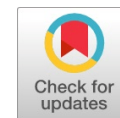


Novel Benzimidazole Bejeweled Pyrazole: Synthesis, Characterization and Density Functional Theory Analysis



Ramar Sivaramakarthikeyan, Krishnaraj Padmavathy, Vadivel Saravanan,
 Chennan Ramalingan

Abstract: A novel benzimidazole festooned pyrazolyl acrylonitrile **6** has been synthesized with a good yield via Knoevenagel condensation method and the structure has been elucidated based on analytical and spectroscopic methods. DFT-B3LYP calculation with 6-311 G(d,p) basis set has been performed for optimization of the structure and to determine their structural - energy parameters. The HOMO -LUMO analysis and polarizability cum hyper polarizability values ensure compound **6** is likely to be NLO material that could also find use in solar cells. Besides, the electronic properties and the structural cores imply that the molecule could also serve as bioagent.

Keywords: Knoevenagel condensation, DFT, NLO, pyrazole, benzimidazole.

I. INTRODUCTION

Most of the biologically energetic compounds comprise of nitrogen heterocyclic frame work. Nitrogen heterocycles find applications in pharmaceuticals and agrochemicals [1]. Pyrazole is one such heterocycle with two adjacent nitrogen atoms in aromatic five-membered ring structure [2]. Pyrazole derivatives show extensive bio-potent activities such as antimicrobial [3], antirheumatic [4-6], anti-inflammatory [7-9], anticancer [10], radio protective [11], antiproliferative [12], and anti-tuberculosis [13]. Few pyrazoles were reported to display photosynthetic electron transport inhibition properties [14]. Certain Ir(III) complexes (sublimable and cationic) possessing pyrazole-based ligands were proved to be promising blue-green-emitting OLED [Quantum efficiency - 5.9%; (0.19, 0.30) color coordinates & 11.3%; (0.27, 0.50) color coordinates] [15]. Norbornene category of copolymers possessing dialkylpyrazole motif were reported

to be efficient in stabilizing in-situ produced magnetite nanoparticles [16]. Besides these, they also find applications in semiconductors [17], solar cells [18] and liquid crystals [19]. Benzimidazole is yet another nitrogen heterocyclic compound with fused benzene and imidazole rings. It exhibits wide spread biological activities such as antimicrobial [20], antihistaminic [21], antiparasitic [22], antiallergic [23], anticancer [24] and antioxidant [25]. In addition, its derivatives display efficiency in material science field. Specifically, benzimidazole containing sulfonated polyethersulfones displayed high IEC and proton conductivity value with low swelling ratios, promising a worthy role towards proton exchange membrane applications [26]. The supramolecular assembly of benzimidazole derivatives is reported to find application in sensor fabrication [27], drug delivery systems [28], and fuel cell design [29].

In view on the above-mentioned potential applications, a molecule containing both the pyrazole and imidazole motifs has been designed to synthesize for various applications. This piece of work depicts synthesis and characterization of novel benzimidazole integrated pyrazolyl acrylonitrile **6**. This novel compound has been optimized utilizing DFT-B3LYP [6-311G (d,p)]. Further, quantum chemical parameters such as molecular geometry, HOMO-LUMO, MEP, Mulliken charge distribution and NLO properties of synthesized molecule have also been determined.

II. EXPERIMENTAL SECTION

A. General

All reactants / reagents used in the present study are reagent grade and the solvents were distilled prior to use. TLC and open capillary were used to observe the reactions progress and to measure the melting point, respectively. Shimadzu IR Tracer-100 spectrophotometer and Bruker AVANCE III NMR spectrometer were utilized for recording IR and NMR spectra, respectively.

B. Synthesis of carbaldehyde **4** [30]

A mixture of ketone **1** (0.01 mol) and hydrazine **2** (0.01 mol) in 10 ml glacial acetic acid was heated at 80 °C for 30 minutes. Filtered the reaction mixture after cooling, washed the solid (**3**) thus obtained using dil.HCl solution and recrystallized from ethanol.

Manuscript published on 30 December 2019.

* Correspondence Author (s)

Ramar Sivaramakarthikeyan, Department of Chemistry, School of Advanced Sciences, Kalasalingam Academy of Research and Education (Deemed to be University), Krishnankoil, 626 126, Tamilnadu, India. Email: sivaram.ramar@gmail.com

Krishnaraj Padmavathy, Department of Chemistry, School of Advanced Sciences, Kalasalingam Academy of Research and Education (Deemed to be University), Krishnankoil, 626 126, Tamilnadu, India. Email: ovshada@gmail.com

Vadivel Saravanan, Department of Chemistry, School of Advanced Sciences, Kalasalingam Academy of Research and Education (Deemed to be University), Krishnankoil, 626 126, Tamilnadu, India. Email: saravananvj11@gmail.com

***Chennan Ramalingan**, Department of Chemistry, School of Advanced Sciences, Kalasalingam Academy of Research and Education (Deemed to be University), Krishnankoil, 626 126, Tamilnadu, India. Email: ramalinganc@gmail.com

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an [open access](https://creativecommons.org/licenses/by-nc-nd/4.0/) article under the CC-BY-NC-ND license <http://creativecommons.org/licenses/by-nc-nd/4.0/>

Pure arylhydrazone obtained was treated with Vilsmeier-Haack reagent [DMF (10 ml)-POCl₃ (0.03 mol)] at 0 °C and it was heated at 70-80 °C for 6h. It was then brought in to RT and then poured in to cold water. After neutralization using saturated solution of sodium bicarbonate, followed by washing and drying, the solid thus obtained was recrystallized from ethanol to give pure product **4**.

