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Bonding and Noncovalent Interactions effects in 2,6-Dimethylpiperazine-1,4-Diium Oxalate Oxalic Acid: DFT Calculation, Topological Analysis, NMR and Molecular Docking Studies

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Abstract

The pharmaceutical proprieties and of the 2,6-dimethylpiperazine-1,4-diium oxalate oxalic acid hybrid compound have been studied and the relevant drug design has been considered. The investigated organic–inorganic molecule with the formula $(2,6-(\text{CH}_3)_2\text{C}_4\text{H}_{10}\text{N}_2)_2(\text{C}_2\text{O}_4)_2 \cdot \text{H}_2\text{C}_2\text{O}_4$ (2DPOA) has been characterized by IR, ^{13}C NMR, UV–visible and the DFT calculation at the B3LYP level of theory has been made. The molecular structure and parameters (bond angles and lengths) of the molecule have been optimized using the Gaussian 09 software and compared with the XRD data. The atoms-in-molecules (AIM), electron localization function (ELF), and localized orbital locator (LOL) methods have been utilized to determine the types and nature of noncovalent interactions present within the 2DPOA molecule. These methods offer insights into the characteristics and behavior of these interactions. Furthermore, the presence of these interactions has been confirmed through the Hirshfeld surface (HS) and reduced density gradient (RDG) analysis. The NBO analysis is employed to assess the charge exchange occurring within the studied compound. The molecular reactive sites have been examined using the molecular potential surface and Mulliken atomic charges. The energy gap between HOMO-LUMO and chemical properties of 2DPOA

have been determined within the frontier molecular orbital theory. The UV-Vis spectra of the 2DPOA molecule has been recorded and examined. The calculated and experimental infrared absorption and nuclear magnetic resonance spectra of 2DPOA molecule have been investigated. Finally, the molecular docking simulation has been used to find novel inhibitors and drugs for the cancer and epilepsy disease treatment.

Keywords: DFT; Atoms In Molecules; Hydrogen-bonded; electron localization function; frontier molecular orbital theory; Cancer; Molecular Docking .

1 Introduction

Piperazine and its derivatives represent a family of chemicals with the stimulant effects. As the literature survey revealed [1], the heterocyclic compounds of this type exhibit the diverse pharmacological activities, including the antibacterial activity, carbonic anhydrase inhibition, etc. The present study is examined to develop novel drugs with promising applications in the field of medicine. As a part of our ongoing research, the novel 2,6-dimethylpiperazine-1,4-dium oxalate oxalic acid (2DPOA) compound was selected and its molecular structure was verified by DRX diffractometry. The 2DPOA molecule crystallizes in the monoclinic system with sp.gr. $P21/c$ ($a = 7.9598(16)$, $b = 8.4457(15)$, $c = 18.080(3)$ Å, and $\beta = 106.349(9)^\circ$). The 2DPOA organic and inorganic groups are through with the hydrogen bonds interactions. Therefore, the structural geometry and parameters (bond angles and lengths) of the investigated hybrid 2DPOA were scrutinized using the density functional theory (DFT) simulation. A helpful tool that ensures good agreement between the theory and experiment is the B3LYP method [2]. The AIM (Atoms in Molecules), ELF (Electron Localization Function), LOL (Localized Orbital Locator), and HS (Hirshfeld Surface) approaches were employed to investigate the noncovalent interactions of 2DPOA. These methods provide valuable insights into the characteristics and behavior of noncovalent interactions within the molecular system. Next, the weak interaction was examined by the RDG analyses. The stability and intra molecular interactions of 2DPOA molecule were performed using NBO investigations. The molecular electrostatic potential (MEP) surface and Mulliken atomic charge analysis was used to interpret the structural characteristics of the 2DPOA molecule. The FMOs and global reactive parameters were computed at the same level of theory. The band gap energy ΔE was found from the UV-Vis absorption spectrum by the TD-DFT calculation.

Vibrational spectra of the 2DPOA molecule were registered in the range of 4000–500 cm^{-1} and compared with the observed data. In addition, the NMR spectra of the compound were analyzed. Finally, the molecular docking simulation aimed at designing a new drug with the potential activity against diseases was performed. This technique makes it possible to determine and describe the interactions of four target enzymes with the 2DPOA molecule chosen as a ligand. The results obtained showed that the 2DPOA compound is a good inhibitor for the cancer and epilepsy disease treatment.

