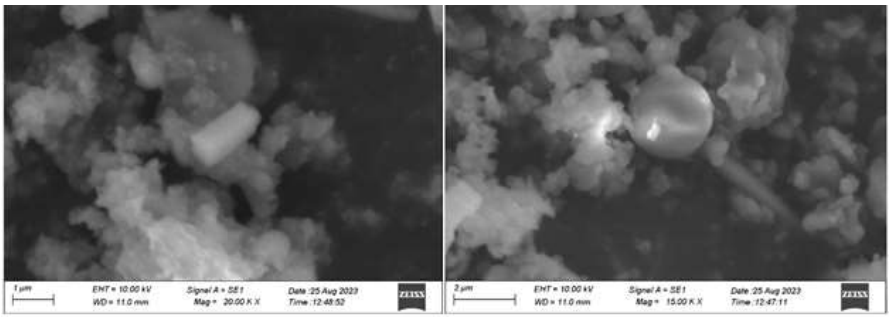


Fig.-5: SEM Images of MONps of 1µm and 2 µm

Utilizing *Vitis vinifera* (grape) seed extract for the preparation of MgO nanoparticles has yielded notable SEM results, demonstrating the spherical morphology of the nanoparticles. This outcome underscores the effectiveness of the green synthesis approach facilitated by the bioactive compounds present in the grape seed extract. The spherical shape observed in the SEM images signifies the successful reduction of Mg ions and controlled nucleation and growth processes mediated by the components of the seed extract.

XRD Analysis

The XRD analysis of MgO nanoparticles reveals distinct diffraction peaks corresponding to specific lattice spacings, indicative of a predominantly cubic shape. The lattice spacing of approximately 4.76800 A˚ corresponds to the (111) plane, suggesting its prevalence in the sample. Other lattice spacing, such as 4.30721A ˚ 4.30721 A˚ and 3.95853A˚ 3.95853 A˚, represent the (200) and (220) planes, respectively, reinforcing the cubic nature[29] of the nanoparticles (JCPDS: file No. 96-901-3063). These findings provide valuable insights into the crystalline structure and orientation preferences of MgO nanoparticles, crucial for various applications, including catalysis and nanoelectronics (Fig.-6).

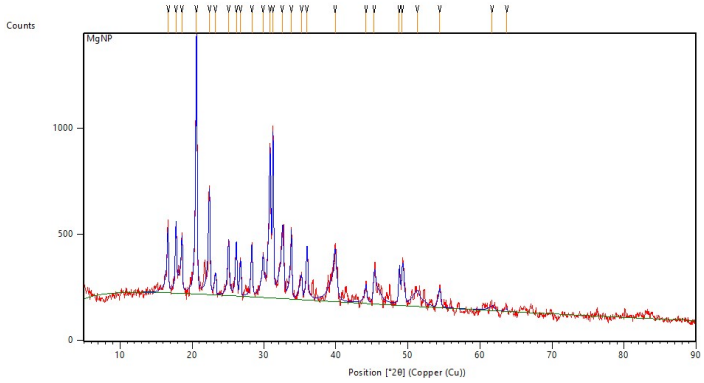


Fig.-6: XRD Analysis of MgO Nanoparticles

Antibacterial Potential

The synthesized magnesium oxide nanoparticles (MONPs) demonstrate potent antimicrobial activity against a variety of pathogens using the agar well diffusion method (Fig.-8). *Staphylococcus pneumoniae* exhibits a zone of inhibition (ZOI) of 22 mm/ml at a concentration of 100 mm/ml, while *Mycobacterium tuberculosis* displays a ZOI of 32 mm/ml at the same concentration. In comparison to their respective controls treated with gentamicin, which exhibit ZOIs of 20 mm/ml, the MONPs show superior efficacy. *Pseudomonas fluorescens* exhibits a ZOI of 20 mm/ml at a concentration of 100 mm/ml, comparable to its control. *Fusarium*, on the other hand, displays a substantial ZOI of 28 mm/ml at the same concentration, surpassing the control ZOI of 22 mm/ml. This enhanced antimicrobial activity can be attributed to several factors inherent to MONPs. Firstly, their high surface area-to-volume ratio enables increased contact with microbial cells, facilitating efficient antimicrobial action. Additionally, MONPs generate reactive oxygen species (ROS) upon exposure to moisture or biological fluids. These ROS induce oxidative stress in microbial cells, leading to damage and ultimately cell death.[30]

Moreover, the small size of MONPs allows for easier penetration of microbial cell walls and membranes, enhancing their antimicrobial efficacy. The specific physicochemical properties of MONPs, such as surface charge and crystalline structure, also contribute to their interaction with microbial cells and subsequent antimicrobial activity.

