

GREEN-SYNTHESIZED AG - NI BIMETALLIC NANOPARTICLES FROM *Mimosa Pudica* LEAF EXTRACT ACHIEVE HIGHLY EFFICIENT PHOTOCATALYTIC DEGRADATION OF CATIONIC TRIARYLMETHANE AND THIAZINE DYES

H. Dhanalakshmi^{1,2}, L. Gowrisankar², M. Dinesh Kumar³, and P. Dhivya^{1,✉}

¹Department of Chemistry, Nirmala College for Women, Coimbatore-641018, Tamil Nadu, India.

²Department of Science and Humanities, Karpagam College of Engineering, Coimbatore-641032, Tamil Nadu, India

³Department of Chemistry, Dr NGP Arts and Science College, Coimbatore-641048, Tamil Nadu, India

✉Corresponding author: dhivsanto@gmail.com

ABSTRACT

Uncontrolled discharge of synthetic cationic dyes from textile and dyeing industries poses serious environmental and health risks, demanding sustainable treatment methods. Here, silver–nickel bimetallic nanoparticles (Ag–Ni BMNPs) were green-synthesised using *Mimosa pudica* leaf extract and characterised by UV–Vis, FTIR, XRD, and SEM–EDX. UV–Vis confirmed nanoparticle formation via a localised surface plasmon resonance band at 421 nm; FTIR identified hydroxyl-, amine-, and carbonyl-containing phytochemicals responsible for stabilisation; XRD revealed a face-centred cubic Ag-rich structure (~31 nm crystallite size); and SEM–EDX confirmed predominantly spherical particles (13–58 nm) with uniform Ag/Ni distribution. Photocatalytic testing against Crystal Violet (CV), Malachite Green (MG), and Methylene Blue (MB) gave degradation efficiencies of 95.2%, 88.4%, and 48.9%, respectively, attributed to efficient Ag–Ni interfacial charge separation and reactive oxygen species generation. These results establish *M. pudica*-mediated Ag–Ni BMNPs as an efficient, low-cost, eco-friendly photocatalyst for dye-contaminated wastewater treatment. By converting a common, non-food plant into a low-cost photocatalyst that removes textile dye pollutants from water, this work contributes directly to SDG 6: Clean Water and Sanitation.

Keywords: Green Synthesis, Bimetallic Nanoparticles, *Mimosa Pudica*, Photocatalysis, Cationic Dye Degradation, Crystal Violet, Methylene Blue, Malachite Green

RASĀYAN J. Chem., Thematic Issue, 2026

INTRODUCTION

Synthetic cationic dyes such as Crystal Violet, Malachite Green, and Methylene Blue are widely discharged from textile and dyeing industries, and their aromatic, resonance-stabilised structures make them persistent and resistant to conventional biological treatment.^{1,2} Conventional physical remediation methods primarily separate or transfer pollutants from one phase to another without destroying them, whereas photocatalysis offers an effective approach for degrading dye pollutants into less harmful products and potentially mineralising them into CO₂, H₂O, and inorganic ions under suitable conditions.^{2,3} Silver-based nanostructures are particularly effective photocatalysts owing to their strong localised surface plasmon resonance and efficient reactive-oxygen-species generation. Green synthesis using plant extracts offers a low-cost, low-hazard alternative to chemical reduction routes, with phytochemicals such as flavonoids and polyphenols acting as simultaneous reducing and capping agents.^{4–6} Green-synthesised bimetallic nanoparticles have recently shown enhanced photocatalytic performance over monometallic systems by improving interfacial charge separation, as demonstrated for Ag–Pd⁷, Fe–Mn⁸, and Ni–Fe⁹ systems synthesised from various plant extracts. However, *Mimosa pudica* extract has so far only yielded monometallic Ag nanoparticles, and Ag–Ni bimetallic systems - combining Ag's plasmonic activity with Ni's electron-accepting character - remain unexplored using this plant source, particularly for comparative degradation across structurally distinct dye classes. This study addresses that gap by green-synthesising

Ag–Ni BMNPs from *M. pudica* extract, characterizing them via UV–Vis, FTIR, XRD, and SEM–EDX, and evaluating their degradation efficiency against triarylmethane (CV, MG) and thiazine (MB) dyes. This work supports SDG-6 (Clean Water and Sanitation) and SDG-12 (Responsible Consumption and Production) by offering a low-cost, sustainable route to dye-contaminated wastewater remediation.

