# Original Article

# Synthesis, evaluation of antimicrobial activity, and DFT analysis of 1-(4,5-diphenyl-1H-imidazol-2-yl)naphthalen-2-ol

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## ABSTRACT

In the present work, we report synthesis of 1-(4,5-diphenyl-1H-imidazol-2-yl)naphthalen-2-ol an asymmetric catalytic block, flurophore and pharmacologically potent triaryl imidazole derivative having naphthalene ring via solvent free eco-friendly method using Debus-Radiszewski condensation reaction of benzil with 2-hydroxy napthaldehyde in presence of molecular iodine as the catalyst and ammonium acetate as the source of nitrogen this method offered the compound in good yield compared to conventional method. The structure of the compound was established based on FTIR, multi nuclear NMR ($^{1}$H &$^{13}$C) spectral data and mass spectrometry. Pharmacological potency was evaluated through *in-vitro* antimicrobial activity against four different bacterial strains (Gram-ve bacteria *K aerogenes*, *E coli*, *P desmolyticm*, Gram+ve bacteria *S Aureus)* and two strains of fungi (*A flavus* and *C albicans) exhibiting potent Zone of inhibition of* 500µg/50µl and 10µg/50µl respectively in comparison with the standard drugs, followed by *in silico* ADME evaluation obeying the Lipinski's rule, molecular docking studies with the binding energy of -8.3 kcal/mo and -8.8 kcal/mol against docked antifungal and antibacterial protein respectively established the good agreement with the *in-vitro* result. Density functional theory (DFT), electro static potential diagram (ESP) and other computational techniques were utilized to analyze the physicochemical parameters like energy gap, ionization energy, and electron affinity successfully.

***Key words:*** 1-(4,5-diphenyl-1H-imidazol-2-yl)naphthalen-2-ol, *In-vitro* antimicrobial activity, *In silico* ADME, Molecular docking studies, DFT analysis.

Heterocyclic scaffolds having widespread pharmacyological activities have attracted great attention among Imidazole-based heterocyclic scaffolds play a vital role in natural and synthetic organic chemistry, have been well exploited for many medicinal scaffolds exhibiting anti-HIV [1-3], anticancer [4-6], anticonvulsant [7-9], antifungal [10-12] antibacterial [13-15], and anti-tubercular agent [15-17]. This core also has been utilized in other diverse pharmaceutical applications, stands out as a flexible substance with a wide range of uses, including biomedical technology and sophisticated materials. Because of its special blend of electron transport, photo stability [18], fluorescence [19], and catalytic qualities [20], it is an important component of scientific research and technological advancement.

## MATERIALS AND METHODS

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The organic solvents and chemicals were purchased from SD fine and Sigma Aldrich, standard commercial sources used without further purification.$^{1}$H and $^{13}$CNMR spectra were recorded on ECX500 Jeol 400 MHz high resolution multinuclear FT NMR Spectrometer with $LN_2$ cooled probe using deuterated solvent (DMSO-$d_6$), chemical shifts were expressed in parts per million (ppm) and Tetramethylsilane (TMS) as an internal standard. The Mass spectrum was recorded using waters micromass LCT mass detector.

## EXPERIMENTAL

**Synthesis of (4,5-diphenyl-1H-imidazol-2-yl)naphthalen-2-ol [3]:** A mixture of benzyl **(1)** 1mmol, 2-hydroxy-1-naphthaldehyde **(2)** 1mmol, $NH_4OAC$ (1mmol), were heated in presence molecular iodine $I_2$ (0.1 – 0.05mol) catalyst to70$^{o}$C. The reaction progress was monitored by thin layer chromatography using n-hexane-Ethyl acetate (7:3) solvent system. After the completion of the reaction the mixture was poured aqueous

