

SPECTROSCOPIC AND THEORETICAL EXPLORATIONS ON 6-HYDROMETHYL-4-METHOXY-4-METHOXYTETRAHYDRO-PYRAN-2, 3, 5-TRIOI-A BIOMOLECULE

ABSTRACT

The chemical compound 6-hydromethyl-4-methoxy-4-methoxytetrahydro-pyran-2, 3, 5-triol ($C_7H_{14}O_6$), was derived from the ethanol extract of *Senna auriculata* flower via GC-MS. FT-IR and NMR characterization of the compound support covalent bonding information and degree of degeneracy, respectively. 3D molecular structure was optimized to enhance the accuracy of computations. MEP, NBO, HOMO-LUMO, and Mulliken charge distribution studies provide details like reactive sites, electron density dislocation, and molecular interactions, charge transfer within the molecule and frontier orbital energies, electron density on the individual atom, and these were computed using hybrid B3-LYP quantum level with 6-311++G(d, p) basis set. Thermodynamic properties such as heat

capacity, entropy, enthalpy, and their relation with temperature changes for the title molecule were also analyzed using THERMO.PL software. Non-linear optical properties namely polarizability, first-order hyperpolarizability, and electronic dipole moment have also been computed at B3-LYP level with 6-311++G (d, p) basis set. Docking simulation was initiated on the title molecule using Autodock 4.2 software and found to be an excellent inhibitor of ALR2, an enzyme.

Keywords: GC-MS, DFT, HOMO-LUMO, NBO, IN- SILICO, DOCKING

1. INTRODUCTION

Natural or synthetic compounds containing heterocyclic pyran moiety are well known for their biological activities and play a vital role as lead molecule in the field of drug designing. Pyran moiety is a core unit in benzopyrans, chromones, coumarins, flavonoids, and numerous naturally occurring compounds, and exhibits pharmacological activities such as antiviral [1], antimicrobial[2], antitumor[3], cancer therapy[4], antifungal[5], antidiabetic [6], and anti-inflammatory[7,8]. The field of medicine is greatly influenced by chromenes due to their antivasular [9]. anti-oxidant[10], antifungal[11], antiviral[12], antimalarial[13], antiproliferative[14], anti-Alzheimer, anti-Parkinson and Huntington's diseases [15,16], Coumarins (1-benzopyran-2-one) are naturally found in many plants possess a

variety of biological properties, including antimicrobial, antiviral, anti-inflammatory, antidiabetic, antioxidant, and enzyme inhibitory activity. Flavonoids are rich sources of natural antioxidants in human diets and they neutralize the harmful effects of free radicals and thus aid in the prevention of many diseases. International Diabetes Federation predicts as many as 438 million will have diabetes by 2030 and the number of Americans with diabetes projected to be doubled or triple by 2050. Diabetes is a group of diseases that involve problems with the hormone insulin and occur when the pancreas produces very little or no insulin. As yet, there is no cure; diabetes causes an estimated death of 3.2-5.0 million per year. The pathogenic mechanism leading to diabetic complications is usually linked to increased activity of the enzyme Aldose Reductase (ALR2). Using Autodocking algorithms, an in-silico design to complement and accelerate in-vivo practices had been carried out to understand the capability of the title compound as an effective enzyme Aldose Reductase inhibitor (ALR2).

The worldwide prevalence of Covid-19 or Corona Virus and its implication (increased mortality) on diabetic patients have prompted us to take the present antidiabetic study on the title molecule using DFT method and in-silico evaluation.

2. EXPERIMENTAL

2.1 Elucidation of 6-hydroxymethyl-4-methoxy-4-methoxytetrahydro-pyran-2, 3, 5-triol

The flowers of *Cassia auriculata* Linn were collected from Udumalpet, Tamil Nadu, dried under shade and crushed into a coarse powder. Then the powder was completely soaked in ethanol (solvent) and stirred well using a magnetic stirrer at constant temperature (780rpm) for about 2h, and filtered for the extract of the flowers of *Cassia auriculata*. The GC-MS spectra of the extract were obtained using the JEOL GCMATE II GC-MS with data system available in the sophisticated analytical instrumentation facility at IIT-M, Chennai. 6-hydroxymethyl-4-methoxy-4-methoxy tetrahydro-pyran-2, 3, 5-triol is one of the eight chemical compounds identified from the ethanol extract of the flowers of *Cassia auriculata* using GC-MS spectral data

2.2 Spectroscopic and computational particulars

The experimental Fourier transform infrared spectrum (FT-IR) of the *Cassia auriculata* flower extract was recorded in the range of 4000-400 cm^{-1} , Model FT/IR-4100typeA at SAIF, Indian Institute of Technology (IIT-M), Chennai. Optimized 3D molecular structure and stabilization energy, normal mode frequencies and the associated wave number assignments based on potential energy distribution (PED), ^1H , ^{13}C NMR spectra, reactive sites on molecular surface (MEP), charge transfer within the molecule (HOMO-LUMO), electron population over individual atoms (Mulliken charges), molecular interactions and thus the stability of the compound (NBO), and NLO properties of the title molecule was computed by DFT-B3LYP level with 6-311++G(d, p) basis set using Gaussian 09W software program package [17]. The relationship between thermodynamical variables and the temperature was established using THERMO.PL [18]

3. RESULTS AND DISCUSSION

3.1 Optimized molecular geometry

The 3D molecular structure (Fig. 1) was obtained using the 2D chemical structure of the title molecule as input to Gaussian 09W and studied for its optimized geometries at B3LYP level with 6-311++G(d,p) basis set by GIAO approach[19]. The molecule, $\text{C}_7\text{H}_{14}\text{O}_6$, consisting of 27 atoms including a six-membered heterocyclic pyran

ring, and those atoms were bonded via C-C, C-O, and C-H single bonds. In the structure, the C-C, C-O and C-H single bond distances (Table 1) are in the range of 1.5539-1.5728Å, 1.4248-1.4365Å and 0.9609-1.101Å, respectively, and these values are in good agreement with the experimental values [20]. Negligibly small deviation observed between the experimental and theoretical bond geometries maybe because the X-ray diffraction data were collected using a sample in the solid-state whereas theoretical computations were performed in the gaseous state of the material.