2 Description of the Structure

The 2DPOA compound contains two asymmetric units per unit cell along the three directions, which creates a three-dimensional (3D) structure. They are held together by hydrogen bonds. **Figure 1** is an ORTEP representation of the configuration of different entities of the 2DPOA structure. An organic cation, an oxalate anion, and an oxalic acid molecule are highlighted. The oxalate anions and the 2,6-dimethylpiperazinium cation are linked by a medium and weak hydrogen bonds. **Figure 2** presents a projection of the structure onto the [100] direction and illustrates the atomic organization of all the species included in the structure: the oxalate groups, organic cation, and water molecules. It can be seen that oxalate anions and the organic groups are interconnected through N–H...O and C–H...O hydrogen bonds and form a 3D network. The unit encountered in this hydrogen bond network is $R^3_2(6)$ [3]. The crystal stacking of the molecule consists of the cationic and anionic groups alternating along the c^* axis.

3 Computational Details

Molecular geometry of the hybrid 2DPOA was optimized by calculating the total energy. All the DFT computations with B3LYP/6-311++G(d,p) level of theory were performed by using Gaussian 09 program [4]. To clarify the nature and types of hydrogen bonds, the theoretical method (the AIM analysis) was implemented in the AIMall package [5]. In addition, the ELF was visualized throughout the Multiwfn 3.8 program [6]. The HS and fingerprint plot analysis was generated by CrystalExplorer program [7]. The RDG was used to explore the weak interactions in the wfn and VMD software [8]. The MEP surfaces and energy gap between HOMO-LUMO were determined by the GaussView program [9]. The UV-Vis spectroscopy study was carried out within the TDDFT in the same basis set. The IR absorption assignments for all 2DPOA bands were made using the Veda4x software [10] and compared with the theoretical vibrational frequencies. In addition, the NMR was used. Finally, the structural data on the four selected target proteins were deposited in the Protein Data Bank (PDB) [11] to conduct the molecular docking simulation. The obtained picture of

different protein complexes and the 2DPOA ligand were minimized and build in the MOE program[12]using the MMFF94 forcefield.

4 Results and Discussion

The optimization of the hybrid 2DPOA was obtained and geometrical parameters are listed in Table 1. The experimental structure of the 2DPOA compound belongs to space group P21/c. The minimum energy of the ground state of the compound was found to be -1103.60 Hartree. The dipole moment of the molecule was determined to be 17.73 Debye. Figure 3 depicts a schematic representation of the most stable molecular structure with atom numbering. As indicated by **Table 1**, the obtained parameters align well with the experimental data. The C-H bond length of 2DPOA molecule between in the range of 1.090 – 1.104 (DFT) and 0.980 – 1.000 Å (XRD), respectively. All the C–O bond lengths were reported in the ranges of 1.197 – 1.347 Å for the B3LYP calculation and 1.208 – 1.508 Å for the XRD experiment. Theoretically, the O–H intermolecular distances are 0.970 (O₃₇–H₃₈), 1.657 (O₃₃–H₃₄), 1.012 (O₂₉–H₃₄), and 0.986 Å (H₄–O₂₇). It was observed that the distances O–H and H–O closely match the experimental lengths distances. Table 1 indicates that the N₃–H₄ interatomic distance exhibits the longest binding length at 2.005 Å. The respective calculated maximum bond angle (160.2°) was observed between N₃–H₄–O₂₇. The DFT computation yielded a moderate hydrogen angle (113.4°) from H₄–O₂₇–C₂₆. The hydrogen bond parameters are crucial role for stability investigations of the hybrid compound. The slight differences between the theoretical and X-ray diffraction (DRX) parameters can likely be attributed to intermolecular interactions in the crystalline state. **Table 1** provides the theoretical and DRX geometric parameters, including the root-mean-square deviation (RMSD). The RMSD values for the bond lengths (0.140) and bond angles (2.83) indicate a good agreement between the theoretical and XRD data, highlighting their concordance.