C. Synthesis of novel acrylonitrile **6**

To a methanolic mixture of carbaldehyde **4** (0.5 g, 1.58 mmol) and imidazolyl acetonitrile **5** (0.25 g, 1.58 mmol), was added piperidine (0.16 ml, 1.58 mmol) dropwise. It was stirred at 60 °C for 6h. After completion of the reaction, it was poured into water (ice-cold). A saturated solution of potassium carbonate was then added drop-wise until neutralization. It was filtered, washed (water), dried and recrystallized (ethanol) to give pure target compound **6**. Yield, 89 %; MP: 310-311°C; FT-IR (KBr, cm⁻¹): ν 3290.4, 2240.1, 1600.7, 1531.3, 1418.1, 1355.3, 1244.5, 1111.2, 1052.7, 969.6, 856.5, 813.3, 757.0, 677.7, 663.5, 635.3, 497.6; ¹H NMR (400 MHz, CDCl₃): δ 8.76 (d, *J* = 8 Hz, 2H), 8.6 (s, 1H), 7.77-7.64 (m, 5H), 7.52-7.42 (m, 3H), 7.36 (t, *J* = 8 Hz, 1H), 7.28 (s, 2H), 5.24 (s, 1H) ppm; ¹³C NMR (100 MHz, CDCl₃): δ ppm 180.1, 136.1, 129.8, 129.6, 129.3, 127.2, 125.5, 123.8, 119.1 ppm.

D. Computational details

The entire set of calculations of **6** has been made by exploiting DFT-B3LYP (6-311G (d,p) method [Gaussian 09 program] [31]. The DFT-B3LYP is a universally accepted cheap method of computation for structural optimization [32]. Optimized molecular geometry, HOMO-LUMO energy calculations, MEP, Mulliken atomic charge distributions and NLO properties of the compound **6** were acquired from the above computational method.

III. RESULTS AND DISCUSSION

Chemistry

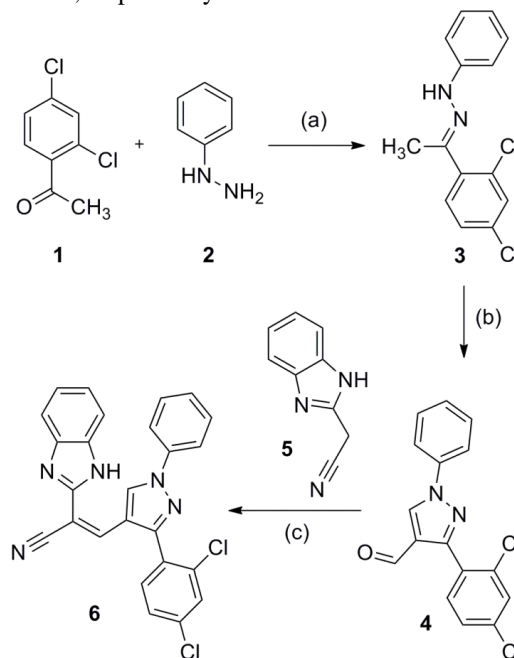
A. Synthesis and characterization

The phenyl hydrazone derivatization of 1-(2,4-dichlorophenyl)ethanone **1**, followed by cyclization and formylation using Vilsmeier Haack reagent yielded the carbaldehyde intermediate **4**. Knoevenagel condensation between the carbaldehyde **4** and benzimidazolyl acetonitrile **5** using piperidine as catalyst eventually rendered the target acrylonitrile **6** as shown in **Scheme 1**. The absence of characteristic vibrational frequency in the region of carbonyl absorption in the IR spectrum and absence of one proton singlet in the aldehydic proton region (~ δ 9.5 ppm) in the ¹H NMR spectrum and the presence of medium peak at 2240 cm⁻¹, consistent to nitrile group, confirms the target compound. The proton and carbon spectra agreed well with the structure of target molecule **6**.

B. Geometry Optimization

The structural optimization of compound **6** was made using computational DFT/B3LYP [6-311G (d,p)] method. The optimized structure (ground state) is depicted in **Fig. 1** and structural parameters (bond lengths, bond angles, and dihedral angles) are furnished in **Tables 1 & 2**. As exposed in

Fig. 1, the molecular geometry of the parental pyrazole structural ornament has a typical butterfly form. The N25-H43, C17-Cl23, C19-Cl22, and C1-N4 bond lengths are 1.0071, 1.7533, 1.7533 and 1.1549 Å respectively agrees with the expected values 1.0 (N-H), 1.76 (C-Cl) and 1.16(CN). The bond angles between C8-C3-H33, C2-C3-C8, C3-C8-C9, and C3-C2-C24 are 114.233, 130.171, 130.124 and 127.719, respectively.