The various bond angles around C atom[C-C-O, O-C-H, C-C-C, H-C-H, H-C-O, O-C-H and O-C-C] are lies between [104.0406-116.0061]°, representing the distorted tetrahedron structure of the molecule. The pyran ring of the title molecule adopts chair conformation (the shape assumed by the ring) which is shown in the Fig.2.

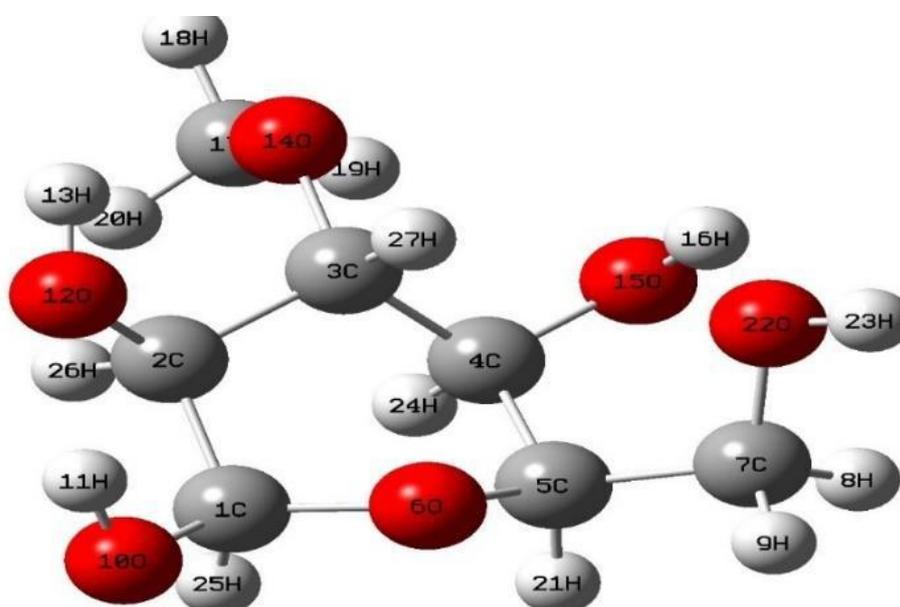


Fig.1. Optimized 3D Molecular Structure

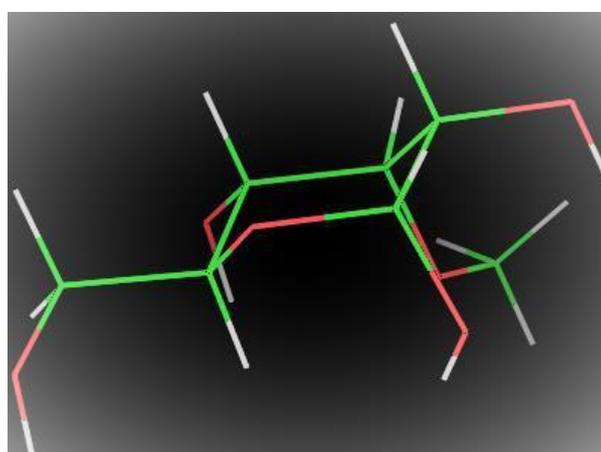


Fig.2 Ring Conformation of the pyran ring

TABLE 1. OPTIMIZED BOND GEOMETRIES

| Atoms | Distance (Å)/Angle(°) | Atoms | Angle (°) |
|-----------------|-----------------------|----------------|-----------|
| C1-C2 | 1.5539 | C2-C1-O6 | 109.4549 |
| C1-O6 | 1.4298 | C2-C1-O10 | 112.7043 |
| C1 - O10 | 1.379 | C2-C1-H25 | 109.8769 |
| C1 - H25 | 1.0989 | O6-C1-O10 | 109.3076 |
| C2-C3 | 1.5337 | O6-C1- H25 | 108.058 |
| C2 - O12 | 1.4263 | O10 - C1 - H25 | 107.3166 |
| C2 - H26 | 1.0977 | C1-C2-C3 | 110.2538 |
| C3-C4 | 1.5385 | C1- C2- O12 | 108.219 |
| C3 - O14 | 1.4253 | C3-C2- O12 | 110.4605 |
| C3 - H27 | 1.0922 | C3-C2- H26 | 110.3014 |
| C4-C5 | 1.5728 | O12 - C2 - H26 | 109.1229 |
| C4 - O15 | 1.4161 | C2-C3-C4 | 110.124 |
| C4 - H24 | 1.094 | C2-C3-O14 | 111.0077 |
| C5-O6 | 1.4281 | C4-C3-O14 | 116.0061 |
| C5-C7 | 1.5212 | C4-C3-H27 | 107.7989 |
| C5 - H21 | 1.101 | O14 - C3 - H27 | 104.0406 |
| C7-H8 | 1.0948 | C3-C4-C5 | 107.7947 |
| C7-H9 | 1.0935 | C3-C4-O15 | 113.3086 |
| C7 - O22 | 1.4365 | C5-C4-O15 | 113.3584 |
| O10 - H11 | 0.9685 | O15 - C4 - H24 | 104.3527 |
| O12 - H13 | 0.9644 | C4-C5-O6 | 111.7713 |
| O14 - C17 | 1.4248 | C4-C5-C7 | 113.3945 |
| O15 - H16 | 0.9684 | C4-C5-H21 | 108.6944 |
| C17 - H18 | 1.0901 | O6-C5-C7 | 107.0762 |
| C17 - H19 | 1.0935 | O6-C5-H21 | 108.8188 |
| C17 - H20 | 1.0972 | C7-C5-H21 | 106.8927 |
| O22 - H23 | 0.9609 | C1-O6-C5 | 112.5604 |
| C4 - O15 - H16 | 107.5584 | C5-C7 - H8 | 109.334 |
| O14 - C17 - H18 | 105.9769 | C5-C7-H9 | 107.8401 |
| O14 - C17 - H19 | 111.1136 | C5-C7-O22 | 109.5498 |
| O14 - C17 - H20 | 112.4154 | H8-C7-H9 | 109.2913 |
| C1 - O10 - H11 | 107.4534 | H8-C7-O22 | 109.9711 |
| C2 - O12 - H13 | 108.0068 | H9-C7- O22 | 110.8141 |