EXPERIMENTAL

Material and Methods

Analytical-grade AgNO_3 and $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (Precision Scientific Company) were used as received; all solutions were prepared in double-distilled water (DDW). Dried, powdered *Mimosa pudica* leaves were suspended in DDW, heated at 60°C for 30 min, cooled, and filtered (Whatman No. 1) to obtain the aqueous leaf extract, which was stored at 4°C until use. For nanoparticle synthesis, 50 mL of leaf extract was stirred continuously at room temperature while 50 mL of 0.2 M $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (5 mmol Ni^{2+}) was added dropwise, followed by 3 h of continued stirring. Precipitation was induced by dropwise addition of 25 mL of 0.1 M NaOH, after which 25 mL of 0.1 M AgNO_3 (2.5 mmol Ag^+) was added to give a final Ag: Ni molar ratio of 1: 2. The mixture was left undisturbed overnight at room temperature to allow complete reduction. The precipitate was isolated, washed with distilled water and ethanol, dried at 80°C , ground, and calcined at 400°C for 3 h to yield crystalline MP–Ag–Ni bimetallic nanoparticles.

RESULTS AND DISCUSSION

UV–Vis spectroscopy of MP–Ag–Ni BMNPs (200–800 nm) showed a shoulder at 259 nm, assigned to $\pi \rightarrow \pi^*$ transitions of polyphenolic/flavonoid phytochemicals, and a broad peak at 421 nm corresponding to the localised surface plasmon resonance (LSPR) of the Ag–Ni nanostructure (Fig.-1a), consistent with reported LSPR ranges (418–430 nm) for green-synthesised Ag-based mono- and bimetallic nanoparticles.^{5,10,11} This red-shift relative to monometallic Ag NPs (~ 400 –410 nm) reflects Ni-induced modification of the Ag electron cloud, offering early spectroscopic evidence of Ag–Ni interfacial coupling that underlies the enhanced photocatalytic charge separation. The absence of a broad peak beyond 500 nm suggests predominantly spherical particles with limited aggregation. FTIR (4000–400 cm^{-1} ; Fig.-1b) showed transmittance minima at 3880.77, 3556.73, and 3209.54 cm^{-1} , corresponding to free and hydrogen-bonded O–H/N–H stretching of phenolic, flavonoid, and amine/amide phytoconstituents involved in metal-ion reduction and capping^{12,13}, while the weak 2337.72 cm^{-1} band is attributed to atmospheric CO_2 . Fingerprint-region bands at 948.97, 833.24, and 740.66 cm^{-1} are tentatively assigned to Ag–O/Ni–O lattice vibrations, though a contribution from residual phytochemical C–H bending cannot be excluded.¹⁴ The persistence of these phytochemical bands after calcination indicates a residual surface capping layer that likely stabilises the nanoparticles and assists interfacial charge transfer during photocatalysis, distinguishing this green-synthesised system from purely chemically reduced Ag–Ni analogues. XRD (Fig.-1c) showed Bragg reflections at $2\theta = 38.126^\circ$, 44.263° , 64.374° , and 77.311° , indexed to the (111), (200), (220), and (311) planes of face-centred cubic Ag (JCPDS 04-0783), with no separate Ni reflections — indicating an integrated Ag–Ni nanostructure rather than a physical mixture.¹⁴ Average crystallite size (Debye–Scherrer, $K = 0.9$, $\lambda = 1.5406 \text{ \AA}$) was $\sim 31 \text{ nm}$ (range 29.1–33.6 nm across planes), consistent with reported green-synthesised Ag–Ni BMNPs.^{15–17} Peak broadening at higher 2θ is attributed to lattice strain from Ni incorporation into the Ag lattice.¹⁶ This absence of distinct Ni reflections, combined with lattice strain rather than phase segregation, confirms Ni substitution within the Ag lattice as the structural basis for the interfacial electronic coupling inferred from the UV–Vis LSPR red-shift, directly linking crystal structure to the enhanced charge-separation mechanism proposed for photocatalytic activity. SEM micrographs (15.0k $\times$, 30.0k $\times$, 84.2k $\times$; Fig.-2) revealed dense, agglomerated, quasi-spherical nanoparticle clusters with a rough, porous surface, typical of phytochemically capped bimetallic nanoparticles. At the highest magnification, individual particles measured 12.94–58.01 nm (mostly 20–30 nm), consistent with reported sizes for *Salvadora persica*- and *Mimosa pudica*-mediated Ag–Ni nanoparticles.¹⁸ The broader size range likely reflects variable phytochemical reducing strength and secondary aggregation via hydrogen bonding/electrostatic interactions among surface-bound biomolecules identified by FTIR. This porous, agglomerated morphology is significant for photocatalysis, as it increases exposed surface area and active-site density available for dye adsorption and reactive-oxygen-species generation, providing a morphological basis for the high degradation efficiencies

observed for CV and MG despite the nanoscale size range being broader than chemically synthesized analogues.

