

THE GREEN PREPARATION AND CHARACTERIZATION OF NANOCRYSTALLINE ZnAl_2O_4 AND ITS SUPERIOR CATALYTIC ACTIVITIES IN THE SYNTHESIS OF BENZIMIDAZOLE DERIVATIVES

T. V. Nitha and Sebastian Britto✉

Department of Chemistry, St. Joseph's College (Autonomous), Affiliated to Bharathidasan University, Tiruchirappalli-620002, Tamilnadu, India.

✉Corresponding Author: brittoseba@yahoo.com

ABSTRACT

In this study, nanosized ZnAl_2O_4 was prepared using plant extract, *Cymbopogon citratus* (lemon grass) to examine their catalytic activity towards the synthesis of 2-aryl-substituted benzimidazole derivatives. X-ray Diffraction (XRD), Fourier-Transform Infrared Spectroscopy (FT-IR), Scanning Electron Microscopy (SEM), Energy-Dispersive X-ray Spectroscopy (EDX), and UV-visible Diffuse Reflectance (DRS) spectra were used for comprehending the character of the produced catalysts. The XRD findings showed that the mixed metal oxide nanoparticles' size distribution ranges from 1 to 11 nm. To the best of our knowledge, the nanometer-sized ZnAl_2O_4 is found to be the most active catalyst in the condensation reactions, performed in this study. It was found that when the catalyst is recycled, the catalytic performance has not been changed.

Keywords: Nanocomposite, Catalytic Activity, Green Synthesis, 2-Aryl Benzimidazole, Recyclable Catalyst.

RASAYAN J. Chem., Vol. 16, No. 2, 2023

INTRODUCTION

Benzimidazole derivatives are the most prevalent heterocyclic scaffolds, in medicinally valuable and biologically active compounds and they can be found in an extensive range of natural products.¹ The use of benzimidazole in organic synthesis is inevitable, and benzimidazole scaffolds are present in a variety of medications as potential anticancer, Histamine H_4 receptor binders, anti-parasitic, cardiovascular, antimicrobials, and antihypertensives.^{2,3} By condensation of *o*-phenylenediamine and aromatic acids at temperatures ranging from 80-90°C with ammonium chloride as catalyst, 2-aryl substituted derivatives of benzimidazole have been created.⁴ This reaction becomes challenging to perform at room temperature, and mild reaction conditions like mild catalysts, are much required in scaling up the reaction to industrial production. In order to overcome these problems, various mineral acids⁵ and Lewis acids⁶ have been employed as catalysts to get quite mild reaction conditions and better yield of the benzimidazole derivatives. In this study cheap, non-volatile, easily separable, and non-hygroscopic catalyst system, ZnAl_2O_4 , which is prepared as nanocrystalline solids via green chemical way, is utilized in the benzimidazole syntheses in very little amount. Thus, this methodology becomes adaptable to the industrial scale where the processing steps require easy separation and recyclability. Various plant extracts like *Opuntia dillenii*⁷, *Impatiens balsamina* L⁸, *Aloe vera*⁹, and *Sesamum indicum*¹⁰ have been examined as capping agents in the preparation of ZnAl_2O_4 nanocatalyst, the leaf extract of renowned traditional medicinal plant (lemon grass) *Cymbopogon citratus* is not much explored in this regard. In the current investigation, the latter is found to serve better for this purpose. The variety of phytochemicals existing in this plant is liable for the stabilization of metal oxide precursors.¹¹

EXPERIMENTAL

Materials

Aluminum nitrate nonahydrate (98%), zinc sulfate, ortho-phenylenediamine, aromatic aldehydes, and ethanol (95%) were purchased from Merck. solid aldehydes were purified by recrystallization using ethanol and liquid aldehydes were used after distillation. Other reagents and solvents were taken to the reaction directly without any purification.

General Procedure for the Preparation of Plant Extracts

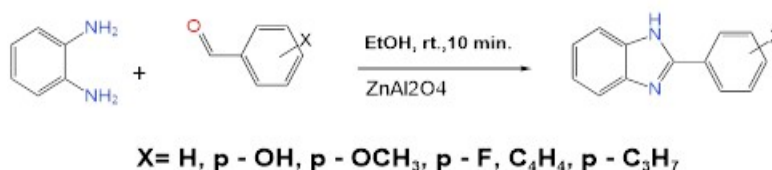
About 10 g of fine powder of shade-dried plant leaves was taken in a beaker and mixed with 100 mL of distilled water. The suspension was heated in a water bath for 30 minutes at 80 °C and filtered using Whatman No.1 filter paper to obtain the extract.