3.2 Normal mode frequencies assignment-FT-IR

There are 27 atoms in the non-linear molecule 6-hydroxymethyl-4-methoxy-4-methoxy tetrahydro-pyran-2,3,5-triol, and thus the normal modes of vibrations of the molecule [3N-6] is 75 as listed in Table S1. FT-IR spectrum recorded experimentally following KBr pellet technique in the range 4000-450 cm^{-1} along with the theoretically obtained spectrum using the DFT method, the integrated B3LYP level with 6-311++G(d, p) basis set is depicted in Fig. 3. Potential Energy Distribution (PED) was estimated for all the 75 normal modes of vibration among the local coordinates and using the software program GAR2PED [21]. Normal mode frequencies and the associated wave numbers were assigned based on the information provided by PED calculations. The mismatch observed between the experimental and

theoretical vibrational frequencies (Table S1) is attributed to an incomplete basis set, unaccounted electron correlation, anharmonicity in vibrations and inaccurate estimation of force constants. The systematic errors introduced by the above-said shortcomings can be diminished by scaling procedure [22]. For B3LYP/6-311++G(d, p) level of calculations, the wavenumbers above 1700 cm^{-1} are scaled as 0.958 and below 1700 cm^{-1} scaled as 0.983 [23], and this makes the theoretical values much closer to the experimental values.

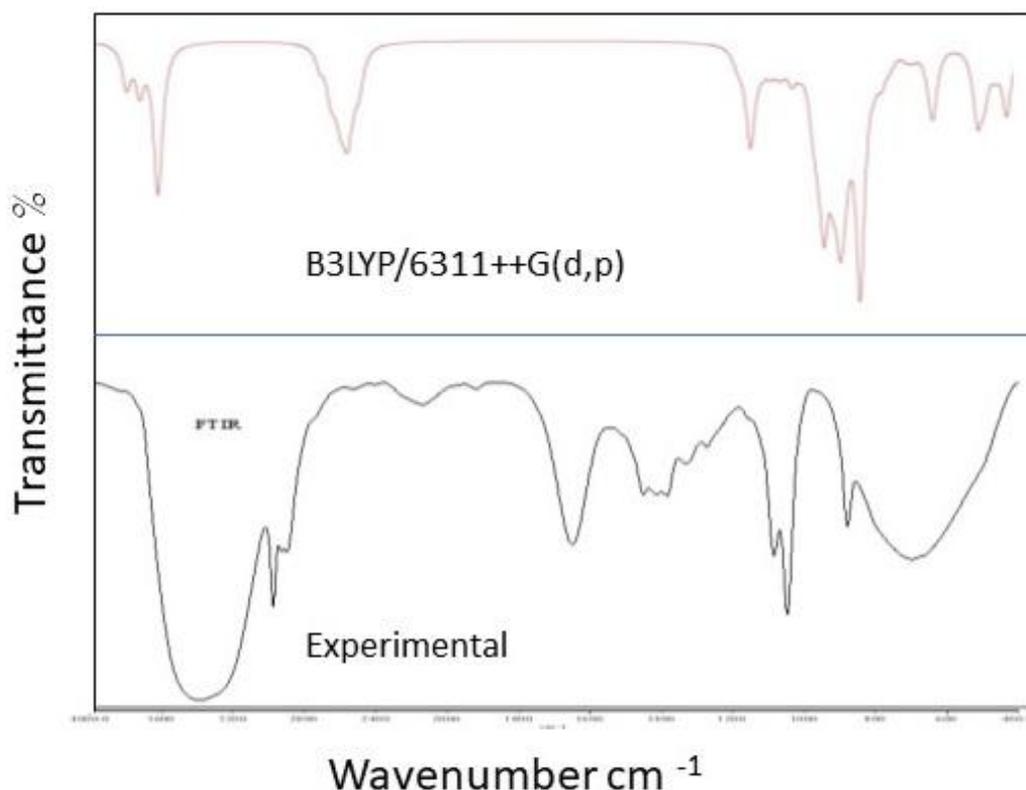


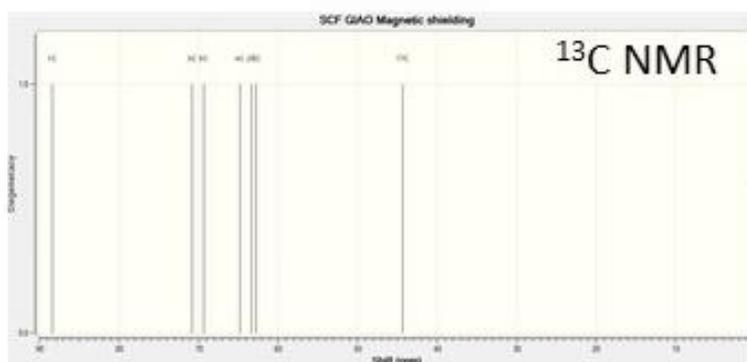
Fig.3. Experimental and theoretical FTIR spectra of the title molecule

The O-H, C-H, O-C and C-C (ring) stretching vibrations are generally expected to occur around the wave number 3500 , 2900 , 1300 and 900 cm^{-1} , respectively, in the FT-IR spectrum [24-28]. In this work, the broad absorbance band around 3400 cm^{-1} is assigned to O-H stretching vibrations in the experimental spectrum while the peaks around 2900 , 1100 and 800 cm^{-1} are ascribed to C-H, O-C and C-C(ring) stretching vibrations. However the wave numbers in the range $3709-3588$ (100% PED), $2993-2850$ ($\approx 100\%$ PED), $1103-832\text{ cm}^{-1}$ (O-C 47% PED and C-C ring 28% PED) are attributed to O-H, C-H, O-C and C-C(ring) normal mode vibrations in the theoretically recorded FT-IR spectrum. Normal mode vibration observed around 1400 cm^{-1} in the experimental FT-IR and in the range $1370-1353\text{ cm}^{-1}$ (75% PED) in theoretical spectra is accredited to HCO bending vibration.