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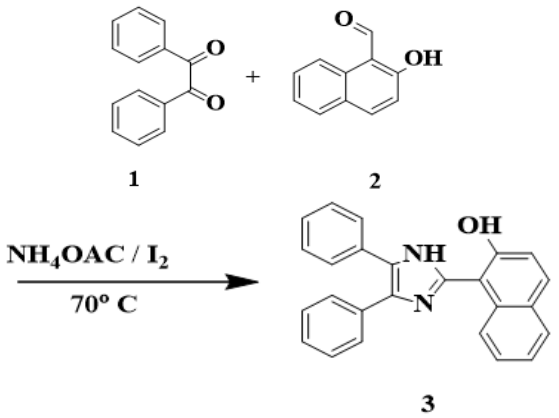
sodium thiosulphate ($Na_2S_2O_3$) as the desired compound separated out with excess of iodine destroyed by the thiosulphate, the crude compound was recrystallized using hot ethanol to obtain a dark yellow solid.




**Scheme 1: Synthetic route for iodine assisted synthesis of 1-(4,5-diphenyl-1H-imidazol-2-yl)naphthalen-2-ol (3).**

## RESULTS

**Chemistry:** 1-(4,5-diphenyl-1H-imidazol-2-yl)naphthalen-2-ol**(3)** was synthesized as depicted (**scheme-1**) in the presence of $I_2$ system. Further analytical characterization of the synthesized compound found to be **IR (ATR):** 3332cm$^{-1}$(br) (Imidazole–NH),2920cm$^{-1}$ (intramolecular hydrogen bonded OH), 1613cm$^{-1}$ (aromatic, -C=C), 1503 cm$^{-1}$ (Imidazole, –C=N), 1083 cm$^{-1}$ (C-O, alcohol stretching) **$^1$H NMR (400MHz, DMSO-d$_6$, δ, ppm):** 6.071(b, 1H, Ar-OH), 7.233-8.901 (m, 16H, ArH) 12.010 (s,1H, imidazole NH).**$^{13}$C NMR (100MHz,DMSO-d6, δ, ppm ):**117.889, 118.866, 119.834, 122.497, 123.829, 128.582, 130.057, 130.153, 132.204, 133.190, 133.401, 134.350, 136.113, 136.640, 154.634, 157.29. **calcd m/z from** MF ($C_{25}H_{18}N_2O$) = 362.1 **found m/z** = 363 ($M^{+1}$).

***In-vitro* Anitimicrobial Activity:** 1-(4,5-diphenyl-1h-imidazol-2-yl)naphthalen-2-ol **(3)** was assessed for their *in vitro* antibacterial activity against Gram-ve bacteria *K.aerogenes*, *E.coli*, *P.desmolyticm*, Gram+ve bacteria *S.Aureus* and the antifungal potency of these compounds was also tested against two fungal strains *A.flavus* and *C.albicans* using the using the agar well method. The antibacterial activity results of 1-(4,5-diphenyl-1h-imidazol-2-yl)naphthalen-2-ol**(3)**revealed good antibacterial activity against tested bacterial strains group in comparison with the standard Ciprofloxacin (CPFX) as shown in **Table 1**. And from the antifungal results, it is evident that compound showed excellent inhibition effects against the tested fungal strains compared to Clotrimazole (CLT) may be due to the presence of electron-donating –OH group. The results of this antifungal activity were given in **(Table 2).** The measurements were made in triplicate for each compound and their average values are reported.

**Table 1: The antibacterial activity of the 1-(4,5-diphenyl-1h-imidazol-2-yl)naphthalen-2-ol (3)**

| Sample | Treatment | Zone of Inhibition in mm | | | |
|---|---|---|---|---|---|
| | | Antibacterial activity | | | |
| | | *K. aerogenes* | *E. coli* | *P. desmolyticm* | *S. Aureus* |
| **3** | 250µg/50µl | 10 ± 0.03** | 10 ± 0.03** | 12 ± 0.04** | 13 ± 0.06** |
| | 500µg/50µl | 11 ± 0.05** | 12 ± 0.00** | 14 ± 0.05** | 13 ± 0.11** |
| **CPFX** | 5µg/50µl | 19 ± 0.5** | 18 ± 0.5** | 17 ± 0.5** | 33 ± 1.0** |
| **DMSO** | - | - | - | - | - |