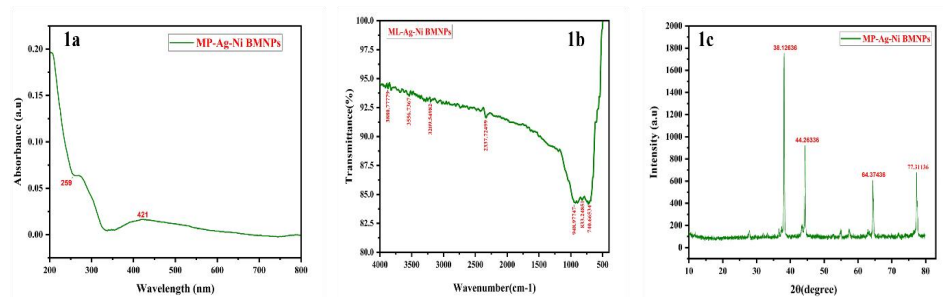


Fig.-1: UV-Vis (a), FTIR (b), and XRD (c) Spectra of MP-Ag-Ni BMNPs

EDX (Fig.-3) confirmed Ag (~3.0 and 3.2–3.4 keV, $L\alpha$) and Ni (~7.5 keV, $K\alpha$) emission peaks, verifying successful bimetallic formation, alongside a minor oxygen peak (~0.5 keV) attributed to surface-bound oxygen-containing phytochemicals, with a possible minor contribution from nickel surface oxidation.^{19,20} Elemental mapping showed homogeneous Ag/Ni distribution without segregation, and the absence of major impurity peaks indicates a high-purity product.

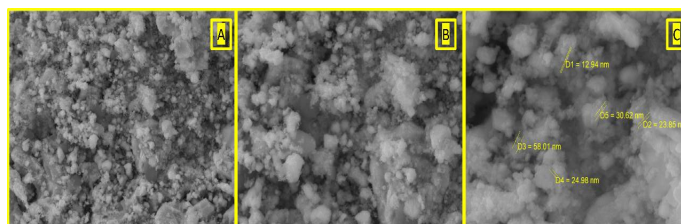


Fig.-2: SEM Micrographs of MP-Ag-Ni BMNPs at 15.0 k× (A), 30.0 k× (B), and 84.2 k× (C) Magnification

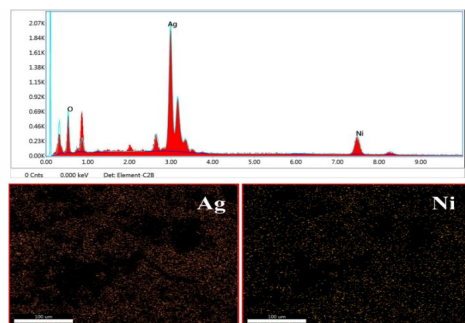


Fig.-3: EDX Spectrum and Elemental Mapping of MP-Ag-Ni BMNPs

Photocatalytic Dye Degradation Studies

Photocatalytic activity of Ag-Ni BMNPs was evaluated against Crystal Violet (CV), Malachite Green (MG), and Methylene Blue (MB) by monitoring the decrease in each dye's characteristic $\lambda_{\max}$ absorbance over 1, 2, and 3 h relative to a dye-only control, using $\%DE = [(A_0 - A_t)/A_0] \times 100$. Results are summarized in Table-1. CV ($\lambda_{\max} \approx 432$ nm) showed a rapid, time-dependent hypochromic effect with no $\lambda_{\max}$ shift, indicating chromophore destruction rather than adsorption: absorbance fell from 6.28 to 0.30 by 2 h (95.2% degradation) and plateaued thereafter, consistent with the high radical-susceptibility of its central methine carbon (Fig.-4a).¹ MG ($\lambda_{\max} \approx 398$ –400 nm) degraded steadily across all intervals without plateauing, reaching 88.4% by 3 h, reflecting its greater steric bulk and resonance stabilisation relative to CV³ (Fig.-4b). MB ($\lambda_{\max} \approx 383$ –385 nm) declined more gradually, reaching only 48.9% by 3h, consistent with the greater aromatic/planar stability of its phenothiazine core and prior reports requiring ≥ 120 min for comparable Ag-nanoparticle-mediated MB degradation² (Fig.-4c).