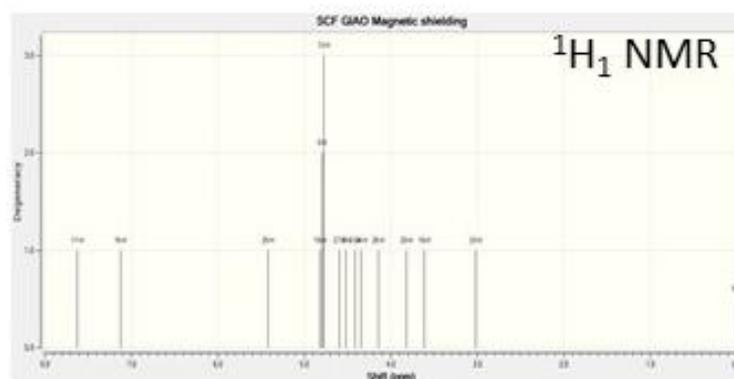
3.3 NMR spectral analysis

The NMR spectrum of the title sample is not recorded experimentally but recorded theoretically using integrated DFT -B3LYP with 6-311++G(d, p) basis set available in

Gaussian 09W software package. From the ^1H NMR spectrum (Fig.4), it is clear that except 8H and 13H all other hydrogen atoms are occupying the same energy state ($n=1$) and thus the degree of degeneracy is 12. Hydrogen atoms 8H and 13H are associated with $n=2, 3$ energy states, respectively. Whereas the ^{13}C NMR spectrum (Fig.4) shows the carbon nuclei occupying the same energy state ($n=1$). Theoretically computed resonance peak positions in ^1H NMR and ^{13}C NMR spectra and the chemical shift with respect to Tetramethylsilane (TMS) are listed in Table 2 and Table 3, respectively. Generally, deshielded/shielded nuclei resonate at higher/lower δppm values. The observed chemical shift (δppm) values from both ^1H NMR and ^{13}C NMR spectra are in good agreement with the literature and reported values [29].



[a]



[b]

Fig. 4. [a] Carbon and [b] Proton NMR spectra of the title molecule

TABLE 2. THEORITICAL CHEMICAL SHIFT VALUES OF ^1H NMR

| Hydrogen Nuclei | Resonance peaks at | Chemical shift (δppm) |
|-----------------|--------------------|---------------------------------------|
| | 31.882TMS | |
| 11-H | 7.62404 | 24.25796 |
| 16-H | 7.12275 | 24.75924 |
| 25-H | 5.41878 | 26.46321 |
| 19-H | 4.81762 | 27.06437 |
| 8-H | 4.79493 | 27.08706 |
| 13-H | 4.77605 | 27.10594 |
| 27-H | 4.59544 | 27.28656 |
| 9- H | 4.52185 | 27.36015 |
| 21-H | 4.41489 | 27.46710 |
| 24-H | 4.34662 | 27.53537 |
| 26-H | 4.14625 | 27.73574 |
| 20-H | 3.81775 | 28.06424 |
| 18-H | 3.61348 | 28.26851 |
| 23-H | 3.01943 | 28.86256 |

TABLE 3.

THEORITICAL CHEMICAL SHIFT VALUES - ^{13}C NMR

| Carbon Nuclei | Resonance peaks at | Chemical shift (δppm) |
|---------------|--------------------|---------------------------------------|
| | 182.466TMS | |

| | | |
|------|----------|-----------|
| 1-C | 88.38389 | 94.08210 |
| 3-C | 70.79034 | 111.67565 |
| 5-C | 69.37007 | 113.09592 |
| 4-C | 64.77217 | 117.69382 |
| 2-C | 63.32622 | 119.13977 |
| 7-C | 62.76722 | 119.78772 |
| 17-C | 44.31596 | 138.15003 |

3.4 Molecular Electrostatic Potential (MEP)

The molecular electrostatic potential energy values for the title molecule is calculated using B3LYP\6-311++G (d, p) basis set at the optimized geometry level and the MEP map of the title compound is shown in Fig.5. Electrostatic potential energy is basically a measure of the strength of the nearby charges, nuclei and electrons, at a particular position [30]. In order to make the electrostatic potential energy data easy to interpret, a color spectrum, with red as the lowest electrostatic potential energy value and blue as the highest [31,32], is applied to convey the varying intensities of the electrostatic potential energy values.

In the present analysis, MEP of the title molecule shows no strong potential regions for electrophilic and nucleophilic strike. Less intense blue color around H23 atom and yellowish orange color over the oxygen atoms O6, O10, and O12 represent the weak electrophilic and nucleophilic charge centers, respectively. Absence of electronegative atomic regions ruled out the possibility for the intra and intermolecular hydrogen bond formation and thus the van der Waals forces play a vital role in stabilizing the molecule.

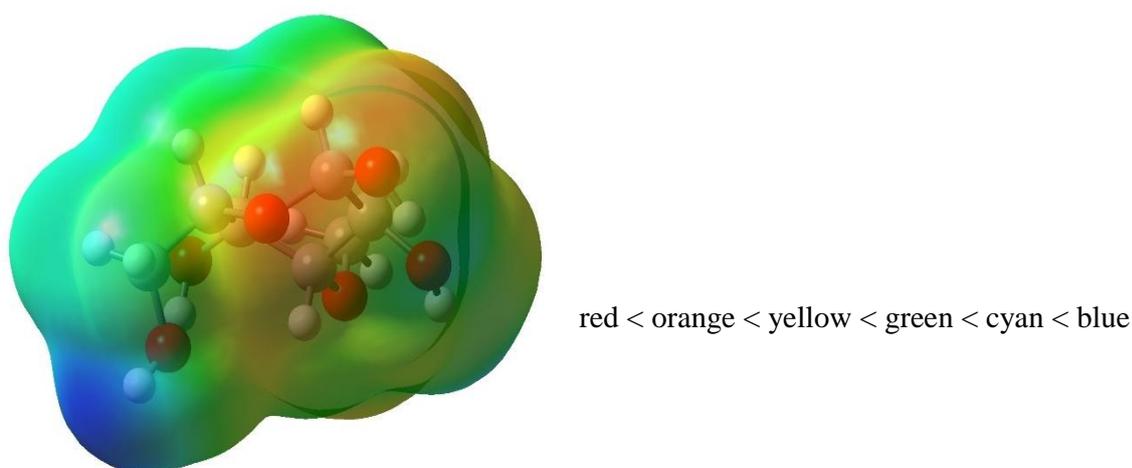


Fig.5. Molecular Electrostatic Potential energy surface of the title molecule

3.5 Frontier molecular orbital analysis

The molecular energies corresponding to the HOMO-LUMO molecular orbital and the energy gap between them have been calculated using TD-DFT at B3LYP level with 6-