Scheme 1: Synthesis of target molecule **6. Reagents and conditions: (a) Glacial acetic acid, reflux, 30 min; (b) DMF-POCl₃, 70-80 °C, 6h; (c) Piperidine, methanol, 60 °C, 6h.**

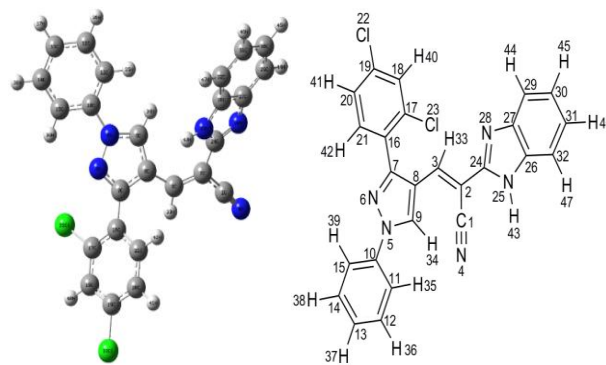


Fig. 1. Optimized Structure of **6**

TABLE 1: BOND LENGTH OF **6**

Bond lengths	(Å)	Bond lengths	(Å)
C1-C2	1.4335	C16-C17	1.4046
C1-N4	1.1549	C16-C21	1.4029
C2-C3	1.3607	C17-C18	1.3915
C2-C24	1.4675	C17-Cl23	1.7533
C3-C8	1.4488	C18-C19	1.3892

C3-H33	1.0852	C18-H40	1.0808
N5-N6	1.3536	C19-C20	1.3896
N5-C9	1.3564	C19-C122	1.7533
N5-C10	1.4251	C20-C21	1.3885
N6-C7	1.3249	C20-H41	1.0816
C7-C8	1.4356	C21-H42	1.0833
C7-C16	1.4759	C24-N25	1.3831
C8-C9	1.3899	C24-N28	1.3126
C9-H34	1.0760	N25-C26	1.3812
C10-C11	1.3959	N25-H43	1.0071
C10-C15	1.3957	C26-C27	1.4154
C10-C11	1.3959	C26-C32	1.3947
C10-C15	1.3957	C27-N28	1.3808
C11-C12	1.3917	C27-C29	1.3998
C11-H35	1.0829	C29-C30	1.3869
C12-C13	1.3927	C29-H44	1.0829
C12-H36	1.0836	C30-C31	1.4086
C13-C14	1.3939	C30-H45	1.0837
C13-H37	1.0835	C31-C32	1.3898
C14-C15	1.3904	C31-H46	1.0839
C14-H38	1.0837	C32-H47	1.0839
C15-H39	1.0810		

TABLE 2: BOND ANGLE OF 6

Bond Angles	[°]	Bond Angles	[°]
C1-C2-C3	117.3249	C16-C17-C18	121.5509
C1-C2-C24	114.9401	C16-C17-C123	121.4788
C3-C2-C24	127.7186	C18-C17-C123	116.9432
C2-C3-C8	130.1709	C17-C18-C19	119.2361
C2-C3-H33	115.5713	C17-C18-H40	120.1155
C8-C3-H33	114.2332	C19-C18-H40	120.6459
N6-N5-C9	112.1044	C18-C19-C20	121.1037
N6-N5-C10	119.9915	C18-C19-C122	119.1377
C9-N5-C10	127.8950	C20-C19-C122	119.7583
N5-N6-C7	105.6323	C19-C20-C21	118.6553
N6-C7-C8	111.3188	C19-C20-H41	120.4743
N6-C7-C16	121.4943	C21-C20-H41	120.8691
C8-C7-C16	127.1523	C16-C21-C20	122.3135
C3-C8-C7	125.7543	C16-C21-H42	118.6775
C3-C8-C9	130.1238	C20-C21-H42	118.9997
C7-C8-C9	103.6365	C2-C24-N25	123.3527
N5-C9-C8	107.2959	C2-C24-N28	124.0894
N5-C9-H34	121.9375	N25-C24-N28	112.4880
C8-C9-H34	130.5823	C24-N25-C26	107.1375
N5-C10-C11	120.2499	C24-N25-H43	125.8585
N5-C10-C15	119.1463	C26-N25-H43	126.8608
C11-C10-C15	120.6037	N25-C26-C27	104.5443
C10-C11-C12	119.4433	N25-C26-C32	132.9686
C10-C11-H35	120.7421	C27-C26-C32	122.4870
C12-C11-H35	119.8055	C26-C27-N28	110.2965
C11-C12-C13	120.4170	C26-C27-C29	119.8389
C11-C12-H36	119.3362	N28-C27-C29	129.864
C13-C12-H36	120.2431	C24-N28-C27	105.5299
C12-C13-C14	119.6218	C27-C29-C30	117.9713
C12-C13-H37	120.1477	C27-C29-H44	120.0614
C14-C13-H37	120.2299	C30-C29-H44	121.9669
C13-C14-C15	120.6257	C29-C30-C31	121.4197
C13-C14-H38	120.0990	C29-C30-H45	119.5950
C15-C14-H38	119.2741	C31-C30-H45	118.9850
C10-C15-C14	119.2803	C30-C31-C32	121.6675
C10-C15-H39	119.1215	C30-C31-H46	119.1625
C14-C15-H39	121.5976	C32-C31-H46	119.1699
C7-C16-C17	123.6723	C26-C32-C31	116.6147
C7-C16-C21	119.1921	C26-C32-H47	122.1085
C17-C16-C21	117.1352	C31-C32-H47	121.2758