**Table 2: The antifungal activity of the 1-(4,5-diphenyl-1h-imidazol-2-yl)naphthalen-2-ol (3)**

| Sample | Treatment | Zone of Inhibition in mm | |
|---|---|---|---|
| | | Antifungal activity | |
| | | *C. albicans* | *A. flavus* |
| **3** | 5µg/50µl | 11 ± 0.33** | 14 ± 1.0** |
| | 10µg/50µl | 25 ± 0.05** | 28 ± 1.0** |
| **CLT** | 5µg/50µl | 18 ± 0.03** | 23 ± 0.33** |
| **DMSO** | - | - | - |

**CPFX:** Ciprofloxacin, **CLT:** Clotrrimazole, **NA:** No activity, (±) Standard deviation values are the mean of three determinations, the ranges of which are <5% of the mean in all cases.

***In-silico* ADME evaluation:** The molecular properties and Lipinski rule of five for the compounds were determined by Swissadme online server [21]. Exploration of *in-silico* ADME properties of synthesized compounds in terms of molecular properties and toxicity profile are listed in **(Table 3).** Drug-likeness is a quantitative parameter that measures a compound's oral bioavailability. Abbot bioavailability score predicts the chance of a compound to have at least 10% oral bioavailability in rat or measurable Caco-2 cell line permeability experiment using a model for human intestinal absorption of drugs Drug-likeness scores were also calculated by considering (ALogP, TPSA, nAtoms, nON, nOH/NH, rotb& MW) based on Lipinski's rule for the prediction of bioactivity score. The results of these prediction showed that the compound obeyed Lipinski's rule. This semi-quantitative rule-based score defines the compounds into four probability score classes i.e. 11%, 17%, 55% and 85%. The acceptable probability score is 55% which indicates that it passed the rule of five. Further, synthetic accessibility was assessed to quantify the complexity of the molecular structure. The results showed that the score 3.00 revealed that the compounds does not have complex synthetic route [22].

**Table 3: *In-silico* ADME properties**

| Comp | MW | Alog P | nHBA | nHBD | nRB | TPSA (Å) | nViolations |
|---|---|---|---|---|---|---|---|
| | 362.42 | 4.01 | 2 | 2 | 3 | 48.91 | 0 |
| 3 | Bioactivity Score | | Synthetic accessibility | | Skin Sensitization | | BBB Score |
| | 0.55 (55%) | | 3.00 | | Nil | | 0.044 BBB+ |

**nHBA:** Hydrogen Bond Acceptor, **nHBD:** Hydrogen Bond Donor, **MW:** Molecular Weight, **Alogp:** Logarithm of partition b/w n-octanol and water, **nRB:** No. rotatable bonds, **TPSA:** Topological Polar Surface Area. **MW < 500 Dalton, *Alog P < 5 *nHBA<5 *nHBD< 5, *nRB< 10, * TPSA b/w 40-130*

**Molecular Docking Studies & Computational analysis:** The molecule structures were generated based on spectral data multi nuclear NMR ($^{1}H$ & $^{13}C$) and Mass Spectrometry. These structures were drawn in Marvin JS software and they were cleaned & orientation to 3D. All these molecule structures were prepared in Auto Dock 4.2 software and exported into PDB file format. The crystal structure of anti-fungal protein target - candida albicans n-myristoyltransferase **(PDB ID: 1IYL),** and anti-bacterial protein target – C (30) carotenoid dehydrosqualene synthase from staphylococcus aureus **(PDB ID: 3ACX),** were retrieved from Protein Data Bank. These protein structures prepared by removing the water molecules and small molecules in the complex.The molecular docking was performed in Auto Dock Vina 1.1.2 software to evaluate the binding affinity of the synthesized molecules with the protein targets. The Kollman charge was added to the protein residues and Lamarckian genetic algorithm was incorporated as scoring function. The grid box size for each protein was set significantly to cover the active site residues were standard drug bound. The default values were taken for all other parameters. Based on docking the top 10 poses will be generated and ranked based on binding energy.Docking Results are listed in **(Table 4)** and 2D binding pattern / poses of compound is shown in **(Figure 1, 2)** extracted using Schrodinger visualizer, it's found to be 1-(4,5-diphenyl-1H-imidazol-2-yl)naphthalen-2-ol **(3)** is nearly as potent as other standard drugs with a minute difference in binding score [23-25].