| Chemical descriptors | Computed values | Chemical descriptors | Computed values |
|-----------------------------|-----------------|------------------------------|-----------------|
| E_{HOMO} (eV) | -7.054592 | Chemical potential(μ) | -3.824476 |
| E_{LUMO} (eV) | -0.59436 | Electronegativity (χ) | 3.824476 |
| Energy gap (ΔE eV) | 6.46023 | Global hardness (η) | 3.230116 |
| Ionization potential(IP) | 7.05492 | Chemical softness(S) | 0.309586 |
| Electron affinity(EA) | 0.59436 | Electrophilicity (ψ) | 2.264101 |

311++G (d, p) basis set for the title molecule. The energy gap between the HOMO-LUMO molecular orbital is the measure of the rate of charge transfer between the frontier molecular orbital and thus the electrical conductivity [33, 34]. The surface representing the HOMO orbitals covered the entire molecule whereas the surface that of LUMO orbital invade only the fraction of the molecular surface (Fig.6). This difference actually demonstrates the readiness of HOMO orbital to donate electrons and LUMO orbital to accept electrons, and also explains the σ - σ^* type excitation across the molecular orbital. Moreover, the large differences in the charge distribution between the HOMO-LUMO orbitals pave way for the effective charge transfer across the energy gap or within the molecule. The frontier molecular orbital (FMO) analysis has been carried out to deduce knowledge about the distribution of charge density within the molecule, regions of exchange of charge density, interaction between molecules, calculation of HOMO-LUMO energies and the energy gap, molecular reactivity, capacity of the molecule to absorb light and chemical reactivity of the molecule [35-38]. For the title molecule the calculated HOMO-LUMO energies are -7.054592 eV and -0.594360 eV, respectively, and the estimated HOMO-LUMO energy gap is 6.46023 eV. Generally, HOMO energy is the estimated value of ionization potential (energy required to dislodge the electron from HOMO) while that of LUMO is the electron affinity (the neutral atom's likelihood of gaining an electron). FMO analysis can also be used to compute global chemical reactivity descriptors namely Electronegativity (χ), chemical potential (μ), global hardness (η), softness (S), and electrophilicity index (ψ). These global reactivity descriptors for the title molecule were computed theoretically and are listed in Table 4. The high IP and very low EA values support the greater strength and stability of the present compound. Rigidity of the molecule is confirmed from the larger hardness and smaller softness values. The chemical descriptor electrophilicity index (ψ) assists in explaining the biological activity of the title molecule [39].

TABLE 4. THEORETICALLY COMPUTED VALUES OF THE GLOBAL CHEMICAL REACTIVITY DESCRIPTORS

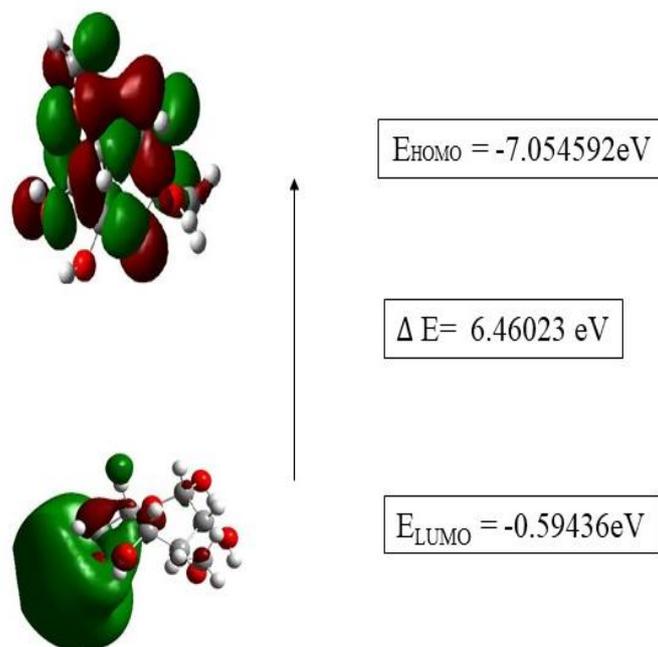


Fig. 6 The energy and the distribution of HOMO and LUMO orbitals

3.6. Estimation of mulliken charges

The Mulliken atomic charges are considered as the measure of electron density of each chemical species in the molecule [40] and they decide the molecular properties such as dipole moment, molecular polarizability, electronic structure, the magnitude of charge distribution over the chemical elements, interactions between the positively and negatively charged atoms and hydrogen bond formation, etc. [41,42]. For the title molecule, the Mulliken charges are estimated theoretically via the calculation of electron population of each atom using B3LYP level with 6-311++G (d, p) basis set and are listed in Table 5. The structural representation of the quantum of atomic charges is shown in Fig.7. The charge distribution of the title molecule shows all the hydrogen atoms are positively charged. Except for the C5 carbon atom, all other carbon atoms along with oxygen atoms are with negative charges. The positive charges on the C5 carbon atom may be due to heavy negatively charged nearby oxygen atom O6. It is evident from the table that the atom C3 is distributed with maximum negative charges (-0.349781) while the atom H27 is with maximum positive charges (0.352040). The presence of large negative charges on carbon and oxygen atoms and net positive charges on hydrogen atoms advocate the formation of intermolecular interactions and consequently promote the formation of hydrogen bonds.