Synthesis of Nanocatalyst ZnAl₂O₄

The aqueous solution of 25 mL of 0.1 M aluminum nitrate and 50 mL of zinc sulfate (1:2 ratio) mixture was taken in a burette and it was added dropwise into the beaker containing 75 mL of the above plant extract with stirring at 80°C and 600 RPM. The resulting mixture of pH 3.1 was allowed to stand at room temperature for 24 hours. The residue obtained was centrifuged and washed with ethanol. Then it was calcined in a furnace at 800 °C for 2 hours and cooled slowly to room temperature to yield the nanocomposite ZnAl₂O₄ which was characterized by various techniques.

General Procedure for the Synthesis of 2- Aryl Substituted Benzimidazole Derivatives.

In accordance with the procedure reported by S. R. Rithe *et al*, the synthesis of benzimidazole derivatives was performed.⁴ A mixture of ortho-phenylenediamine (1 mmol, 0.108 g), aldehyde (1 mmol), ZnAl₂O₄ NPs (0.025 g), and 15 mL of ethanol was taken in an RB flask. The suspension was stirred for 10 min at room temperature. TLC, which is composed of the ratio 6:4 hexane to ethyl acetate, was employed to monitor the completion of the reaction. After the accomplishment of the reaction, the mixture was centrifuged to remove the catalyst. The centrifugate was poured into 20 mL of distilled water. The precipitate thus obtained was collected, filtered, and then rinsed with water. Recrystallization with ethanol (20mL) was used to refine the crude output. The catalyst thus recovered was used for another reaction and similar catalytic behavior, as it was used for the first time, was observed.



Scheme-1

Spectral data of produced benzimidazole derivatives.

2-Phenyl 1H-benzimidazole(1)

m.p. 236-237°C; IR: 3448.8, 1623.3 and 1591.3 cm⁻¹; ¹H NMR: δ 7- 8.3(m,9H) ppm; ¹³C NMR: δ 151.8, 139.2, 130.1, 129.8, 128.9, 126.8, 122.3 and 115.1 ppm; MS: m/z 196.1, 195.1 (100%).

2-(4-Hydroxyphenyl)-1H-benzimidazole (2)

m.p. 242-243°C; IR: 3450.9, 3252.4, 1609.8, 1499.9 and 1251.5 cm⁻¹; ¹H NMR: δ 6.8-8.1(m,8H)ppm; ¹³C NMR: δ 164.5, 156.9, 143.4, 133.4,127.0, 125.3, 120.8 and 119.4 ppm; m/z 212.1, 211.1 (100%).

2-(4-Methoxyphenyl)-1H-benzimidazole (3)

m.p.226-227°C; IR:3453.5, 1613.2, 1585, 1330 and 1100 cm⁻¹; ¹HNMR:δ 6.8 – 8.1 (m,8H) ppm; ¹³CNMR:161.3, 151.9, 128.2, 139.9, 122.8, 122.3, 115, 114.5, and 55.4ppm; MS: m/z 226.1, 225.1 (100%).

2- (4-Fluorophenyl)-1H-benzimidazole (4)

m.p.250-251°C; IR: 3435.1cm⁻¹,1601.8, 1475.5 and 1226.8 cm⁻¹; ¹H NMR δ 7–8.1(m,8H) ppm; ¹³CNMR:δ 150.5, 140.1, 128.7, 128.6,117.1, 116.4, 116.2,115.8 ppm; MS: m/z 214.1, 213.1(100%)

2-(1-Naphthalene-1-yl)-1H-benzimidazole (5)

m.p.200-201°C; IR: 3433, 1646.5 and 1559.2 cm⁻¹ ;¹H NMR: δ 7–8.6 (m,8H); ¹³CNMR: δ156.5, 143.9, 138.6, 135.9, 133.2, 132.9, 131.9, 129.9, 127.2 and 120.1 ppm; MS: m/z 246.1, 245.1(100%).

2- (4-isopropyl phenyl)-1-H-benzimidazole (6)

m.p.222-223°C; IR: 3445.8, 1646.7 and 1554.7 cm^{-1} ; ^1H NMR: δ 7.1–8.2 ppm; ^{13}C NMR: 156.6, 155.9, 143.5, 131.9, 131.8, 131.7, 127.3, 119.7, 45.4, 38.7, and 28.6 ppm; MS: m/z 238.1, 237.1 (100%).

