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# Structural and Spectral Analysis of Epicatechin Molecule by Density Functional Theory Method

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***Abstract** —In this study, firstly the minimum energy structure of the title compound was determined by a result of the scanning of the potential energy surface at DFT(B3LYP)/6-31 G (d, p) from -180$^o$ to -180$^o$ at 20$^o$ steps at a dihedral angle. Then, the ground state optimized structure and spectral results of the molecule were calculated by using DFT(B3LYP) method at 6-311++G(d,p) level of theory. Its optimized structure parameters (bond lengths, bond angles and torsion angles), vibrational frequencies and chemical shift values were listed and, compared with the corresponding experimental results.*

**Keywords:** Optimization, Epicatechin, Vibrational Frequency, Chemical Shift, DFT.
**Mathematics Subject Classification:** 90C26.

## 1 Introduction

To understand the properties of molecules, definitely, their experimental structural and spectral results should be taken in hand with together theoretical results The methods like ab initio Hatree-Fock (HF) and Density Functional Theory (DFT) are approach methods to understand the situation of systems with many particle, totally. They are withstand to calculate, numerically, ground state structure parameters (bond length and bond angle, i.e), energies, spectroscopic [Infrared (IR), Raman, Ultra-voile (UV), Nuclear Magnetic Resonance (NMR)] results and i.e. of molecules [1,2].

Tea is a popular beverage around the world as black tea and green tea. Green tea is also common in Asian countries, especially Japan, China, Korea and India [3]. Green tea contains a large amount of catechin (ECG; epigallocatechin gallate, EGC; epigallocatechin, EC; epicatechin). These tea catechins belong to the “flavonoid family”. In recent years, due to their various pharmacological activities they have attracted serious attention as example, anti-mutagenic (mutation reducing agent) activities [4, 5], anti-carcinogen (substance that

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balances carcinogenic effects or inhibits cancer growth) effects [6], i.e. Widespread controversy in the mechanism of their biological and pharmacological effects is the antioxidant activities of this tea catechin (oxidation-inhibiting chemical or compound) [7,8]. These have shown that; EGCG, ECG, EGC and EC act as low-density in-hybrids to lipoprotein oxidation (biochemical compounds composed of both protein and lipids) [9]. Some catechins have been reported the destructive effects of free radicals; for example; DPPH radicals (1,1 diphenyl-2-pycrylhydrazyl)[10], superoxide anions [11], free lipid and hydroxyl radicals [12]. Some authors have studied the synergistic scavenging effects of these 4 catechins (EGCG, ECG, EGC and EC) in superoxide anions [13].

Here, in this study, after the determination of the optimized structure of the title molecule, its IR vibrational and NMR chemical shift analyzes were done. By comparing of the obtained theoretical results with the corresponding experimental results, the precise informations about the molecule were reached.

## 2 Theoretical Details

Gaussian 03 package and Gauss-View molecular visualization program were used in all the calculations [14]. Firstly the minimum energy structure of the compound was determined by a result of the scanning of the potential energy surface at DFT(B3LYP)/6-31 G (d, p) from -180$^o$ to -180$^o$ at 20$^o$ steps at the dihedral angle C3-C2-C11-C16. After, the optimized structure parameters (bond lengths, bond angles and torsion angles) of the compound were calculated by the density functional theory (DFT) method at the B3LYP/6-311 ++ G (d, p) basis set level. The vibrational frequencies and chemical shifts were also calculated at the same level. The calculated vibrational frequencies were scaled with the scale factor of 0,9614 [16]. Approximate descriptions of vibration modes were made with VEDA 4 program [17]. The $^1$H and $^{13}$C NMR chemical shifts (in gas phase) were done by Gauge Including Atomic Orbitals **(**GIAO) method. In the chemical shift calculations tetramethylsilane (TMS) was used as a reference molecule, and the theoretical chemical shift $^1$H and $^{13}$C values were obtained by subtracting the GIAO isotropic magnetic shielding (IMS) values [18, 19].

## 3 Results and Discussion

The optimized molecular structure of (-)-epicatechin is given in Fig.1. In the figure is also given PLUTO drawing with the atomic numbering scheme [20]. The optimized energy value of the molecule is 1031.380486 a.u. The geometric parameters (bond length, bond angle and dihedral angles) according to the numbered atoms in Fig.1 are given in Table 1. To compare the experimental values are also given in the table [20]. The correlation values (R$^2$) between the theoretical and experimental values are written in the last line of the charts. From the R$^2$ values, we can say that the theoretical calculations are compatible with the experimental data, especially in the bond length.