This CV > MG > MB trend reflects structure-dependent susceptibility to ROS attack - the exposed, electron-rich methine core of triarylmethane dyes is more accessible to oxidative attack than MB's fused, planar phenothiazine ring.²¹ This trend indicates that dye molecular architecture, rather than catalyst

loading alone, governs degradation efficiency - a factor relevant for treating real effluents containing mixed dye classes.²²

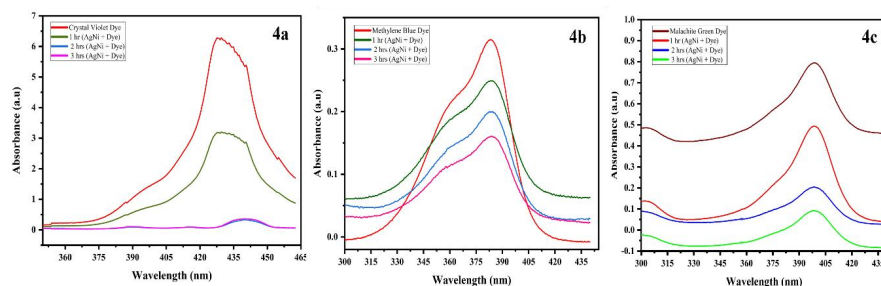


Fig.-4: UV-Vis Spectra of CV (a), MB (b), and MG (c) before and after Treatment with Ag-Ni BMNPs

Table-1: Time-dependent Degradation Efficiency (%DE) of CV, MB, and MG with Ag-Ni BMNPs

Dye	λ_{max} (nm)	A0	A (1 h)	%DE (1 h)	A (2 h)	%DE (2 h)	A (3 h)	%DE (3 h)
Crystal Violet	432	6.28	3.20	49.0	0.30	95.2	0.32–0.35	~95
Methylene Blue	383–385	0.317	0.245	22.7	0.198	37.5	0.162	48.9
Malachite Green	398–400	0.795	0.492	38.1	0.202	74.6	0.092	88.4

Proposed Mechanism of Photocatalytic Degradation by Ag-Ni BMNPs

Under light irradiation, the Ag component's surface plasmon resonance and Ni's semiconducting character together generate electron-hole (e^-/h^+) pairs ($\text{Ag-Ni} + h\nu \rightarrow e^-(\text{CB}) + h^+(\text{VB})$). At the Ag-Ni junction, Ni acts as an electron sink: photogenerated electrons migrate from Ag to Ni across the interface, suppressing e^-/h^+ recombination and prolonging charge-carrier lifetime, as reported for other Ag-based bimetallic/composite photocatalysts.^{20,23} The separated charges react with surface water/hydroxide and dissolved oxygen to generate $\cdot\text{OH}$ and $\cdot\text{O}_2^-$ radicals (Fig.-5), which attack the electron-rich chromophoric centres of the dyes, causing N-demethylation and ring-opening of CV/MG's methine core, and stepwise demethylation of MB via Azure B/A/C intermediates before mineralisation to CO_2 , H_2O , and inorganic ions.²⁴ The absence of a λ_{max} shift during degradation supports this ROS-mediated oxidative pathway over simple surface adsorption.