RESULTS AND DISCUSSION**Characterization of ZnAl_2O_4 Nanocomposite**

The XRD spectra were used to calculate the average particle size of nanomaterial using the Debye-Scherrer equation.¹² They were found to lie between 1 and 11 nm for the prepared catalyst ZnAl_2O_4 . The particle sizes were similar to those produced through co-precipitation, hydrothermal, and microwave hydrothermal methods.¹³ The phase composition in the calcined nanocomposite of ZnAl_2O_4 at different temperatures, 200°C, 400°C, 600°C, 800°C and 1000°C was established by powder XRD (Fig.-1). At 200°C-400°C, the catalyst was amorphous, whereas the sample calcined at 800°C showed the crystalline phases (220), (311), (422), (511), and (440) at corresponding angles. The sample calcined at both the temperatures, 800°C and 1000°C is cubic spinel phase, and in good agreement with the reported values.¹⁴ FT-IR analysis of the sample supported the formation of nano-composite ZnAl_2O_4 . The band at 3434.5 cm^{-1} in the IR data was due to OH stretching in the H_2O molecules and the band seen at 1650 cm^{-1} could be ascribed to the interlayer water molecule bending vibration, which was probably caused by water absorption during the preparation of the sample. The Zn–O, Al–O, and Zn–O–Al bond vibrations were accountable in the range of 490 - 990 cm^{-1} (Fig.-2).

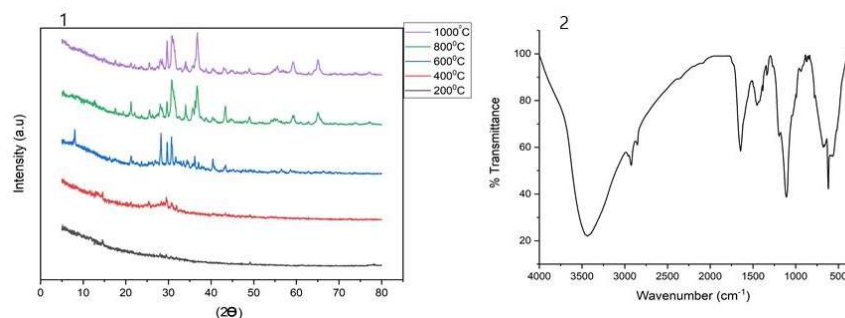


Fig.-1: XRD Spectra of ZnAl_2O_4 Nanocomposite at Different Temperatures

Fig.-2: FT-IR Spectrum of ZnAl_2O_4 at 800°C

The scanning electron micrographs showed a homogeneous and narrow particle size distribution, which was similar to syntheses performed by Ragupathi *et al.*⁷ From the SEM images (Fig.-3 a, b), it was clear that there were agglomerated nanoparticles that are approximately spherical in shape. The nano- and microparticles were uniformly dispersed in the form of tiny particles and large agglomerates with a structure that was almost spherical. These samples' agglomerated structures are a result of the possibility of solid-state welding occurring during the annealing process at 800°C, which may generate fine particles.

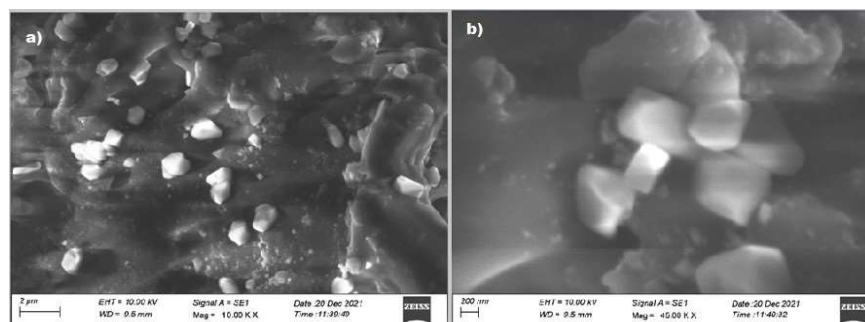
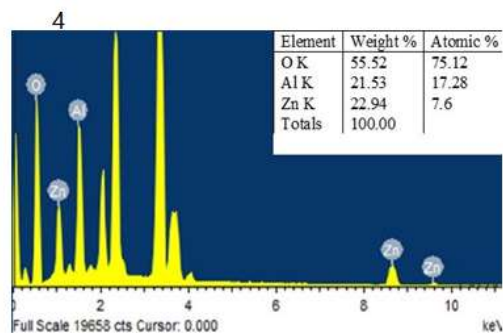
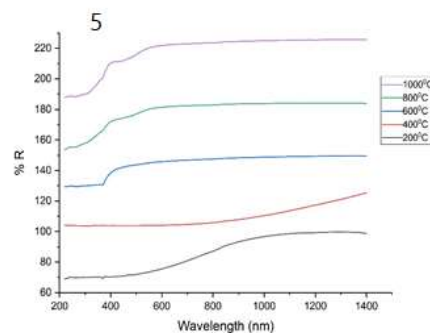