4-1 Analysis of the Noncovalent Interactions

4-1-a Atoms in molecules

In this study, we thoroughly investigated the noncovalent interactions within the 2DPOA compound by the AIM analysis. This method is used to evaluate the density of electron and bonding characteristics of compounds[13]. To elucidate the intermolecular interaction of bond critical points (BCPs) were obtained by AIMall package. The molecular graph of the stable 2DPOA geometry is shown schematically in **Figure 4**. The BCPs and RCPs (ring critical points) are colored in red and green. The topological parameters, including the Laplacian and the electron densities, ellipticity, interaction energy, kinetic and potential electron density were

utilized to establish the hydrogen bonds nature (**Table 2**). It can be seen from Figure 4 and Table 2 show three types of hydrogen bonds: C–H...O, N–H...O, and O–H...N. The calculated parameters given in Table 2 show that all the $\nabla^2\rho(r)$ and positive H_{BCP} values are obtained, with the exception of the case of hydrogen bonds: N₁₁–H₁₃...O₃₃ and O₂₉–H₃₄...O₃₃. Roza et al., reported all the hydrogen bonds are moderately and partially covalent, with the exception of the C₈–H₁₀...O₂₉ and C₂₁–H₂₄...O₂₇ interactions, which are weak and electrostatic. Additionally, the interaction energies $E_{interaction} < 12.0$ kcal/mol (weak) and $12.0 < E_{interaction} < 24.0$ kcal/mol (medium) [14] indicate that hydrogen bonds of both types are formed between the organic and inorganic units.

4-1-b ELF and LOL analysis methods

To estimate the concentration of electron density in the hybrid compound under study, the electron localized function (ELF) technique was carried out. This tool is effective to identify the sites of bond pairs, lone pairs and size of the bonding the studied compound [14]. The colour filled -ELF and LOL maps of the header molecule is generated by using Multiwfn 3.8 and displayed in **Figure 5**. This color map is designed in the range 0-1.0, indicating that they have chemical similarities. The region 0.5-1.0 indicating the bonding and nonbonding localized electrons, whereas the region with value < 0.5 corresponds to the delocalized electrons. In this figure, the large ELF zones (red color) are noted about the hydrogen atom, which specify the high localization of bonding and non-bonding electrons. The blue region around oxygen (O₃₀, O₃₇) and carbons (C₃₆, C₈) atoms indicate the presence electron could delocalisation. In LOL map (fig.5.b), the red regions that are presented near hydrogen atoms with high LOL values are due to covalent bonds. As seen in Fig. 5.b, the electron density of the hydrogen atoms is more than the upper limit of the color scale (0.8), resulting in the color of the hydrogen atoms being white. Small blue circles around carbon and oxygen atoms in the header composite designate that electron depletion exists between the outermost and inner layers respectively.

4-1-c Hirshfeld surface

The HS analysis is a valuable instrument for studying intermolecular interactions in crystal molecules. **Figure 6** shows the HS of the 2DPOA compound generated in the CrystalExplorer program. Different intermolecular interactions can be found around the two groups (organic and inorganic) by analyzing of the HSs in the d_{norm} map. Different hydrogen bonds interactions N–H...O and O–H...O are shown by bright red spots and the H...H and C...H/H...C contacts are situated in blue and white zones. **Figure 7** presents two-

dimensional (2D) plots of the cationic and anionic moieties. In this 2D graph, pairing of the O...H/H...O contacts is represented by a percentage of 54.8% of the total HS and is composed of two thin spots with $d \sim 1.8$, which allude to the presence of C...H...O and N...H...O bonds containing hydrogen. The H...H contacts occupying 34% of the HS are reflected by two weak peaks around $d \sim 2.6$. The C...H/H...C, C...O/O...C, and O...O contacts contribute with percentages of 4.7% and 1.9% of the HS, respectively. In addition, the electrostatic potential of the compound under investigation was carried out with the available .cif file using CrystalExplorer 3.1 software package. The electrostatic potential was mapped on the HS as shown in **Figure 8**. The arearanges between -0.263 (red) and 0.332 (blue). Oxalate anions are attributed with negative potential areas, and organic cations, notably hydrogen atoms, are credited with positive potential areas. These results imply that there is an overall electrostatic affinity between the organic cation and the oxalate anions as in 2DPOA compound [15].

4-1-d Reduced density gradient

Information concerning the hydrogen and van der Waals bonds, steric interactions, and steric interactions can be obtained by the RDG analysis. [16]. Different regions of these interactions were graphically visualized in the VMD 1.9.2 program on the basis of the Multiwfn 3.8 software outputs. The 2D scatter plot and 3D RDG isosurface densities for 1EPBH are presented in **Figure 9**. Dark blue spots between hydrogenoxylate atoms represent as O–H...O (strong hydrogen bond). This interaction (strong attractive) has a negative sign $(\lambda^2)\rho$ and lies in the range -0.010 and -0.020 a.u. The blue patch between the nitrogen atom of the organic unit and the hydrogen atom of the inorganic unit corresponds to a moderate H-bond, like O–H...N, seen in the RDG plot between -0.025 and -0.030 a.u. The 2DPOA contains atoms that exhibit the van der Waals interaction (green zone). This interaction occurs in the area of $\text{sign}(\lambda^2)\rho = 0$. The red zone inside the atoms clearly illustrates the strong steric contacts. In addition, one can see the mixed color (red–green) between the hydrogenoxylate oxygen atoms. The mixed color (green–red) spikes in the RDG scatter spectra between 0.010 and 0.020 are indicative of the weak H...H and C–H... π noncovalent interactions.