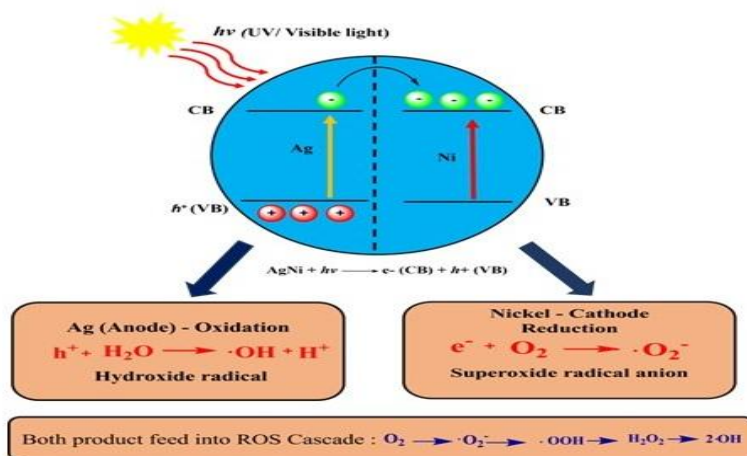


Fig.-5: Proposed Photocatalytic Mechanism of Ag-Ni BMNPs

These findings hold direct relevance to SDG-6 (Clean Water and Sanitation): the demonstrated 95.2% and 88.4% removal of Crystal Violet and Malachite Green within 2–3 h illustrates the practical potential of MP-Ag-Ni BMNPs for treating triarylmethane-dye-laden industrial effluents using a low-cost, reagent-free approach. By employing *Mimosa pudica* leaf extract, a readily available, non-toxic plant biomass, as both a reducing and capping agent in place of hazardous chemical reagents, this synthesis route aligns with SDG 12 (Responsible Consumption and Production), supporting cleaner nanomaterial production practices applicable to scalable wastewater remediation technologies.

CONCLUSION

Mimosa pudica leaf extract was successfully used to green-synthesise crystalline, phytochemically capped Ag–Ni bimetallic nanoparticles (MP–Ag–Ni BMNPs), confirmed by UV–Vis, FTIR, XRD, and SEM–EDX characterisation. The nanoparticles showed strong photocatalytic activity toward cationic dyes, achieving 95.2% degradation of Crystal Violet (2 h), 88.4% of Malachite Green (3 h), and 48.9% of Methylene Blue (3 h), with the CV > MG > MB trend attributed to Ag–Ni interfacial charge separation, enhanced reactive-oxygen-species generation, and structure-dependent susceptibility of the dye chromophores to oxidative attack. These results establish MP–Ag–Ni BMNPs as an efficient, low-cost, scalable, and environmentally sustainable photocatalyst for dye-contaminated wastewater remediation. In addressing the discharge of persistent cationic dyes into water bodies using a reagent-free, plant-derived synthesis route, this study supports SDG 6 Clean Water and Sanitation. Future work should assess catalyst reusability, performance under natural sunlight, and optimisation of the Ag: Ni ratio and pH to accelerate degradation of more resistant dyes like MB.

ACKNOWLEDGMENTS

The authors used ChatGPT for language editing assistance. All experimental design, data analysis, interpretation, and conclusions were performed and verified by the authors.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-6: Clean Water and Sanitation*. 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:

H. Dhanalakshmi  <https://orcid.org/0009-0008-0626-2470>

L. Gowrisankar  <https://orcid.org/0000-0001-5700-8343>

M. Dinesh Kumar  <https://orcid.org/0000-0003-0147-0875>

P. Dhivya  <https://orcid.org/0000-0002-3910-8129>

Open Access: This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

Cite this article as: H. Dhanalakshmi *et al.*, *Rasayan J. Chem.*, Vol.19, Special Issue, 141-146(2026), <https://doi.org/10.31788/RJC.2026.19510114>

REFERENCES

1. R. N. Boucetta, M. Khelfaoui, N. Ammouchi, S. Boucetta, M. N. Khelifi, E. Can, A. Djermoune, F.A Merzeg, W. Sobhi and F. Djazi, *RSC Advances*, **16**, 5915(2026), <https://doi.org/10.1039/d5ra08684a>
2. M. Y. Tahir, A.Ahmad, A. A. Alothman, M. S. S. Mushab and S.Ali, *Bioinorganic Chemistry Applications*, (2022), <https://doi.org/10.1155/2022/7268273>
3. Z. Xu, N. Zada, F. Habib, H. Ullah, K. Hussain, N. Ullah, M. Bibi, M. Bibi, H. Ghani, S. Khan, K. Hussain, X. Caiand, H. Ullah, *Molecules*, **28(17)**, 6241(2023), <https://doi.org/10.3390/molecules28176241>
4. M. Gopinath1, B. Bharathiraja, J. Iyyappan1, R. Gnanasekaran, D. Yuvaraj, V. Dhithya, *Proceedings of the National Academy of Sciences India Section B-Biological Sciences*, **90**, 1025(2020), <https://doi.org/10.1007/s40011-020-01175-1>
5. V. Gvozdic, Z. Uzarevic, E.K. Andric, V. Galic, L. Kalinic, M.J. Kovac, I. Coric, K. Kirchbauer, D. Vidosavljevic, V. Pavic, *Molecules*, **30**, 3979(2025), <https://doi.org/10.3390/molecules30193979>
6. S.Ahmed, M.Ahmad, B.L Swami, S Ikram, *Journal of Advanced Research*, **1**,17(2016), <https://doi.org/10.1016/j.jare.2015.02.007>