Fig.-3: SEM Images of ZnAl_2O_4 (a) with the Magnification of 10 K (b) 45 K

In addition to scanning electron micrographs, an EDX analysis was carried out to determine the composition of the nanoparticles. For instance, both point and region studies revealed that the atomic ratios of Zn, Al,

and O for the catalyst ZnAl_2O_4 were 7, 17, and 75%, respectively (Fig.-4), which are comparable to the outcomes found by Bhavani *et al.*¹⁵ For the samples calcined at different temperatures, the corresponding absorbance spectra were recorded (Fig.-5), in which, it is observed that the broad shoulder obtained at 390 nm for the samples calcined at 200°C-1000°C. The intensity of this shoulder reduced when the sample was sintered at higher temperatures, suggesting that the absorption edge steepened as the calcination temperature rose.

Fig.-4: EDX Spectrum of ZnAl_2O_4 at 800°CFig.-5: UV-DRS Spectrum of ZnAl_2O_4 Calcined at Different Temperatures

Optimization of Reaction Conditions

It is necessary to tune the temperature, duration of the reaction, and catalyst amount to achieve the best outcomes from the nanocatalyst. For this purpose, we indeed to perform a benchmark reaction for the synthesis of benzimidazole derivatives. The condensation reaction between *o*-phenylene diamine (1mmol) and benzaldehyde (1mmol) was used for the production of benzimidazole. In the instance of benzimidazole, we obtained a higher yield from the use of ZnAl_2O_4 nanocatalyst within 10 minutes at room temperature. When the quantity of nanocatalyst was increased, the yield of the product also got increased and then product formation could not be achieved, when the reaction is carried out without a catalyst. We build the model reactions with various amounts of catalyst to figure out the appropriate quantity of the nanocatalyst (Table-1).

Table-1: Optimization of the Catalytic Amount in the Model Reactions.

Entry	Catalyst (g)	Yield (%)	Time (min.)
1	0.01	73	30
2	0.015	80	20
3	0.02	88	10
4	0.025	94	10

Afterward, other benzimidazole analogs were synthesized using optimized process parameters. The yield for benzimidazole derivatives that were obtained while utilizing various aryl aldehydes was recorded (Table-2). The yields from these reactions are shown to be remarkably high. The synthesized benzimidazole derivatives are characterized by FTIR, ^1H NMR, ^{13}C NMR, and mass spectral data. The results from previous reports were compared and tabulated (Table-3) in order to verify the superior catalytic activity of ZnAl_2O_4 benzimidazole synthesis. To the best of our knowledge, no catalysts served in such an efficient manner in the synthesis of both the heterocycles that are reported here.

Recovery and reuse of a catalyst are the cost-effective industrial processes that are retrieved by ZnAl_2O_4 . After performing the reaction, the reaction mixture was centrifuged and filtered for the removal of the catalyst.

The filtrate was taken for aqueous work and the residue was washed with ethanol and dried. The recovered catalyst was then reintroduced in the model reaction with the same quantity. The catalytic activity of the nanocatalyst did not significantly fall off even after the recycling. Also, FTIR measurements were done to confirm the stability and structural property of regenerated ZnAl_2O_4 (Fig.-6).