C. Mulliken charge distribution

Mulliken population method yields the net atomic charge distribution of specific atoms in a molecule and thereby, the acceptor and donor pairs connecting the charge transfer in the molecule can be established [33, 34]. MEP analyses of **6** was attained from the optimized structural calculation and the results are given in **Table 3**. The apparent atomic charge distribution of compound **6** is represented by coloring in **Fig. 2**. The net atomic charge distribution of compound is shown in **Fig. 2**. The output clearly indicates that the atom C24 of benzimidazole ring has got more positive charge due to electron-withdrawing character of nitrile moiety attached to the adjacent carbon atom and two neighboring electronegative nitrogen atoms. Also, the C7 atom of pyrazole ring holds almost nearer positive charge as that of C24 due to adjacent nitrogen atom, whereas the nitrogen N25 showed greater negative charges.

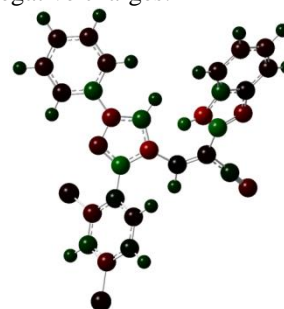


Fig. 2. Optimized Structure and Mulliken charge distribution of 6

Table 3. Mulliken atomic charges of 6

Atom	Charges	Atom	Charges
C1	0.074416	N25	-0.467867
C2	-0.036626	C26	0.186284
C3	0.003821	C27	-0.016192
N4	-0.220347	N28	-0.318904
N5	-0.337571	C29	-0.059183
N6	-0.218109	C30	-0.102555
C7	0.294978	C31	-0.108248
C8	-0.414329	C32	-0.058206
C9	0.228837	H33	0.138563
C10	0.208587	H34	0.144945
C11	-0.108912	H35	0.110456
C12	-0.099164	H36	0.104865
C13	-0.078347	H37	0.104076
C14	-0.098311	H38	0.107065
C15	-0.060896	H39	0.138675
C16	0.035685	H40	0.144074
C17	-0.208725	H41	0.126993
C18	0.148479	H42	0.108412
C19	-0.237820	H43	0.246255
C20	0.029788	H44	0.105149
C21	-0.045363	H45	0.098377
C122	-0.046463	H46	0.098213
C123	-0.046666	H47	0.093148
C24	0.308664		

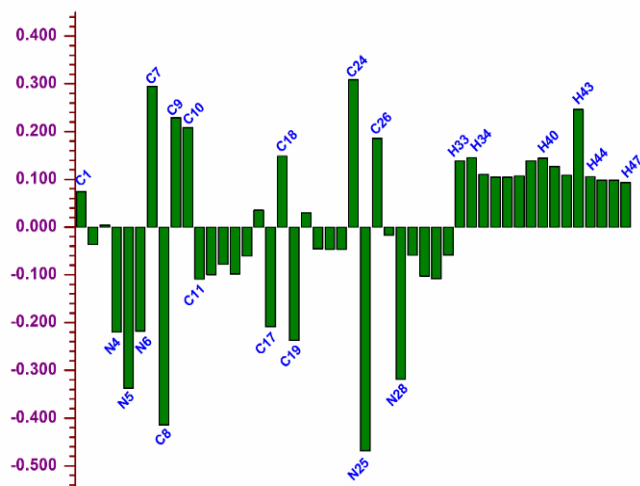


Fig. 3. Mulliken charge distribution of 6

D. HOMO-LUMO Analysis

The kinetic stability and chemical reactivity of a compound can be demonstrated based on the energy gap and localization of FMOs. HOMO-LUMO energy gap assist in determination of charge transport properties and electronic structure of a molecule [35]. Larger the difference between HOMO and LUMO greater will be the stability and chemical hardness. The electron distribution in the frontier molecular orbitals and their corresponding energy related values of the title acrylonitrile 6 are shown in Fig. 4 and Table 4, respectively. HOMO orbitals are mostly located on the pyrazole ring and the LUMO orbitals are largely placed on the