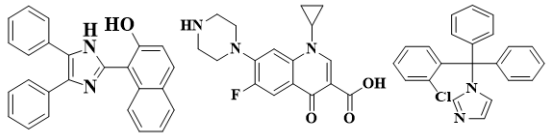



**Table 4: Binding / Docking Energy**

| Comp Code | PDB ID Role | Binding Score (Kcal/mol) | No of Interactions | Interactive residues |
|---|---|---|---|---|
| **3** | **1IYL** Anti-fungal protein target | -8.3 | **21** | Leu 415, Glu 109, Val 108, Tyr 107, Gly 212, Thr 211, Phe 176, Phe 117, Thr 119, Val 449, Leu 450, Leu 451, Leu 357, Tyr 335, Tyr 225, Tyr 354, Leu 394, Gln 226, Hid 227, Cys 393, Asn 392. |
| **CLT** | | -9.4 | | - |
| **3** | **3ACX** Anti-bacterial protein target | -8.8 | **19** | PHE 22, LEU 164, GLN 165, TYR 248, ASN 168, ARG 171, ASP 172, GLU 175, ASP 176, ARG 265, TYR 129, TYR 183, HIS 18, TYR 41, CYS 44, VAL 137, ARG 45, ASP 48 |
| **CPFX** | | -9.6 | | - |