4-1-e Atomic charge distribution in $(2,6-(\text{CH}_3)\text{C}_4\text{H}_{10}\text{N}_2)_2(\text{C}_2\text{O}_4)_2 \cdot \text{H}_2\text{C}_2\text{O}_4$

The Mulliken population analysis is used to clarify the chemical nature of compounds [18]. The Mulliken atomic charges in 2,6-dimethylpiperazine-1,4-dium hydrogenoxylates obtained by the above-mentioned basis set simulated method tabulated in **Table 3** and the graphical picture is presented in **Figures 10** and **11**. The color gradient of Fig 10 varies from red -more electronegative to blue -less electronegative via brown region with the range from -0.641 to

0.641 (red to green) respectively. The data from **Figure 11** and **Table 3** show that hydrogen atoms bear positive charges, while all the other atoms (nitrogen, oxygen, and carbon) have positive and negative charges, but varying from one atom to another. Hydrogen atoms bonded to heteroatoms (O, N) have the significant positive charges as compared with other hydrogen atoms. The largest positive charge was observed on the H5 atom. Therefore, there is charge transfer from the carbon to oxygen atom. High negative charges are seen for the oxygen atoms involved in hydrogen bonds as acceptors.

4-1-f Natural Bond Orbital (NBO)

The intramolecular interactions and the stabilization energy of the 2DPOA compound were explored by the NBO method. The NBO data are listed in **Table 4**. In this table, the stabilization energy exceeding 3 kcal/mol was chosen. The energy values of the $\pi^*(C_{28}-O_{29}) \rightarrow \pi^*(O_{25}-C_{26})$, $\pi(O_{35}-C_{36}) \rightarrow \pi^*(O_{31}-C_{32})$, and $\pi^*(O_{35}-C_{36}) \rightarrow \pi^*(O_{31}-C_{32})$ interactions are 81.32, 4.22, and 56.76 kcal/mol, respectively, which indicates that they cause the great stabilization in the 2DPOA molecule. According to the data given in the table, the lone pair LP(O) with $\pi^*(C-O)$ and $\sigma^*(C-C)$ yields more energy stabilization than the donor-acceptor interactions of other types. The very strong interaction was observed between the lone pair LP₃(O₃₀) and $\pi^*(C_{28}-O_{29})$ with an energy of 97.86 kcal/mol. Hyper-conjugative interactions among the LP(O) i.e., lone pair oxygen and antibonding acceptors mention the existence of the hydrogen interactions in the 2DPOA compound. The stabilization energies E(2) of the LP₁(O₂₇) \rightarrow $\sigma^*(N_3-H_4)$, LP₂(O₂₇) \rightarrow $\sigma^*(N_3-H_4)$, LP₁(O₂₉) \rightarrow $\sigma^*(O_{33}-H_{34})$, and LP₂(O₂₉) \rightarrow $\sigma^*(O_{33}-H_{34})$ interactions are 5.41, 16.41, 8.49, and 38.04 kcal/mol, respectively. Thus, the interpretation from NBO calculation established the existence of bonds O-H...O and N-H...O respectively.

4-2 Electronic Properties

4-2-a Molecular electrostatic potential surface (MEP)

Using the MEP surface analysis, the sites of nucleophilic and electrophilic reactions and the hydrogen bonding interaction [19] were studied. The MEP surface (**Figure 12**) was computed to predict the reactive sites for the investigated compound. In **Figure 12**, red color corresponds to the regions of the most electronegative potential and blue color, to the regions of the most positive electrostatic potential. The color code of this map ranges between -8.001×10^{-2} a.u. (deepest red) and 8.001×10^{-2} a.u. (deepest blue). Moreover, it appears from the MEP map that the negative zones in the 2DPOA molecule are located around oxygen atoms of the oxalate unit. The maximum positive zones localized around hydrogen atoms in the organic unit, which

can be considered as potential sites for the nucleophilic attack. Thus, the MEP map provides information about the area from which the compound can have intermolecular interactions and confirms the formation of hydrogen bonds between the two units.