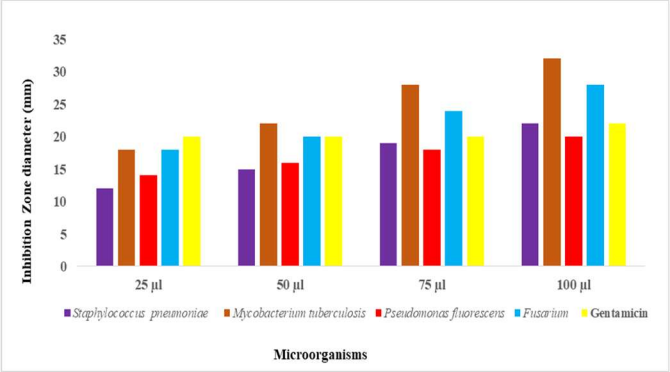


Fig.-7: Bar Chart of ZOI of MgONPs

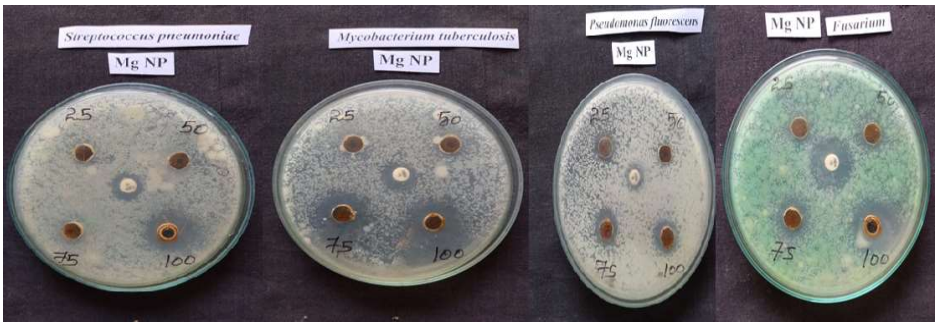


Fig.-8: Inhibition Zones of Microbes by Agar Well Diffusion Method

CONCLUSION

This study successfully synthesized magnesium oxide nanoparticles (MONPs) from *Vitis vinifera* seeds and characterized their properties using various techniques. The FTIR analysis revealed distinct peaks at specific wavenumbers, indicating the presence of surface functional groups and lattice vibrations. UV absorbance measurements showed peaks at 398.80 nm and 416.25 nm, reflecting the optical properties of the MONPs with absorbance values of 0.344 AU and 0.360 AU, respectively. Dynamic light scattering (DLS) analysis yielded a polydispersity index (PDI) of 0.347, suggesting a moderate degree of size variation among the nanoparticles, with an average diameter of 94.3 nm. SEM imaging confirmed the morphology of the nanoparticles, and XRD analysis indicated a predominantly cubic structure. Furthermore, antimicrobial assays demonstrated the potent efficacy of the MONPs against various pathogens. Staphylococcus pneumoniae exhibited a zone of inhibition (ZOI) of 22 mm/ml at a concentration of 100 mm/ml, while *Mycobacterium tuberculosis* displayed a ZOI of 32 mm/ml at the same concentration. *Pseudomonas fluorescens* showed a ZOI of 20 mm/ml, comparable to its control, while *Fusarium* exhibited a substantial ZOI of 28 mm/ml, surpassing the control ZOI of 22 mm/ml. These results underscore the potential of MONPs for biomedical applications as effective antimicrobial agents against a variety of pathogens.