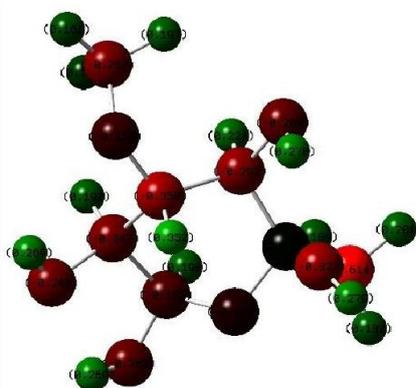


Fig.7 Mulliken charges on individual atoms of the title molecule

TABLE 5. DISTRIBUTION OF MULLIKEN CHARGES OVER THE CHEMICAL SPECIES OF THE TITLE MOLECULE

| Atom | Quantum of Charges | Atom | Quantum of Charges |
|------|--------------------|------|--------------------|
| C1 | -0.162205 | O15 | -0.209317 |
| C2 | -0.247397 | H16 | 0.278376 |
| C3 | -0.349781 | C17 | -0.267391 |
| C4 | -0.291590 | H18 | 0.161216 |
| C5 | 0.012314 | H19 | 0.196526 |
| O6 | -0.071312 | H20 | 0.112438 |
| C7 | -0.613561 | H21 | 0.184375 |
| H8 | 0.201452 | O22 | -0.327298 |
| H9 | 0.182368 | H23 | 0.279377 |
| O10 | -0.202459 | H24 | 0.222543 |
| H11 | 0.269293 | H25 | 0.197630 |
| O12 | -0.245712 | H26 | 0.191632 |
| H13 | 0.269466 | H27 | 0.352040 |
| O14 | -0.123023 | | |

3.7 Natural bonding orbital (NBO) analysis

NBO analysis is a well-chosen technique for the description of hyper conjugative interactions and electron density transfer across the valence space. In hydrogen-bonded (X–H...Y) systems, the momentousness of hyper conjugative interactions and electron density transfer from filled lone electron pairs LP(Y) into an empty anti-bond σ^* (X–H) have been reported earlier [43-45].

The second-order Fock matrix was performed to elucidate the donor-acceptor interactions in NBO analysis at B3LYP level with 6-311++G (d, p) basis set [46] and those interactions always results in the loss of occupancy from the localized NBO of the idealized Lewis structure into an empty non-Lewis orbital. For each donor (i) and acceptor (j), the stabilization energy $E(2)$ associated with the delocalization $i \rightarrow j$ is estimated as $E(2) = \Delta E_{ij} = q_i (F_{ij})^2 \alpha \epsilon_i - \epsilon_j$, where, q_i is the donor orbital occupancy, ϵ_j and ϵ_i are diagonal elements and F_{ij} is the off-diagonal NBO Fock matrix element. For the present study, the NBO analysis outcomes are listed in Table S2. The highly intense interaction between electron donors and electron acceptors can be identified from the larger $E(2)$ value. The molecular stabilizing donor- acceptor interactions are generally due to the delocalization of electron density between occupied Lewis type to non-Lewis type NBO orbitals. From Table S2, the hyper conjugative interaction between the donor type σ (C1-C2) and the acceptor type σ^* (C2-O12) shows the highest stabilization energy 13.59kJ/mol followed by σ (C1-C2, C5-C4) with σ^* (C3-O4, C4-C5 and C1-C2) interaction energies 9.53, 9.06 and 6.89kJ/mol. In the present study the observed bonding- anti-bonding orbital interactions ($\sigma - \sigma^*$) show no significant contribution to the stabilization of the molecule.

3.8 Thermodynamic parameters

The knowledge of vibrational frequencies computed based on the optimized geometrical parameters along with statistical thermodynamics are employed to estimate few a thermodynamic functions namely heat capacity ($C_{p,m}$), entropy(S_m), enthalpy (ΔH), and Gibbs free energy(ΔG). These thermodynamic parameters of the title molecule were estimated by the DFT/B3LYP level with 6-311++G (d,p) basis set at 298.15K and 1.00 atmospheric pressure and listed in Table 6. In practice, the changes in the thermodynamic

functions with temperature over a range of 100-1000K was computed and they are found to increase with the increase of temperature. The relationship between the thermodynamic parameters and the temperatures was established using quadratic formulae [47] and the Scale factors have been introduced to narrow down the deviations of the computed parameters from that of observed parameters [48]. A graph is plotted as thermodynamic parameters Vs. temperature (Fig.8) and the observed interdependence may be attributed to the increased vibrational intensities of the molecule with temperature [49].

The spontaneity of the adsorption process and the direction of chemical reactions can be derived from the data ΔG and the entropy, and of enthalpy, respectively. As a whole, the computation and analysis of thermodynamic parameters are of great help to note the thermal stability of the substance which is vital in defining the chemical reactivity descriptors of the title molecule and its suitability in biological activity studies.

TABLE 6. THEORETICALLY COMPUTED THERMODYNAMIC PARAMETERS FOR VARIOUS TEMPERATURE

| T(K) | S (J/mol-K) | C _p (J/mol-K) | ΔH (kJ/mol) |
|--------|-------------|--------------------------|---------------------|
| 100 | 310.324 | 97.884 | 5.976 |
| 150 | 357.079 | 134.117 | 11.808 |
| 200 | 400.037 | 165.574 | 19.307 |
| 250 | 440.236 | 195.85 | 28.342 |
| 298.15 | 477.245 | 225.3 | 38.48 |
| 300 | 478.642 | 226.434 | 38.898 |
| 350 | 515.84 | 256.853 | 50.983 |
| 400 | 552.065 | 286.095 | 64.564 |
| 450 | 587.36 | 313.393 | 79.56 |
| 500 | 621.694 | 338.391 | 95.865 |
| 550 | 655.027 | 361.05 | 113.36 |
| 600 | 687.335 | 381.515 | 131.933 |
| 650 | 718.615 | 400.007 | 151.479 |
| 700 | 748.882 | 416.763 | 171.905 |
| 750 | 778.163 | 432.004 | 193.13 |
| 800 | 806.495 | 445.921 | 215.083 |
| 850 | 833.917 | 458.679 | 237.703 |
| 900 | 860.471 | 470.411 | 260.934 |
| 950 | 886.199 | 481.231 | 284.729 |
| 1000 | 911.14 | 491.234 | 309.043 |