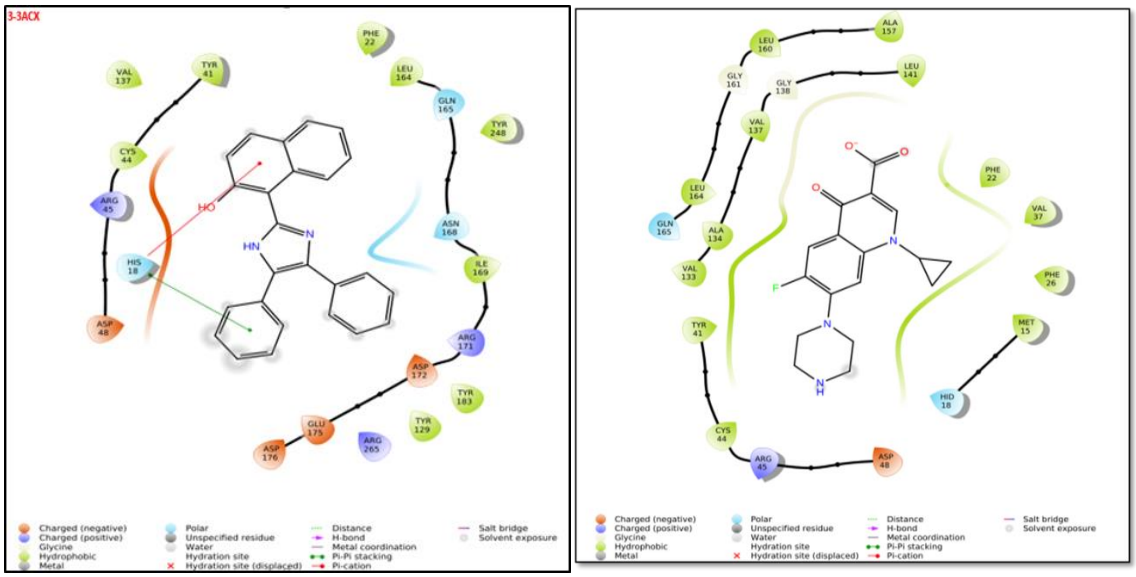



**Figure 1: 2D docking poses / binding patterns with 3AC**

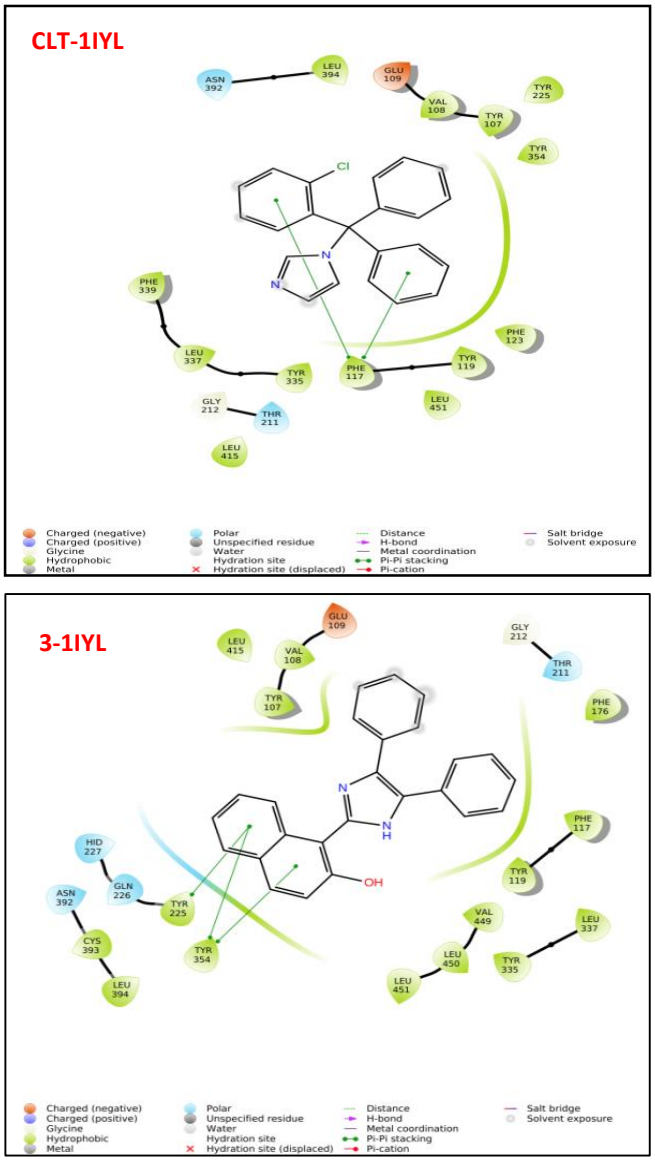



**Figure 2: 2D docking poses / binding patterns with 1IYL**

**DFT Analysis:** The theoretical calculations using density functional theory (DFT) have been utilized to study molecular properties like charge analysis, reduced density gradient (RDG) analysis, along with molecular electrostatic potential surface analysis gives a clear understanding of the structure of the molecule [26-27]. The molecular orbital energies and electrostatic potential of the molecule were calculated in the ground state using DFT. The reduced density gradient and global descriptors such as chemical potential, electronegativity, hardness, softness, and electrophilicity index were studied [28-29].

**Theoretical calculations:** The Becke's three parameter hybrid functional (B3) for the exchange part and the Lee-Young-Parr (LYP) correlation function at 6-31G(d,p) is used to perform the density functional theory calculations using *GAMESS-US* software [30]. All DFT calculations were performed in the gas phase only. The required input for the gamess software was generated using *Avogadro* [31]. The same parameters were used for the optimization structure and to calculate electronic properties. The surface potential and RDG were generated using *Multiwfn-3.8* [32], and visualized using *Visual Molecular Dynamics (VMD)* software [33].