4-2-b Frontier molecular orbitals

To better understand the chemical reactivity, kinetic stability, and molecular electrical transport in the chemical structure, the FMO study was carried out. The quantum calculation was based on the data on the 2DPOA compound obtained by using GaussView 09 software. The HOMO and LUMO molecular orbitals for the compound are presented in **Figure 13**. The calculated chemical parameters are given in **Table 5**. **Figure 13** contains two colors, red and green, for the positive and negative phase, respectively. The HOMO-LUMO is primary parameters for molecular investigations, which is applied to calculate several chemical reactivity parameters such as molecule softness, hardness, energy gaps, ionization potential, electron affinity etc. The energy gap is simply explained for inter molecular interactions and stability of the molecular nature. The HOMO and LUMO energies for the investigated for title compound are -6.98 and -1.60 eV, respectively. The band gap of the compound is extremely wide: $\Delta E = 5.48$ eV, which exceeds 3 eV [20] and therefore, electrons cannot change from the valence to conduction band. The prepared materials are isolates. The higher energy gap is observed present molecule, as a result suggests the title molecule is most stable [21]. The high stability nature is observed for title molecule

4-2-c UV-Visible spectroscopy

In this part of the work, the UV-Vis spectra were determined in order to establish the HOMO-LUMO electronic transitions in the molecule under study. The (2,6-(CH₃)C₄H₁₀N₂)₂(C₂O₄)₂.H₂C₂O₄ UV-Vis spectrum was recorded in the range of 200 and 400 nm (**Figure 14a**). A single intense band is observed at a peak wavelength of 274 nm, potentially associated with the $n \rightarrow \pi^*$ transition. Furthermore, this molecule demonstrates high transparency in both the UV-Vis spectral ranges, making it a promising candidate for non-linear optical (NLO) applications. By employing UV-Vis spectrophotometry, we can determine the energy gap (E_g) between the highest occupied molecular orbital (HOMO), which contains at least one electron and possesses the highest energy, and the lower energy unoccupied molecular orbital (LUMO). The optical gap E_g was determined from the Tauc formula [22]. The Tauc's method was used to determine the energy gap of the title hybrid compound: 4.9 eV (**Figure 14b**). This is comparable with the values found within the

LUMO–HOMO theory. Owing to the wide band gaps, these materials can have higher transmittances in the visible spectral range.

4-3 Calculated and Experimental Infrared Absorption Spectra

In Figure 15, the superposition of two spectra, experimental and theoretical, is depicted. The IR spectrum of the compound under investigation was captured within the range of 4000 to 400 cm^{-1} . It exhibits distinct bands associated with the organic cation and oxalate groups, including N–H and C–H bonds, as well as the C–N and O–H frameworks. Table 6 provides a summary of the comparison between the experimental and calculated IR spectra. The spectrum contains broad high-intensity bands between 3437 and 2500 cm^{-1} , which can be assigned to the (NH_2), (CH_2), and (CH_3) valence vibrations. These bands were theoretically predicted between 3461 and 2310 cm^{-1} . The wavenumber at 1735 cm^{-1} was attributed to the carbonyl group (C=O) vibrations, while the stretching bands are observed between 1625 and 1465 cm^{-1} . Theoretically, these stretching vibrations occur between 1835 and 1142 cm^{-1} . The bands located between 1380 and 1260 cm^{-1} were attributed to the C–O stretching and C–N asymmetric bands. The DFT calculation yielded these bands in the region between 1390 and 1270 cm^{-1} . The wave number at 1130 and 1050 cm^{-1} were assigned to the C–C bands and predicted theoretically at 1150 and 1060 cm^{-1} . The bending ($\delta(\text{COH})$, $\delta(\text{COO}^-)$, and $\delta(\text{CCN})$) bands are observed at 960, 760, 560, and 460 cm^{-1} , which, according to the theory, appear at 970, 808, 681, 515, and 427 cm^{-1} . There is a significant correlation plot of vibration analyses as shown in **Figure 16**.