7. J. Narenkumar, A. Kannabiran, S. Ramalingam, P. Parthipan, B. Das, M.S. Alsalhi, S.Devanesan, *Environmental Geochemistry and Health*, **46**, 200 (2024), <https://doi.org/10.1007/s10653-024-01978-5>
8. S. Naz, R. Kalsoom, F. Ali, N. Amjed, U. Younas, M. Pervaiz, M. Alsaiani, M. Faisal, F.A. Harraz, R. Luque, *Water*, **14**, 3535(2022), <https://doi.org/10.3390/w14213535>
9. S.Mohan, I Karuppusamy, A.Manickam, S.Sivakumar, S,Elangomannan, *Scientific Reports*, **16**, 19918(2026), <https://doi.org/10.1038/s41598-026-51691-9>
10. A.H. Ali, A.M Mengesha, W.W Melkamu, A. Abebe, *Results in Chemistry*, **16**, 102395(2025), <https://doi.org/10.1016/j.rechem.2025.102395>
11. P. Chaison, W.Tongpoothorn, K.Wittayanarakul, M.Sriuttha, *Engineering & Applied Science Research* **52**,159(2025), <https://doi.org/10.14456/easr.2025.14>
12. J. Aarthi, S.S. Kaviya, K. Kirubavathi, K.Selvaraju, F.Shakeel, S.Gowri, and M. Faiyazuddin, *Journal of Molecular Structure*, **1321**, 140178(2025), <https://doi.org/10.1016/j.molstruc.2024.140178>
13. M.R Kamli, E.A. Alzahrani, S.M Albukhari, A. Ahmad, J.S.M Sabir, M.A Malik, *Journal of Fungi*, **8**, 733(2022), <https://doi.org/10.3390/jof8070733>
14. B.I. Egbewole, B.O. Ogunsile, A.O. Adeola, D.B.Olawade, Y.A. Adekunle, and P.N. Nomngongo, *Biomass Conversion and Biorefinery*, **14**, 14083(2024), <https://doi.org/10.1007/s13399-022-03463-4>
15. A. Abimbola Akinsiku, K.Oluseyi Ajanaku, E.Olugbenga Dar, *Journal of Physics: Conference Series*, **1299**, 012133(2019), <https://doi.org/10.1088/1742-6596/1299/1/012133>
16. J.A Adekoya, E.O Dare, M.A Mesubi, N.Revaprasadu, *Journal of Materials*, **2014**, 184216, (2014), <https://doi.org/10.1155/2014/184216>
17. M.N Bhatu, G.R Malvankar, A.Chavan, P.P.Baikar, D.S Raut, S.P Patil, *Iranian Journal of Catalysis* **16**,101(2026), <https://doi.org/10.57647/j.ijc.2026.1601.07>
18. I.U.Din, R.Ajaj, A.Rauf, Z.Ahmad, N.Muhammad, S.Ali, H.A. Hemeg, I.Ullah, *PLoS One*, **20**(7), e026858 (2025), <https://doi.org/10.1371/journal.pone.0326858>
19. T. Shahzadi, S. Iqbal, T. Riaz, M. Zaib, *Journal of Taibah University for Science*, **16**, 912(2022), <https://doi.org/10.1080/16583655.2022.2123206>
20. B.Patel, N.Choudhary, D.Dudhagara, M.Shahid, R.Syed, V.K Yadav, D.K Sahoo, A.Patel, *RSC Advances*, **15**,1565(2025), <https://doi.org/10.1039/d4ra07541b>
21. S. Mohan and M.V .Devan, *Green Processing and Synthesis*, **8**, 895(2019), <https://doi.org/10.1515/gps-2019-0060>
22. K.A.S. Arasu, A.G. Raja, R. Rajaram, *Inorganic Chemistry Communications*, **151**, 110620(2023), <https://doi.org/10.1016/j.inoche.2023.110620>
23. D. S. Idris, A. Roy, A. Malik, A. A. Khan, K. Sharma, A. Roy, *Journal of Inorganic and Organometallic Polymers and Materials*, **35**, 594(2025), <https://doi.org/10.1007/s10904-024-03316-9>
24. S. González, X. J. Fierro, *International Journal of Molecular Sciences*, **26**, 1756(2025), <https://doi.org/10.3390/ijms26041756>

[RJC-10114/2026]