**Frontier molecular orbital (HOMO-LUMO) analysis and chemical reactivity indices:** The frontier molecular orbitals (FMO) analysis is very helpful in understanding the nature of orbitals involved in chemical reactions. The FMO energy level of the compounds was computed using the DFT method at B3LYP/6-31G(d,p) level of theory in the gas phase. The surface of some important FMO's along with MEPs and RDGIs shown in (**Figure 3)**. The energy gap between the highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) was calculated found to be 9.969ev indicating its stability, further promoting high temperature conditions or acidic media for the reactiveness. The chemical reactivity parameters like chemical hardness (η), electronegativity (χ), electronic chemical potential (μ), and electrophilicity index (ω) were also calculated. The chemical hardness is given by $\eta=(E_{LUMO}-E_{HOMO})/2$ is connected with the stability and reactivity of a chemical system [34]. The electronegativity is defined as the ability to attract electrons towards it and is given by the expression $\chi=-(E_{HOMO}+E_{LUMO})/2$ found to be -0.1967 which is helpful in transport of electrons which is further supported by presence of aromatic rings. The negative of the electronegativity of a molecule is determined by using an equation $\mu=(E_{HOMO}+E_{LUMO})/2$ is known as chemical potential. Parr has introduced the electrophilicity index (ω), is calculated using the electronic chemical potential and chemical hardness from the equation $\omega=\mu^2/2\eta$. The calculated values of chemical reactivity parameters are listed in **(Table 5)**.

**Table 5: The calculated values of chemical reactivity parameters**

| $E_{HOMO}$ (eV) | $E_{LUMO}$ (eV) | Energy gap (Δ) (eV) | Ionization energy (I) (eV) | Electron affinity (A) (eV) |
|---|---|---|---|---|
| -5.1814 | 4.788 | 9.969 | 5.1814 | -4.788 |
| Electronegativity (χ) (eV) | Chemical potential (μ) (eV) | Global hardness (η) (eV) | Global softness (s) ($eV^{-1}$) | |
| -0.1967 | 0.1967 | 4.9847 | 0.200 | |

## DISCUSSION

The synthesized organic derivative via environmentally benign approach found to be potent biological agent exhibiting ZOI of 10mm, 10mm, 11mm & 13mm against four different strain of bacteria's *K aerogenes E coli P desmolyticm S Aureus* respectively and two different fungi strainst *C albicans A.flavus*

found to be susceptible witth the ZOI of 11mm and 14mm respectively at 5µg/50µl concentraion in comprison with the statnadrd drug, the evaluation of preliminary ADME properties foud to be compound is obeying the Lipinski's rule of five and *in-vitro* data are further supported with the *in silico* molecular docking analysis, obtained binding enegy values are supportig the *in-vitro* data. The DFT anaylsis established the molecular paramerters.

## CONCLUSION

In this work, we have successfully prepared 1-(4,5-diphenyl-1H-imidazol-2-yl) naphthalen-2-olimidazole (3) a versatile asymmetric building blockusing $I_2$ as catalyst. *In-vitro* antimicrobial activity followed by computer aided drug designing involving ADMETox and molecular docking studies were performed to establish the pharmaceutical activity and the physiochemical parameters were calculated using DFT analysis. In this paper we discuss the synthesis of of 1-(4,5-diphenyl-1H-imidazol-2-yl)naphthalen-2-ol **(3)** a versatile building block for assymetric catalyst was synthesized using modified method reported by the only available synthetic report, further the compound was evaluated for its pharmacological potency against bacterial and fungi strains. Additionally, computer aided drug discovery approaches like ADME, and molecular docking studies were carried out against 2 proteins. Results were compared against extensively used antibacterial,and antifungal standard drugs Ciprofloxacin **(CPFX)**, Clotrimazole **(CLT)** respectively. Finally, the synthesized title compound was subjected to DFT analysis to establish physicochemical parameters.