Table-2: The Benzimidazole Derivatives Synthesized and Their Yield

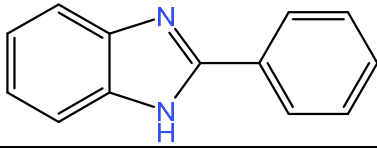
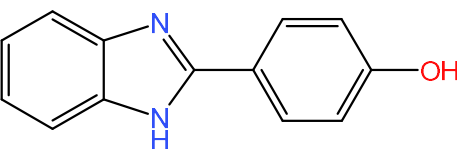
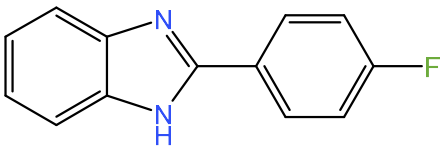
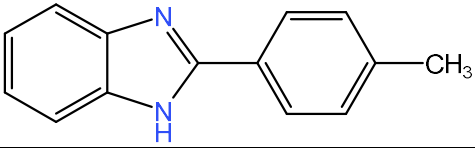
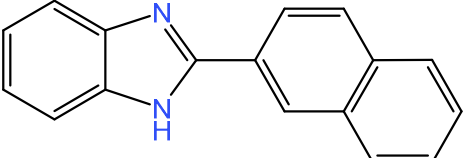
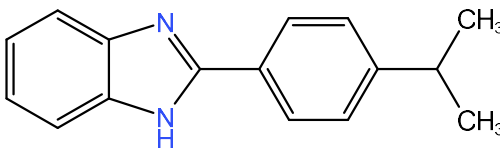
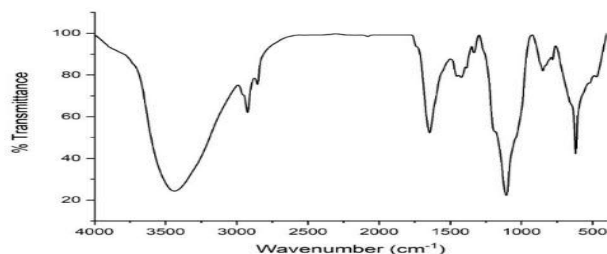
Entry	Aldehydes	Products	Yield (%)
1	Benzaldehyde		94
2	4-Hydroxybenzaldehyde		90
3	4-Fluorobenzaldehyde		88
4	4-Methoxybenzaldehyde		93
5	1-Naphthaldehyde		91
6	4-Isopropylbenzaldehyde		92

Table-3: Analyzing the Effectiveness of Various Catalysts for the Production of Benzimidazoles

Entry	Catalyst	Temperature (°C)	Time (min.)	Yield (%)	Ref.
1	Al ₅ Y ₃ O ₁₂	70	5	98	2
2	SBSA	r.t.	90	73	16
3	CoCl ₂ .6H ₂ O	r.t.	240	81	17
4	CAN	50	120	98	18
5	MK10	60	5	95	19
6	NH ₄ Cl	80	180	80	20
7	ZnO/SiO ₂ -NC800	40	60	91	21
8	ZnAl ₂ O ₄	r.t	10	94	Present Work

Fig.-6: FT-IR Spectra of recycled ZnAl₂O₄ NPs

CONCLUSION

In this article, the nanocomposite ZnAl_2O_4 was produced by a green chemical procedure utilizing plant extract as a capping agent, especially extract of *Cymbopogon citratus* as a stabilizing agent for the first time for making it and employed as a catalyst in the condensation reaction discussed in this report. The catalysts' physical and chemical characterization was carried out using XRD, SEM, EDX, UV, and IR techniques. The very little reaction time observed in this report showed the higher catalytic activity of ZnAl_2O_4 than the conventional catalysts used in the same reaction. Its performance is 24 times higher than that of other catalysts, due to the moderate Lewis acidity obtained when the metal oxides are mixed together.

ACKNOWLEDGEMENTS

The management and principal of St. Joseph's College, (Autonomous), Thiruchirapalli – 02, are thanked by the authors for providing the necessary facilities to carry out research work and Nitha T.V. is grateful to the financial support from SJC-RG 2022-23.

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:

T.V. Nitha  <https://orcid.org/0000-0002-4126-7129>

Sebastian Britto  <https://orcid.org/0000-0002-3869-228X>

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.