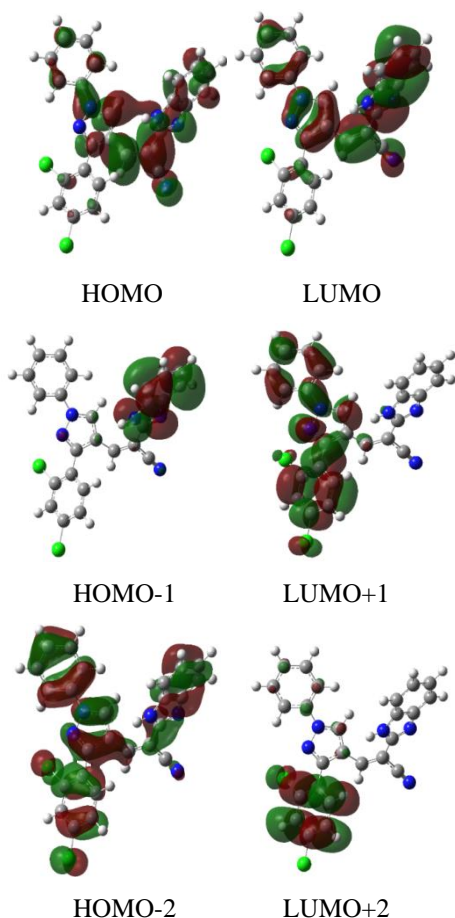


Fig. 4. Frontier Molecular Orbitals of 6

benzimidazole and pyrazole moieties. However, the HOMO-1, LUMO+1, HOMO-2 and LUMO+2 molecular orbitals are located on benzimidazole scaffold, pyrazole ring and other phenyl rings attached to it, entire molecule and dichloro substituted phenyl ring, respectively thus, supporting intermolecular electron transfer.

Table 4. Energy distribution in FMO of 6

Parameters	eV
HOMO	-6.3016
LUMO	-2.5875
ΔE	3.7141
HOMO-1	-6.7239
LUMO+1	-1.7894
ΔE_1	4.9345
HOMO-2	-6.9354
LUMO+2	-1.2719
ΔE_2	5.6635

E. Molecular electrostatic potential analysis

The MEP predicts the reactivity of any molecule as it is related to electron density (ED) [36]. The MEP is supportive in identifying the locations for electrophilic and nucleophilic attack [37]. It is interpreted as a color spectrum (blue – highest and red – lowest electrostatic potential). MEP map of 6 was resulted from optimized structural calculation.

The Fig. 5 shows the total density and electrostatic potential with its contour model of 6 (0.002 a.u. isosurface). It could be observed from MEP images that the color code of the maps is in the range between 0.111 E (nucleophilic attacking sites) and -0.111 E (electrophilic attacking site). The areas of red, high potential, are considered by abundance of electrons. From Fig 5, it is indicative that the nitrile (red) is most reactive site for electrophilic attack.

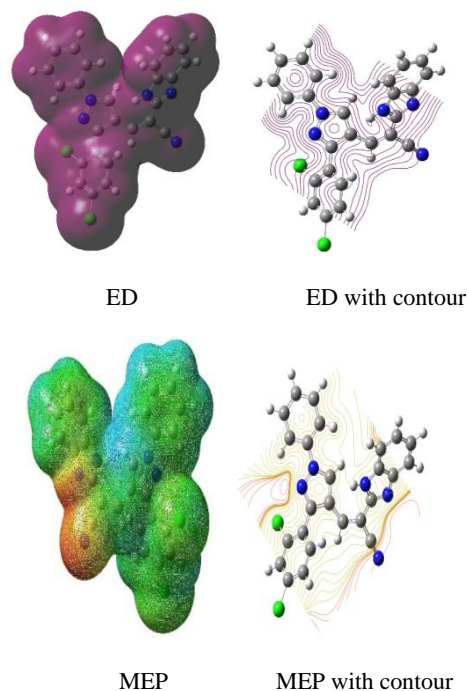


Fig. 5. Molecular electrostatic potential map of 6

F. Non-linear optical characteristics

To realize the relation between NLO characteristics and molecular structure, the hyperpolarizabilities besides polarizabilities and dipole moments of **6** was calculated and the results are furnished in Table 5. It is documented that molecules with high values of hyperpolarizability, polarizability, and dipole moment exhibit potent NLO behaviors. The total dipole moment (calculated one) is found to be 7.9778 Debye and average polarizability and hyperpolarizability are found to be 4.9128×10^{-23} Debye-Ang and 3.0902×10^{-30} esu, respectively. The hyperpolarizability of the synthesized molecule **6** is observed to be 3.8 times greater than urea molecule, a typical NLO material [38]. Thus, the compound **6** would be a promising NLO material.