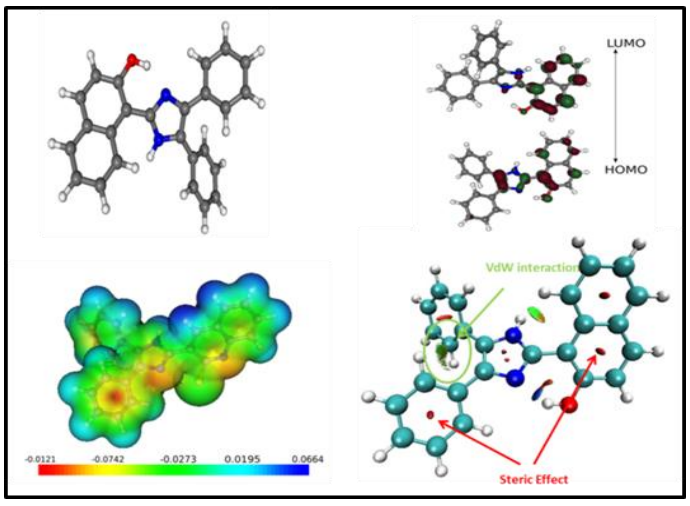



**Figure 3: HOMO-LUMO energy gap of compound along with electrostatic potential diagram and RDG**

## REFERENCES


1. Pouria Shirvani, Afshin Fassihi, Lotfollah Saghaie, et al. Synthesis, anti-HIV-1 and antiproliferative evaluation of novel 4-nitroimidazole derivatives combined with 5-hydroxy-4-pyridinone moiety. J Molecular Struc. 2020; (1202):127344.
2. Zhan P, Liu X, Zhu J, et al. Synthesis and biological evaluation of imidazole thioacetanilides as novel non-nucleoside HIV-1 reverse transcriptase inhibitors. Bioorg Med Chem. 2009; 17(16):5775-81.
3. Ganguly S, Vithlani VV, Kesharwani AK, et al. Synthesis, antibacterial and potential anti-HIV activity of some novel imidazole analogs. Acta Pharm. 2011; 61(2):187-201.
4. Sharma P, LaRosa C, Antwi J, et al. Imidazoles as Potential Anticancer Agents: An Update on Recent Studies. Molecules. 2021; 26(14):4213.
5. Heydari M, Moghadam ME, Tarlani A, et al. DNA as a Target for Anticancer Phen-Imidazole Pd(II) Complexes. Appl Biochem Biotechnol. 2017; 182(1):110-127.
6. Rahimzadeh Oskuei S, Mirzaei S, Reza Jafari-Nik M, et al. Design, synthesis and biological evaluation of novel imidazole-chalcone derivatives as potential anticancer agents and tubulin polymerization inhibitors. Bioorg Chem. 2021; 112:104904.
7. Kishbaugh TL. Pyridines and Imidazopyridines with Medicinal Significance. Curr Top Med Chem. 2016; 16(28):3274-3302.
8. Kapetanovic IM, Kupferberg HJ. Nafimidone, an imidazole anticonvulsant, and its metabolite as potent inhibitors of microsomal metabolism of phenytoin and carbamazepine. Drug Metab Dispos. 1984; 12(5):560-4.
9. Bastaki SM, Abdulrazzaq YM, Shafiullah M, et al. Anticonvulsant and reproductive toxicological studies of the imidazole-based histamine H3R antagonist **2-18** in mice. Drug Des Devel Ther. 2018; 12:179-194.
10. Sharma A, Kumar V, Kharb R, et al. Imidazole Derivatives as Potential Therapeutic Agents. Curr Pharm Des. 2016; 22(21):3265-301.
11. Zhao D, Zhao S, Zhao L, et al. Discovery of biphenyl imidazole derivatives as potent antifungal agents: Design, synthesis, and structure-activity relationship studies. Bioorg Med Chem. 2017; 25(2):750-758.
12. Beggs WH, Andrews FA, Sarosi GA. Action of imidazole-containing antifungal drugs. Life Sci. 1981; 28(2):111-8.
13. Duan YT, Wang ZC, Sang YL, et al. Exploration of structure-based on imidazole core as antibacterial agents. Curr Top Med Chem. 2013; 13(24):3118-30.
14. Andrei GȘ, Andrei BF, Roxana PR. Imidazole Derivatives and their Antibacterial Activity: A Mini-Review. Mini Rev Med Chem. 2021; 21(11):1380-1392.
15. Hu Y, Shen Y, Wu X, et al. Synthesis and biological evaluation of coumarin derivatives containing imidazole skeleton as potential antibacterial agents. Eur J Med Chem. 2018; 143:958-969.
16. Hu Y, Shen Y, Wu X, et al. Synthesis and biological evaluation of coumarin derivatives containing imidazole skeleton as potential antibacterial agents. Eur J Med Chem. 2018; 143:958-969.
17. Meta E, Brullo C, Tonelli M, et al. Pyrazole and imidazo [1,2-b]pyrazole Derivatives as New Potential Antituberculosis Agents. Med Chem. 2019; 15(1):17-27.
18. Gotico P, Herrero C, Protti S, et al. Proton-controlled Action of an Imidazole as Electron Relay in a Photoredox Triad. Photochem Photobiol Sci. 2022; 21(2):247-259.
19. Keum C, Park S, Lee SY. Cancer-Cell Imaging Using Copper-Doped Zeolite Imidazole Framework-8 Nanocrystals Exhibiting Oxidative Catalytic Activity. Chem Asian J. 2018; 13(18):2641-2648.
20. Begum SZ, Nizam NSM, Muhamad A, et al. Imidazole-rich copper peptides as catalysts in xenobiotic degradation. PLoS One. 2020; 15(11):e0238147.
21. Daina A, Michielin O, Zoete V. SwissADME: a free web tool to evaluate pharmacokinetics, drug-likeness and medicinal chemistry friendliness of small molecules. Sci Rep. 2017; 7:42717.