ACKNOWLEDGMENTS

I am grateful to both Management and the students for their great assistance.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing, and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

V. Senthilkumar https://orcid.org/0000-0003-1673-3180
K. K. Ilavenil https://orcid.org/0000-0002-6794-6533

REFERENCES

1. A.A. Yaqoob, H. Ahmad, T. Parveen, A. Ahmad, M. Oves, I.M. Ismail, H.A. Qari, K. Umar, M.N. Mohamad Ibrahim, *Frontiers in Chemistry*, **8**, 341(2020), https://doi.org/10.3389/fchem.2020.00341
2. R.B. Rotti, D.V. Sunitha, R. Manjunath, A. Roy, S.B. Mayegowda, A.P. Gnanaprakash, S. Alghamdi, M. Almehmadi, O. Abdulaziz, M. Allahyani, A. Aljuaid, *Chemistry*, **11**, 1143614(2023), https://doi.org/10.3389/fchem.2023.1143614
3. I. Ijaz, E. Gilani, A. Nazir, A. Bukhari, *Green Chemistry Letters and Reviews,* **13(3)**, 223(2020), https://doi:10.1080/17518253.2020.1802517

4. A. Haleem, M. Javaid, R.P. Singh, S. Rab, R. Suman, *Global Health Journal,* **7(2)**,70(2023), https://doi.org/10.1016/j.glohj.2023.02.008
5. H. R. Raveesha, S. Nayana, D.R. Vasudha, J.S. Begum, S. Pratibha, C.R. Ravikumara, N. Dhananjaya, *Journal of Science: Advanced Materials and Devices,* **4(1)**, 57(2019), https://doi.org/10.1016/j.jsamd.2019.01.003
6. G. Maduraiveeran, M. Sasidharan, V. Ganesan, *Biosensors and Bioelectronics,* **103**, 113(2018), https://doi.org/10.1016/j.bios.2017.12.031
7. S. M. Dizaj, F. Lotfipour, M. Barzegar-Jalali, M.H. Zarrintan, K. Adibkia, *Materials Science and Engineering: C,* **44**, 278(2014), https://doi.org/10.1016/j.msec.2014.08.031
8. Hemlata, Prem Raj Meena, Arvind Pratap Singh, Kiran Kumar Tejavath, *ACS Omega,* **5**, 5520(2020), https://doi.org/10.1021/acsomega.0c00155
9. Mohammad Oves, Mohd Ahmar Rauf, Mohammad Aslam, Huda A Qari, Irfan Ahmad, Gaffar Sarwar Zaman, Mohd Saeed, Hana Sonbol, *Saudi Journal of Biological Sciences,* **29**, 460(2022), https://doi.org/10.1016/j.sjbs.2021.09.007
10. L. R. Yadav, K. Lingaraju, K. Manjunath, G.K. Raghu, K.S. Kumar, G. Nagaraju, *Materials Research Express,* **4(2)**, 025028 (2017), https://doi:10.1088/2053-1591/aa5b49
11. S. Ali, K.G. Sudha, M. Thiruvengadam, R. Govindasamy, *Biomass Conversion and Biorefinery*, 14, 21431(2024), https://doi.org/10.1007/s13399-023-04252-3
12. C. W. Wong, Y.S. Chan, J. Jeevanandam, K. Pal, M. Bechelany, M. Abd Elkodous, G.S. El-Sayyad, *Journal of Cluster Science,* **31(2)**, 367(2020), https://doi.org/10.1007/s10876-019-01651-3
13. L. Todan, L. Predoană, G. Petcu, S. Preda, D.C. Culiță, A. Băran, R.D. Truşcă, V.A. Surdu, B.Ș. Vasile, A.C. Ianculescu, *Gels*, **9(8)**, 624(2023), https://doi.org/10.3390/gels9080624
14. S. Harrat, M. Sahli, A. Settar, L. Foucault, L. Courty, K. Chetehouna, *International Journal of Hydrogen Energy,* **50**, 48(2024), https://doi.org/10.1016/j.ijhydene.2023.06.209