Table 5. NLO Properties of 6

Parameters	Values
Dipole moment	
μ_x	-1.5194
μ_y	6.7469
μ_z	-3.9769
$\mu(D)$	7.9778
Polarizability	
α_{xx}	-191.1592
α_{yy}	-209.5043
α_{zz}	-204.0579
α_{total}	4.9128×10^{-23}
α_0	-201.5738
Hyper-polarizability	
β_{xxx}	-86.5830
β_{xxy}	37.4778
β_{xyy}	25.0073
β_{yyy}	282.2245
β_{xxz}	-13.6552
β_{xyz}	0.7472
β_{yyz}	-68.8795
β_{xzz}	11.8297
β_{yzz}	18.4029
β_{zzz}	-23.0823
β_0	3.0902×10^{-30}

IV. CONCLUSION

To summarize the present work, we have synthesized a novel acrylonitrile **6** and characterized. The quantum chemical parameters such as molecular geometry (bond angles and bond lengths), FMO, MEP, Mulliken charge distribution analyses and NLO properties of the novel molecule were computed. The small HOMO-LUMO energy gap and orbital localization indicated plausible inter electron transfer process, signifying the compound **6** has potential to be applied in the field of organic solar cells. Further, the predicted polarizability (4.9128×10^{-23}) and first order hyperpolarizability (3.0902×10^{-30}) values of the molecule are greater than urea. The result also signifies the compound **6** as a hopeful nonlinear optic material.

ACKNOWLEDGMENT

Financial assistance provided by the Indian Council of Medical research (No.58/16/2013-BMS), New Delhi, India is

gratefully acknowledged.

REFERENCES

- [1] C. Fernando, R-A. Andrés, I-M. María, E. T. John, M. F. Rodolfo, A. Rodrigo, R. K. Alan, C. T. Juan, W. L. Christian, "Synthesis, structural characterization, and theoretical studies of new pyrazole (E)-2-[[5-(tert-butyl)-1H-pyrazol-3-yl]imino]methyl]phenol and (E)-2-[[1-(4-bromophenyl)-3-(tert-butyl)-1H-pyrazol-5-yl] imino]methyl]phenol," *J. Mol. Struct.*, vol. 1184, pp. 59-71, May 2019.
- [2] R. Thomas, Y. S. Mary, K. S. Resmi, B. Narayana, B. K. Sarojini, G. Vijayakumar, C. Van Alsenoy, "Two neoteric pyrazole compounds as potential anti-cancer agents: Synthesis, electronic structure, physico-chemical properties and docking analysis," *J. Mol. Struct.*, vol. 1181, pp. 455-466, April 2019.
- [3] S. Samshuddin, B. Narayana, B. K. Sarojini, M. T. H. Khan, H. S. Yathirajan, C. G. Darshan Raj, R. Raghavendra, "Antimicrobial, analgesic, DPPH scavenging activities and molecular docking study of some 1,3,5-triaryl-2-pyrazoline," *Med. Chem. Res.*, vol. 21, pp. 2012-2022, August 2012.
- [4] E. S. H. Ei-Ashry, L. F. Awad, E. I. Ibrahim, O. K. Bdeewy, "Synthesis of antipyrene derivatives derived from dimedone" *Chinese J. Chem.*, vol. 25, pp. 570, April 2007
- [5] N. Uramaru, H. Shigematsu, A. Toda, R. Eyanagi, S. Kitamura, S. Ohta, "Design, Synthesis, and Pharmacological Activity of Nonallergenic Pyrazolone-Type Antipyretic Analgesics," *J. Med. Chem.*, vol. 53, pp. 8727-8733, December 2010.
- [6] A. M. Isloor, B. Kalluraya, M. Rao, "Sydnone derivatives: part IV: synthesis of 3-aryl-4-(substituted pyrazolidene hydrazine-4-thiazolyl) sydnones as possible analgesic and anticonvulsant agents," *J. Saudi Chem. Soc.*, vol. 4, pp. 265-270, April 2000.
- [7] E. Bansal, V. K. Srivastava, A. Kumar, "Synthesis and anti-inflammatory activity of 1-acetyl-5-substitute daryl-3-(β -aminonaphthyl)-2-pyrazolines and β -(substitute daminoethyl) amidonaphthalenes," *Eur. J. Med. Chem.*, vol. 36, pp. 81-92, September 2001.
- [8] A. A. Bekhit, T. Abdel-Aziem, "Design, synthesis and biological evaluation of some pyrazole derivatives as anti-inflammatory-antimicrobial agents," *Bioorg. Med. Chem.*, vol.12, pp.1935-1945, April 2004.
- [9] M. Youssef, E. G. Neeland, E. B. Villanueva, M. S. White, I. M. El-Ashmawy, B. Patrick, A. Klegeris, A. S. Abd-El-Aziz, "Synthesis and biological evaluation of novel pyrazole compounds," *Bioorg. Med. Chem.*, 2010, vol. 18, pp. 5685-5696, August 2010.
- [10] Sunil, A. M. Isloor, P. Shetty, "Synthesis, characterization and anticancer activity of 1, 2, 4-triazolo [3, 4-b]-1, 3, 4-thiadiazoles on Hep G2 cell lines," *Der. Pharma. Chemica.*, vol. 1, pp. 19-26, June 2009.
- [11] J. Mohan, B. K. Sarojini, B. Narayana, G. Sanjeev, "Radioprotective effect of an edaravone analogue 3-methyl-1- (4-(trifluoromethyl) phenyl)-1,2-dihydropyrazol-5- one," *Indo. Am. J. Pharm. Res.*, vol. 3, pp. 1650-1659, December 2013.
- [12] S. Rao, P. M. Akberali, B. S. Holla, B. K. Sarojini, "Synthesis and Studies on Some New Fluorine Containing Hydroxypyrazolines and 1H Pyrazoles-as Possible Antiproliferative Agents," *J. Pharm and Toxic.*, vol. 3, pp. 102-110, 2008.
- [13] Meta, C. Brullo, M. Tonelli, S. G. Franzblau, Y. Wang, R. Ma, W. Baojie, B. S. Orena, M. R. Pasca, O. Bruno, "Pyrazole and imidazo [1, 2-b] pyrazole Derivatives as New Potential Anti-tuberculosis Agents," *Med. Chem.*, vol. 15, pp. 17-27, February 2019.
- [14] Chiara B. Vicentini, Donatella Mares, Alfredo Tartari, Maurizio Manfrini, and Giuseppe Forlani, "Synthesis of pyrazole derivatives and their evaluation as photosynthetic electron transport inhibitors," *J. Agri. Food Chem.*, 2004, vol. 52, pp. 1898-1906, February 2004.
- [15] Zhang, D. Ma, R. Liu, L. Duan, "High-efficiency blue-green electroluminescence from sublimable cationic iridium (iii) complexes with a pyrazole-type ligand," *J. Mater. Chem. C.*, vol. 7, pp. 3503-3511, February 2019.
- [16] S. Mert, R. Kasimogullari, S. Ok, "A short review on pyrazole derivatives and their applications," *J. Postdoc Research.*, vol.2, pp. 64-72, April 2014.
- [17] Burschka, F. Kessler, M. K. Nazeeruddin and M. Gratzel, "Co(III) Complexes as p-Dopants in Solid-State Dye-Sensitized Solar Cells," *Chem. Mater.*, vol. 25, pp. 2986-2990, June 2013.