22. Yousuf M, Rafi S, Ishrat U, et al. Potential Biological Targets Prediction, *ADME* Profiling, and Molecular Docking Studies of Novel Steroidal Products from *Cunninghamella blakesleana*. Med Chem. 2022; 18(2):288-305.
23. K Pruthviraj, Lohith N, Yeshwanth M, et al. Molecular iodine catalyzed solvent free one pot Synthesis, Characterization, Insilico Adme, Herg Analysis, Molecular Docking Studies and DFT Analysis of 2- substituted 4,5-diphenyl-1h-imidazole derivatives. J Adv Scien Res. 2021; 12(04):211-29.
24. Krishna swamy G, Golla Ramesh, Pruthviraj K, Synthesis, Characterization, Pass prediction, In-silico ADME, Molecular docking and Cyclic voltammetry studies of 1, 4, 5-trisubstituted 1, 2, 3-triazole ethanone and ethanol derivatives via Metal free approach. Science Direct. 2020. Available from: https://doi.org/10.1016/j.cdc.2020.100452.
25. Schulz JD, Gauthier MA, Leroux JC. Improving oral drug bioavailability with polycations? Eur J Pharm Biopharm. 2015; 97(Pt B):427-37.
26. S Gandhimathi, C Balakrishnan, M Theetharappan, et al. Noncovalent interactions from electron density topology and solvent effects on spectral properties of Schiff bases. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 2017; 175:134-144.
27. DV Geetha, FH Al-Ostoot, YHE Mohammed, et al. Synthesis, Elucidation, Hirshfeld surface analysis, and DFT calculations of 4-chloro-N-[2-(2-1H-indol-3-yl-acetylamino)-phenyl]-benzamide. J Molecular Struc. 2019; 1178:384-393.
28. Giuseppe MJ Barca, Colleen Bertoni, Laura Carrington. Recent developments in the general atomic and molecular electronic structure system. J Chem Physics. 2020; 152:154102.
29. Marcus D Hanwell, Donald E Curtis, David C Lonie, et al. Avogadro: an advanced semantic chemical editor, visualization, and analysis platform. J Cheminformatics. 2012; 4:17
30. T Lu, F Chen. Multiwfn: A multifunctional wavefunction analyzer. J Computational Chemistry. 2012; (33):580-592.
31. W. Humphrey, A. Dalke, & K. Schulten, J Molecular Graphics. 1996; 33-38.
32. Govindarajan M, Karabacak M, Suvitha A, et al. FT-IR, FT-Raman, ab initio, HF and DFT studies, NBO, HOMO–LUMO and electronic structure calculations on 4-chloro-3-nitrotoluene. SpectrochimicaActa Part A: Molecular and Biomolecular Spectroscopy. 2012; 89:137-148.
33. RG Parr, ARA Donnelly, M Levy, et al. Electronegativity: The density functional viewpoint. Phys Rev Sec. 1964; 136:864.

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