REFERENCES

1. F.Hakimi, M.F.Mahrjardi, E.Golrasan, *Chemical Methodologies*, **4**, 234(2020), <https://doi.org/10.33945/SAMI/CHEMM.2020.3.2>
2. K.Sravanthi, D.Ayodhya, P.Y.Swamy, , *Materials Science for Energy Technologies*, **2**, 298(2019), <https://doi.org/10.1016/j.mset.2019.02.003>
3. A.Arya, V.Mishra, T.S.Chundawat, *Chemical Data Collections*, **20**, 100190(2019), <https://doi.org/10.1016/j.cdc.2019.100190>
4. S.R.Rithe, R.S.Jagtap, S.S.Ubarhande, *Rasayan Journal of Chemistry*, **8**, 213(2015)
5. S.B.Rathod, M.K.Lande, B.R.Arbad, *Bulletin of Korean Chemical Society*, **31**, 2835(2010), <https://doi.org/10.5012/bkcs.2010.31.10.2835>
6. B.Chen, C.Zhang, L.Niu, X.Shi, H.Zhang, X.Lan, and G.Bai, *Chemistry- A European Journal*, **24**, 3481(2017), <https://dx.doi.org/10.1002/chem.201704823>
7. C.Ragupathi, J.J.Vijaya, S.Narayanan, L.J.Kennady, S.Ramakrishna, *Chinese Journal of Catalysis*, **34**, 1951(2013), [https://doi.org/10.1016/S1872-2067\(12\)60682-2](https://doi.org/10.1016/S1872-2067(12)60682-2)
8. E.Angasa, I.N.Sari, P.K.Wadani, Ghufira, S.P.Yudha, I.Gustian, *Journal of Chemical and Pharmaceutical Research*, **7(10)**, 518(2015)
9. G.Padmapriya, M.Amudhavalli, *Malaya Journal of Matematik*, **2**, (2020), <https://doi.org/10.26637/MJM0S20/0537>
10. C.Ragupathi, J.J.Vijaya, A.Manikandan, L.J.Kennadi,, *Journal of Nanoscience and Nanotechnology*, **13**, 8298(2013), <https://doi.org/10.1166/jnn.2013.7922>
11. D.P.Ruiz, L.S.Botero, L.T.Benitez, J.Hinestroza, A.Herrera, *Environmental Nanotechnology, Monitoring & Management*, **14**, 100377(2020), <https://doi.org/10.1016/j.enmm.2020.100377>

12. Z.Ozturk, F.Sen, S.Sen, *Journal of Material Science*, **47(23)**, 8134(2012), <https://doi.org/10.1007/s10853-021-06352-9>
13. E.L.Foletto, S.Battiston, J.M.Simoes, M.M.Bassaco, L.S.F.Pereira, E.M.M.Flores, E.I.Muller, *Microporous and Mesoporous Materials*, **163**, 29(2012), <http://dx.doi.org/10.1016/j.micromeso.2012.06.039>
14. S.Mathur, M.Veith, M.Hass, H.Shen, N.Lecerf, V.Huch, *Journal of the American Ceramic Society*, **84(9)**, 1921(2001), <https://doi.org/10.1111/j.1151-2916.2001.tb00938.x>
15. P.Bhavani, A.Manikandan, P.Paulraj, A.Dinesh, M.Durka, S.A.Antony, *Journal of Nanoscience and Nanotechnology*, **17**, 1(2017), <https://doi.org/10.1166/jnn.2018.15217>
16. S.Sajjadifar, S.A.Mirshokraie, N.Javaherneshan, O.Louie, *American Journal of Organic Chemistry*, **2(2)**, 1(2012), <https://doi.org/10.5923/j.ajoc.20120202.01>
17. A.T.Khan, T.Parvin, L.H.Choudhury, *Synthetic Communications*, **39**, 2339(2009), <https://doi.org/10.1080/00397910802654815>
18. M.Kidwai, A.Jahan, D.Bhatnagar, *Journal of Chemical Sciences*, **122**, 607(2010), <https://doi.org/10.1007/s12039-010-0095-7>
19. S.Bonacci, G.Iriti, S.Mancuso, P.Novelli, R.Paonessa, S.Tallarico, M.Nurdi, *Catalysts*, **10**, 845(2020), <https://doi.org/10.3390/catal10080845>
20. D.Kathirvelan, P.Yuvaraj, K.Babu, A.S.Nagarajan, S.R.Reddy, *Indian Journal of Chemistry*, **52B**, 1152(2013).
21. B.Chen, C.Zhang, L.Niu, X.Shi, H.Zhang, X.Lan, G.Bai, *Chemistry- A European Journal*, **24**, 3481(2018), <https://doi.org/10.1002/chem.201704823>

[RJC- 8283/2022]