4-5 ^{13}C Nuclear Magnetic Resonance

The 2DPOA compound's ^{13}C CPMAS NMR spectrum displays eight lines, whereas the structural analysis reveals the presence of nine carbon atoms. The lines observed in the range of 42.31 to 55.2 ppm can be attributed to the carbon atoms of the 2,6-dimethylpiperazine-1,4-dium organic group. This finding is consistent with the X-ray diffraction data obtained from the single organic cation within the asymmetric unit. Two lines situated in the most prominent region at 165.5 and 172.4 ppm correspond to the carbon atoms of the oxalate anion and oxalic acid carbonyl groups, respectively (see Figure 17). This indicates that the carbon atoms within each oxalate group resonate as a single line, implying two carbon atoms with a similar chemical environment. By comparing the chemical shifts obtained from DFT calculations using GIAO database with the experimental data, Table 5 provides a comprehensive overview of the different assignments for the theoretical and experimental lines. A scale factor of 0.987 demonstrates a good correlation between the observed and computed chemical shifts (refer to

Figure 18). The slight discrepancy observed between the observed and computed chemical shifts can be attributed to the influence of the mineral matrix.

4-6 Molecular Docking Calculation

The piperazine derivatives, for example, 1-ethylpiperazine and 2,6-dimethylpiperazine, exhibit similar effects in the treatment of various diseases, including the epilepsy disease and cancer [15]. The biological investigation of 2DPOA is performed using molecular docking analysis. This method is used to investigate intermolecular interactions between ligands and receptors. In this work, different target proteins were chosen: carbonic anhydrase VII: PDB ID: 3ML5 and 6SDT and carbonic anhydrase IX: PDB ID: 6RQN, 3DC3. These receptors were confirmed as an attractive target for the finding of selective inhibitors for the epilepsy and cancer therapy [23–25]. To identify the binding sites of the selected receptors with the 2DPOA compound acting as a ligand, molecular docking simulations were performed using the MOE program. Four different top conformations with the lowest energy were generated for each complex and selected for the binding interactions analysis (Figure 19). The simulated docked protein–ligand values are summarized in Table 7, which comprises the binding score, RMSD, bond types and residues of the active sites. The reliability of the docking program was confirmed with the RMSD. It can be seen in Table 6 that the RMSD of the proteins–ligand between 1.46 to 2.31 Å, which is below 3 Å [26–28]. This value verifies that the results obtained for all the examined proteins–ligand presented good docking. The interaction of the 2DPOA ligand with the 3ML5, 6SDT, 6RQN, and 3DC3 proteins at the binding site yields binding scores of –4.47, –2.57, –2.62, and –3.47 kcal/mol, respectively. According to the data from Table 7, the key contributing amino acids in the receptor's sites are H-donor, H-acceptor, and H- π . The 3ML5–2DPOA complex is involved with THR199 and HIS94 residues in H-donor and H- π with distances of 3.09 and 4.40 Å. The key residues involved by the 6SDT–2DPOA complex are HIS94, THR200, and GLN92 through the H-donor and H-acceptor bonds with a distance between 2.78 and 3.35 Å. Similarly, the 2DPOA ligand with the 6RQN and 3DC3 receptor is involved with H-acceptor and H-donor interactions along with distance varies between 2.77 and 3.44 Å. The docking results showed that the examined molecule exhibits the pharmaceutical properties. According to the docking simulation, the 2DPOA molecule chosen as a ligand is a good anti-cancer and anti-epilepsy agent.

5 Conclusions

In this research, the experimental data of the 2DPOA molecule were presented and compared with theoretical results. The molecular structure and geometrical parameters were optimized using DFT calculations. Through topological analysis, AIM, and ELF studies, it was confirmed that the 2DPOA compound possesses two types of hydrogen bonds. The HS analysis revealed the presence of hydrogen bonds- N–H...O and O–H...O. The RDG analysis emphasized the contacts relating hydrogen bonding, Van der Waals forces, and steric effects. The stability of the 2DPOA molecule was assessed using the NBO method. Mulliken atomic charges and MEP surface analysis were employed to evaluate the compound's reactivity. The HOMO–LUMO energy gap provided insights into potential charge transfer interactions and the chemical activity of the studied molecule. Additionally, UV–Vis spectrum analysis, as well as vibrational and NMR analysis, were conducted. Finally, molecular docking simulations demonstrated that the investigated molecule, chosen as a ligand, exhibits promising inhibitory properties against epilepsy and cancer.

Supplementary data

Supporting information (CIF files) can be obtained from the CCDC database free-of charge via <http://www.ccdc.cam.ac.uk/structure-summary-form> quoting the CCDC reference number CCDC-2250449 or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB21EZ, UK; or by email to deposit@ccdc.cam.ac.uk.

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