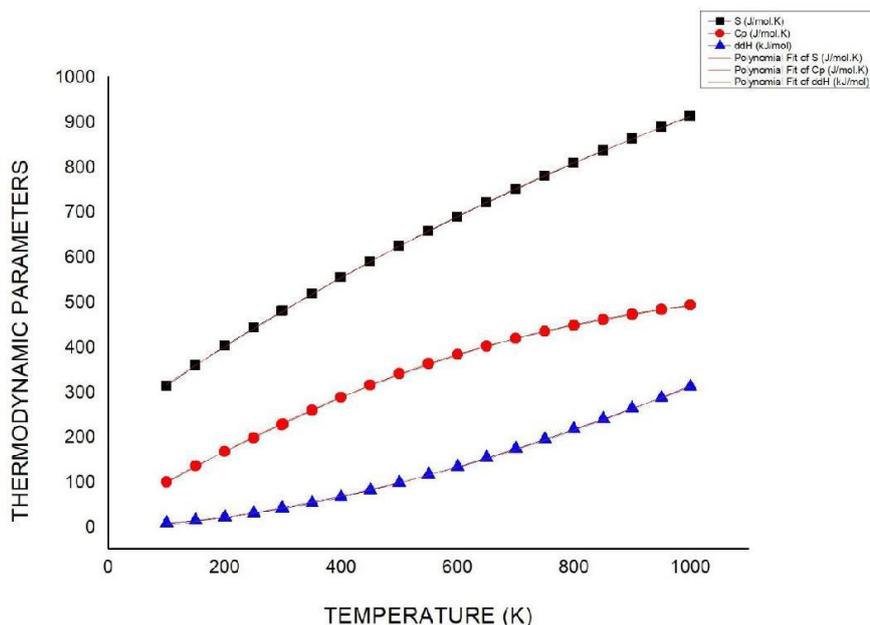


Fig. 8. A graph between thermodynamic parameters and temperature

3.9 Non-linear optical activity

In this study, the anisotropic polarizability and its components, first-order hyperpolarizability, and its components along with dipole moment have been computed using DFT method at B3LYP level with 6-311++G(d,p) basis set by finite field approach and the values are listed in the [Table 7]. Estimates of various defining parameters [Table 7] have been performed using different formulas [50] and the obtained values are analyzed to comprehend the NLO capability of the title molecule. Urea is commonly treated as reference NLO material because of its non-centrosymmetric crystal packing and intramolecular charge transfer (ICT) adeptness. It is noteworthy to mention here that the enormous ' β ' (3.51158×10^{-25} e.s.u) and β_{zzz} (152.77205) values may be due to p-electron cloud movement from donor to the acceptor and the delocalization of electron cloud in that direction. The large value of hyperpolarizability and intramolecular charge transfer (ICT) of the title molecule demonstrate its suitability for NLO applications

TABLE 7. THE COMPUTED VALUES OF STATIC DIPOLE MOMENT, POLARIZABILITY AND FIRST ORDER HYPERPOLARIZABILITY OF THE TITLE COMPOUND USING B3LYP/6311++G(D,P)

| Parameters | Computed values | Parameters | Computed values |
|---------------|-----------------|------------------------|---------------------------|
| β_{xxx} | -62.7616762 | α_{xx} | 113.4520299 |
| β_{xxy} | 23.5929577 | α_{xy} | 1.3469827 |
| β_{xyy} | -19.7667724 | α_{yy} | 113.1525117 |
| β_{yyy} | 0.05451 | α_{xz} | -0.0052406 |
| β_{zxx} | 74.0307695 | α_{yz} | 0.7810766 |
| β_{xyz} | 2.5406983 | α_{zz} | 95.3149756 |
| β_{zyy} | 38.3948804 | α (a.u) | 107.3065057 |
| β_{xzz} | -20.1324695 | α (e.s.u) | 1.59028×10^{-23} |
| β_{yzz} | -3.051753 | $\Delta\alpha$ (a.u) | 38937.69934 |
| β_{zzz} | 152.7720468 | $\Delta\alpha$ (e.s.u) | 5.77057×10^{-21} |

| | | | |
|----------------------|---------------------------|----------|-------------|
| β_x | -102.6609181 | μ_x | -0.7808408 |
| β_y | 20.5957147 | μ_y | 0.3220484 |
| β_z | 265.1976967 | μ_z | 0.0876004 |
| $\beta_{tot}(a.u)$ | 40646.63295 | $\mu(D)$ | 0.000242633 |
| $\beta_{tot}(e.s.u)$ | 3.51158×10^{-25} | | |

3.10 In silico analysis

In this work, the interactions of the title molecule (ligand) with Human Aldose Reductase (target) were examined by molecular docking studies. The three-dimensional structure of the target protein was taken from Research Collaboratory for Structural Bioinformatics (RCSB) Protein Databank (<https://www.rcsb.org/>) and the energy minimized conformation was appropriated as starting conformation for our docking studies. Preparation of both protein and ligand structures was completed using AutoDock Tools 1.5.6 [51] and molecular docking was performed using AutoDock 4.2.6 software [52]. Using the Auto Grid program, a Grid of size $40 \times 40 \times 40 \text{ \AA}^3$ with 0.375 \AA spacing was centered on co-crystallized ligand of the target. The Lamarckian Genetic Algorithm (LGA) [53] docking simulations were initiated with the number of requested GA docking of 10(runs) and maximum energy evaluation of 25×10^5 along with default values for other required parameters. At 298.15K, there are ten conformations and six active torsions about C-O and C-C bonds noted at the end of the docking procedure. Active site binding energy, inhibition constant, and intermolecular energy were perceived for each of the runs and are listed in Table 8. The intermolecular interactions between the ligand and the target established in the protein active site are listed in Table 09. Binding interaction between a small molecule (ligand) and an enzyme (target) may result in inhibition of the activity of that enzyme. The binding mode interaction is characterized by a scoring function with minimum energy. Whereas the inhibition constant (K_i), the concentration needed to reduce the activity of that enzyme by half, is reflective of the binding affinity. The smaller the K_i , the greater the binding affinity and the smaller amount of medication needed to inhibit the activity of that enzyme. Based on the scoring function and other relevant parameters listed in Table 8, the docked pose corresponding to run 4 is considered as the best and the active site interactions [Fig.9] are listed in Table 9. The docking simulation of the title compound into the human ALR2 binding site offers a possible explanation for its good inhibitory activity and may guide the design of new analogues. Estimates of chemical reactivity descriptors and the results of MEP, NBO and HOMO-LUMO analysis also supported the outcome of molecular docking studies on the title molecule.