- [18] R. A. Senthil, J. Theerthagiri, J. Madhavan and A. K. Arof, "Influence of pyrazole on the photovoltaic performance of dye-sensitized solar cell with polyvinylidene fluoride polymer electrolytes," *Ionics*, vol. 22, pp. 425-433, March 2016.
- [19] U. M. Kauhanka and M. M. Kauhanka, "Synthesis of new liquid crystalline isoxazole-, pyrazole-and 2-isoxazoline-containing compounds," *Liq. Cryst.*, vol. 33, pp. 121-127 August 2006.
- [20] H.-B. Liu, W.-W. Gao, V. K. R. Tangadanchu, C.-H. Zhou, R.-X. Geng, "Novel aminopyrimidinyl benzimidazoles as potentially antimicrobial agents: design, synthesis and biological evaluation," *Eur. J. Med. Chem.*, vol. 143, pp. 66-84, January 2018.
- [21] H. Göker, G. Ayhan-Kilcigil, M. Tunçbilek, C. Kus, R. Ertan, E. Kendi, S. Özbey, M. Fort, C. Garcia, A. J. Farré, "Synthesis and antihistaminic H1 activity of 1, 2, 5 (6)-trisubstituted benzimidazoles," *Heterocycles*, vol. 51, pp. 2561-2573, November 1999.
- [22] M. Alp, H. Göker, R. Brun, S. Yıldız, "Synthesis and antiparasitic and antifungal evaluation of 2'-arylsubstituted-1H, 1' H-[2, 5'] bisbenzimidazolyl-5-carboxamidines," *Eur. J. Med. Chem.*, vol. 44, pp. 2002-2008, May 2009.
- [23] H. Nakano, T. Inoue, N. Kawasaki, H. Miyataka, H. Matsumoto, T. Taguchi, N. Inagaki, H. Nagai, T. Satoh, "Synthesis and biological activities of novel antiallergic agents with 5-lipoxygenase inhibiting action," *Bioorg. Med. Chem.*, vol. 8, pp. 373-380, February 2000.
- [24] Z. Hu, L. Ou, S. Li, L. Yang, "Synthesis and biological evaluation of 1-cyano-2-amino-benzimidazole derivatives as a novel class of antitumor agents," *Med. Chem. Res.*, vol. 23, pp. 3029-3038, June 2014.
- [25] G. Ayhan-Kilcigil, S. Gürkan, T. Çoban, E. D. Özdamar, B. Can-Eke, "Synthesis and Evaluation of Antioxidant Properties of Novel 2-[2-(4-chlorophenyl)benzimidazole-1-yl]-N-(2-arylmethylene amino) acetamides and 2-[2-(4-chlorophenyl) benzimidazole-1-yl]-N-(4-oxo-2-aryl-thiazolidine-3-yl) acetamides-I," *Chem. Biol. & Drug Design.*, vol. 79, pp. 869-877, January 2012.
- [26] Y. Qi, Y. Gao, S. Tian, A. R. Hlil, J. Gaudet, D. Guay, A. S. Hay, "Synthesis and properties of novel benzimidazole-containing sulfonated polyethersulfones for fuel cell applications," *J. Polym. Sci. Part A: Polym. Chem.*, vol. 47, pp. 1920-1929, January 2009.
- [27] G. Izzet, H. Akdas, N. Hucher, M. Giorgi, T. Prangé, O. Reinaud, "Supramolecular Assemblies with Calix[6]arenes and Copper Ions: from Dinuclear to Trinuclear Linear Arrangements of Hydroxo-Cu(II) Complexes," *Inorg. Chem.*, vol. 45, pp. 1069-1077, January 2006.
- [28] P. Díez, A. Sánchez, M. Gamella, P. Martínez-Ruiz, E. Aznar, C. De La Torre, et al, "Toward the design of smart delivery systems controlled by integrated enzyme-based biocomputing ensembles," *J. Am. Chem. Soc.*, vol. 136, pp. 9116-9123, June 2014.
- [29] P. Horcajada, R. Gref, T. Baati, P.K Allan, G. Maurin, P. Couvreur, et al, "Metal-organic frameworks in biomedicine," *Chem. Rev.*, vol. 112, pp. 1232-1268, December 2011.
- [30] S. Bansal, M. Bala, S. K. Suthar, S. Choudhary, S. Bhattacharya V. Bhardwaj, S. Singla, A. Joseph, "Design and synthesis of novel 2-phenyl-5-(1, 3-diphenyl-1H-pyrazol-4-yl)-1, 3, 4-oxadiazoles as selective COX-2 inhibitors with potent anti-inflammatory activity," *Eur. J. Med. Chem.*, vol. 80, pp. 167-174, June 2014.
- [31] M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, et. al., Gaussian Inc., Wallingford CT, Gaussian 09, Revision D.01, 2009.
- [32] C. Lee, W. Yang, R. G. Parr, Development of the Colle-Salvetti correlation-energy formula into a functional of the electron density, *Phys. Rev. B.*, vol. 37, pp. 785-789, January 1988.
- [33] R. S. Mulliken, "Electronic Population Analysis on LCAO-MO Molecular Wave Functions. I," *J. Chem. Phys.*, 1955, vol. 23, pp. 1833-1840, December 1955.
- [34] R. S. Mulliken, "Molecular Compounds and Their Spectra. V. Orientation in Molecular Complexes," *J. Chem. Phys.*, vol. 23, pp. 1841-1846, December 1955.
- [35] I. Fleming, "Frontier Orbitals and Organic Chemical Reactions," Wiley-Blackwell, New York, 1976.
- [36] J. S. Murray, K. Sen, "Molecular Electrostatic Potentials, Concepts and Applications," Elsevier, Amsterdam, 1996.
- [37] P. Politzer, P. R. Laurence, K. Jayasuriya, "Molecular electrostatic potentials: an effective tool for the elucidation of biochemical phenomena," *Environ. Health Perspect.*, vol. 61, pp.191-202, September 1985.
- [38] S. F. López, M. P. Meza, F. T. Hoyos, "Study of the nonlinear optical properties of 4-nitroaniline type compounds by density functional theory calculations: Towards new NLO materials," *Comp. Theor. Chem.*, vol. 1133, pp. 25-32, June 2018.