15. M.I. Khan, M.N. Akhtar, N. Ashraf, J. Najeeb, H. Munir, T.I. Awan, M.B. Tahir, M.R. Kabli, *Applied Nanoscience,* **10**, 2351(2020), https://doi.org/10.1007/s13204-020-01414-x
16. R. Dobrucka, *Iranian Journal of Science and Technology, Transactions A: Science*, **42**, 547(2018), https://doi.org/10.1007/s40995-016-0076-x
17. S.A. Kumar, M. Jarvin, S.S.R. Inbanathan, A. Umar, N.P. Lalla, N.Y. Dzade, H. Algadi, Q.I. Rahman, S. Baskoutas, *Environmental Technology & Innovation,* **28**, 102746(2022), https://doi.org/10.1016/j.eti.2022.102746
18. A.F. Farizan, H.M. Yusoff, N. Badar, I.U.H. Bhat, S.J. Anwar, C.P. Wai, A. Asari, M.F. Kasim, K. Elong, *Arabian Journal for Science and Engineering,* **48(6)**, 7373(2023), https://doi.org/10.1007/s13369-022-07282-7
19. P.V. Patil, N.A. Nerlekar, A.R. Kuldeep, P.P. Patil, P.B. Dandge, T.D. Dongale, P.B. Dandge, G.S. Rashinkar, *Plant Nano Biology*, **8**, 100069 (2024), https://doi.org/10.1016/j.plana.2024.100069
20. S. Varshney, A. Nigam, N. Mishra, S.J. Pawar, *Journal of the Korean Ceramic Society,* **60(1)**, 62(2023), https://doi.org/10.1007/s43207-022-00236-7
21. M. Barzegar, D. Ahmadvand, Z. Sabouri, M. Darroudi, *Materials Research Bulletin,* **169**, 112514 (2024), https://doi.org/10.1016/j.materresbull.2023.112514
22. E.U. Ikhuoria, I.E. Uwidia, G.O. Otabor, I.H. Ifijen, *Biomedical Materials & Devices*, **2**, 1078(2023), https://doi.org/10.1007/s44174-023-00139-z
23. G. Sharmila, C. Muthukumaran, H. Saraswathi, E. Sangeetha, S. Soundarya, N.M. Kumar, *Ceramics International,* **45**, 12382(2019), https://doi.org/10.1016/j.ceramint.2019.03.164
24. A. Khan, D. Shabir, P. Ahmad, M.U. Khandaker, M.R.I. Faruque, I.U. Din, *Materials Research Express*, **8(1)**, 015402(2020), https://doi:10.1088/2053-1591/abd421
25. K.T. Khac, H.H. Phu, H.T. Thi, H. Do Thi, *Heliyon*, **9(10)**, e20707(2023), https://doi:10.1016/j.heliyon.2023.e20707
26. A.U. Khan, A.U. Khan, B. Li, M.H. Mahnashi, B.A. Alyami, Y.S. Alqahtani, A.O. Alqarni, Z.U. Haq Khan, S. Ullah, M. Wasim, Q.U. Khan, W. Ahmad, *Photodiagnosis and Photodynamic Therapy*, **33**, 102153(2021), https://doi.org/10.1016/j.pdpdt.2020.102153

27. A. Fouda, K.S. Alshallash, M.I. Alghonaim, A.M. Eid, A.M. Alemam, M.A. Awad, M.F. Hamza, *Chemistry*, **5(3)**, 2009(2023), https://doi.org/10.3390/chemistry5030136
28. R. Pugazhendhi, R. Prabhu, K. Muruganantham, R. Shanmuganathan, S. Natarajan, *Journal of Photochemistry and Photobiology B: Biology*, **190**, 86(2019), https://doi.org/10.1016/j.jphotobiol.2018.11.014
29. S.O. Ogunyemi, F. Zhang, Y. Abdallah, M. Zhang, Y. Wang, G. Sun, W. Qiu, B. Li, *Artificial Cells, Nanomedicine, and Biotechnology,* **47,** 2230(2019), https://doi.org/10.1080/21691401.2019.1622552
30. A. Akshaykranth, N. Jayarambabu, V.R. Tumu, R.K. Rajaboina, *Journal of Inorganic and Organometallic Polymers and Materials*, **31**, 2393(2021), https://doi.org/10.1007/s10904-021-01915-4

[RJC-9012/2024]