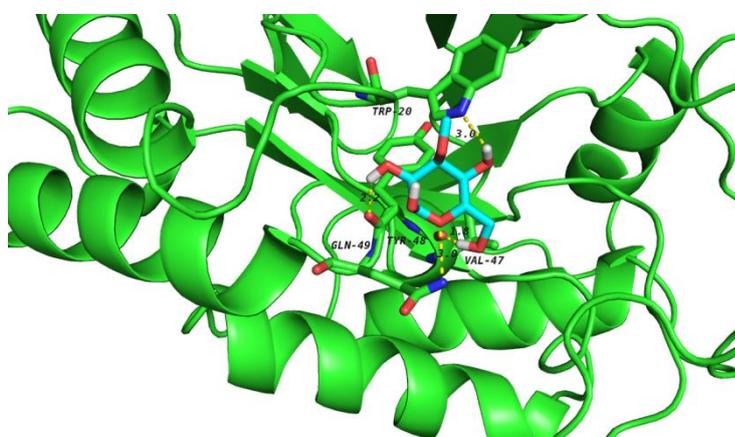
TABLE 8. SCORING FUNCTIONS OBTAINED VIA MOLECULAR DOCKING SIMULATION

| Run No. | Binding energy kcal/mol | Inhibition constant(K_i)mM | Intermolecular energy kcal/mol |
|----------|-------------------------|--------------------------------|--------------------------------|
| 1 | -7.312 | 15.79 | -4.25 |
| 2 | -7.719 | 3.33 | -5.17 |
| 3 | -7.440 | 11.36 | -4.44 |
| 4 | -8.127 | 2.45 | -5.35 |
| 5 | -7.519 | 10.48 | -4.49 |
| 6 | -7.670 | 5.80 | -4.84 |
| 7 | -7.594 | 3.25 | -5.08 |
| 8 | -7.620 | 5.55 | -4.87 |

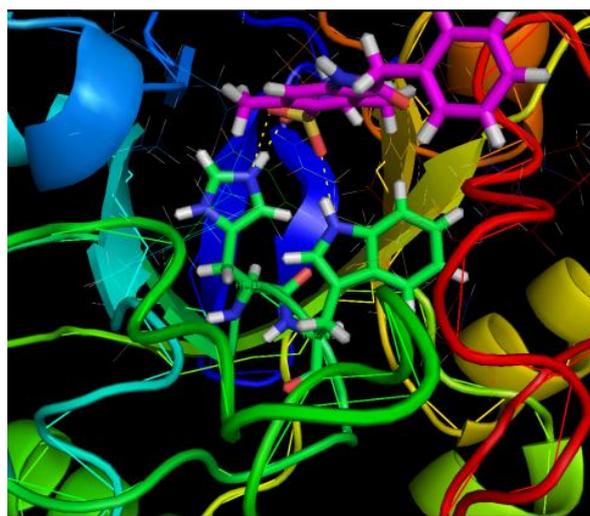
| | | | |
|----|--------|-------|-------|
| 9 | -7.715 | 5.47 | -4.88 |
| 10 | -6.965 | 18.63 | -4.15 |

TABLE 9. BINDING SITE INTERACTIONS AND BINDING ENERGIES

| Ligand | Run No./Pose | Binding site interaction | D-H...A (Å) | Binding energy kcal/mol |
|----------------|--------------|--------------------------|-------------|-------------------------|
| Co-crystal | 5 | HIS110(N-H...O) | 2.724 | -6.714 |
| | | TRP111(N-H...O) | 2.370 | |
| Title molecule | 4 | TRP20(O-H...O) | 3.000 | -8.127 |
| | | VAL47(O-H...O) | 1.800 | |
| | | (N-H...O)TYR48 | 3.000 | |
| | | GLN49(O-H...O) | 2.200 | |



[a]



[b]

Fig.9. Pictures depicting interactions between ligand and target [a] Title molecule and [b] co-crystal

4.0 CONCLUSION

The pyran derivative has been recognized from the ethanol extract of *Senna auriculata* flower (Avaram Poo) using Gas Chromatography-Mass Spectrometry (GC-MS). All the computational work on the title molecule has been carried out using the DFT method at the B3LYP level with a 6311++G (D, P) basis set, incorporated in the Gaussian 09W software package. The 3D molecular structure was obtained and the bond geometries were estimated. The computed FTIR normal mode vibrations were assigned wave numbers based on PED (%) information and compared with experimentally recorded FTIR spectral frequencies. NMR spectrum of the title sample which aid in the estimates of the energy level of the individual atoms and the degree of degeneracy of the molecule as a whole. Mapping of electrostatic potential gives assistance to visualize variably charged regions and the MEP of the title molecule shows no strong potential regions for the electrophilic and nucleophilic strike. The chemical reactivity descriptors derived from HOMO-LUMO analysis undeniably illustrate the intramolecular charge transfer and the appropriateness of the title molecule for biological activities. The characteristic electron population on distinct chemical species was estimated via Mulliken charges analysis. The molecular stabilizing due to the delocalization of electron density between NBO orbitals have been analyzed, which show no significant contribution to the stabilization of the molecule. The direct relationship between the thermodynamical variables such as heat capacity, entropy, and enthalpy with temperature was also studied. The computed hyperpolarizability value supports the superiority of the title molecule over urea (standard) and thus this material can be best suited for optical applications. In-Silico investigation using Autodock algorithm available in Gaussian 09W platform disclose the active site interactions between the ligand (title molecule) and the target (enzyme - ALR2) and propose a possible explanation for its good anti-diabetic activity.

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COMPETING INTERESTS

“Authors have declared that no competing interests exist.”

AUTHORS' CONTRIBUTIONS

“‘Author A’ choose the research problem, performed the experiment, data collection, and the analysis, wrote the manuscript. ‘Author B’ managed the extraction of the compound ‘Author C and author D’ contribute to the analyses of the study. ‘Author A*’ managed the whole manuscript and checked for its correctness and validate the results. All authors read and approved the final manuscript.”

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