AUTHORS PROFILE



Ramar Sivaramakarthykeyan earned his BSc degree in Chemistry from VHNSN College, Virudhunagar, affiliated to Madurai Kamaraj University, Tamilnadu, India in 2013. He completed his MSc in Chemistry in 2015 from Kalasalingam Academy of Research and Education, Krishnankoil. Currently he is pursuing PhD at Kalasalingam Academy of Research and Education, Krishnankoil. He has been working in the area of biopertinent heterocycles.



Krishnaraj Padmavathy received her Bachelor of Science degree in Chemistry from Bharathidasan college for women, Pondicherry in 2004. She obtained her Master's degree from Kanchi Mamunivar Centre for Postgraduate Studies, Pondicherry in 2006. She is currently a PhD student at Kalasalingam Academy of Research and Education, Krishnankoil, India. Her focus of research is methodology development and heterocyclic construction for biological applications.



Vadivel Saravanan graduated (U.G.) from Madurai Kamaraj University, Madurai. He obtained his Masters degree in Chemistry from Kalasalingam Academy of Research and education, Krishnankoil. He is currently a PhD student at Kalasalingam Academy of Research and education, Krishnankoil. His research interest includes green chemistry and synthesis of novel materials for various applications.



Dr. Chennan Ramalingan is serving as Professor of Chemistry at KARE. He received his PhD in Organic Chemistry from Annamalai University (2002). After he served as Research Professor at Kyungpook National University, South Korea followed by Assistant Professor at Osaka University, Japan (8 years), he joined at Kalasalingam Academy of Research and Education, Krishnankoil (2011). His research interests include organic synthesis, medicinal chemistry and material chemistry. He published more than 70 International research articles.