The experimental and theoretical IR spectra of the compound are given in Fig .2. The experimental spectrum is taken from Ref [21]. Table 2 shows the experimental and corresponding theoretical vibrational frequencies. The approximate descriptions of the vibrational modes in the table are obtained with the Veda 4 program [17], which makes potential energy

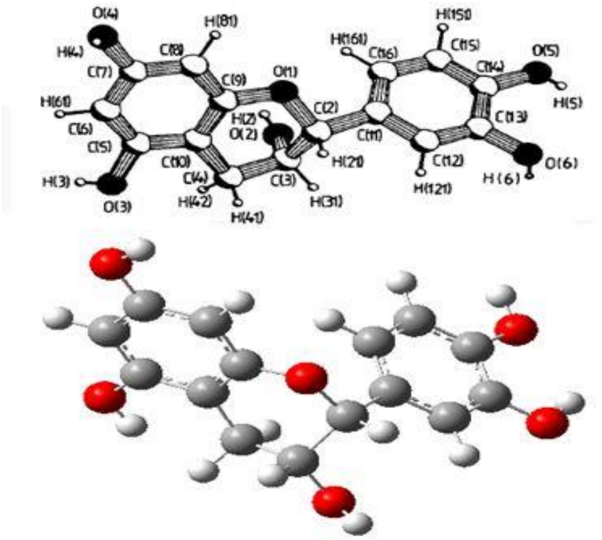

Figure 1: Molecular structure of (-)-epicatechin, a) PLUTO drawing with the atomic numbering scheme, and b) calculated at DFT(B3LYP)/6-311++ G(d,p) level.

Table 1: Calculated optimized geometrical parameters of (-)-epicatechin.

| **Bond length (A⁰)** | Exp.[ 20] | Calculated | **Bond length (A⁰)** | Exp.[ 20] | Calculated |
|---|---|---|---|---|---|
| O(1)-C(2) | 1.46 | 1.44 | C(5)-C(10) | 1.40 | 1.41 |
| O(1)-C(9) | 1.39 | 1.37 | C(6)-C7) | 1.36 | 1.39 |
| O(2)-C(3) | 1.44 | 1.42 | C(7)-C8) | 1.39 | 1.39 |
| O(3)-C(5) | 1.38 | 1.37 | C(8)-C(9) | 1.41 | 1.40 |
| O(4)-C(7) | 1.37 | 1.37 | C(9)-C(10) | 1.38 | 1.40 |
| O(5)-C(14) | 1.38 | 1.38 | C(11)-C(16) | 1.39 | 1.40 |
| O(6)-C(13) | 1.39 | 1.36 | C(11)-C(12) | 1.41 | 1.40 |
| C(2)-C(11) | 1.53 | 1.52 | C(12)-C(13) | 1.38 | 1.39 |
| C(2)-C(3) | 1.53 | 1.55 | C(13)-C(14) | 1.40 | 1.40 |
| C(3)-C(4) | 1.51 | 1.52 | C(14)-C(15) | 1.36 | 1.39 |
| C(4)-C(10) | 1.50 | 1.51 | C(15)-C(16) | 1.37 | 1.40 |
| C(5)-C(6) | 1.38 | 1.39 | | | |

$R^2$=0.91

Table 1: Continued

| **Bond angles (º)** | Exp.[ 20] | Calculated | **Bond angle (º)** | Exp.[ 20] | Calculated |
|---|---|---|---|---|---|
| C(2)--O(1)--C(9 | 114.6 | 118.9 | C(8)-C(9)-C(10) | 122.5 | 121.9 |
| C(3)-C(2)-C(11) | 112.4 | 115.3 | O(1)-C(9)-C(10) | 122.7 | 122.7 |
| O(1)-C(2)--C(3) | 110.5 | 108.4 | C(5)-C(10)-C(9) | 116-5 | 117.1 |
| O(1)-C(2)-C(11) | 105.3 | 112.5 | C(4)-C(10)-C(5) | 121.I | 122.4 |
| O(2)-C(3)-C(2) | 112.2 | 112.8 | C(4)-C(10)-C(9) | 122.4 | 120.4 |
| O(2)-C(3)-C(4) | 112.2 | 108.4 | C(12)-C(11)-C(16) | 120.2 | 118.9 |
| C(2)-C(3)-C(4) | 109.5 | 110.1 | C(2)-C(I l)-C(16) | 123.3 | 122.4 |
| C(3)-C(4)-C(10) | 109.7 | 109.6 | C(2)-C(I l)-C(12) | 116.4 | 118.8 |
| C(6)-C(5)-C(10) | 122.5 | 122.2 | C(l l)-C(l 2)-C(13) | 119.4 | 121.0 |
| O(3)-C(5)-C(6) | 122.1 | 116.4 | O(6)-C(13)-C(12) | 122.2 | 119.7 |
| O(3)-C(5)-C(10) | 115.3 | 121.4 | C(12)-C(13)--C(14) | 119.8 | 119.6 |
| C(5)-C(6)-C(7) | 118.8 | 118.8 | O(6)-C(13)-C(14) | 118.0) | 120.7 |
| C(6)-C(7)-C(8) | 122.3 | 121.0 | O(5)--C(14)-C(15) | 119.0 | 124.7 |
| O(4)-C(7)-C(8) | 118.3 | 122.0 | C(13)-C(14)-C(15) | 119.3 | 120.0 |
| O(4)-C(7)-C(6) | 119.4 | 117.0 | O(5)-C(14)-C(13) | 121.7 | 115.3 |
| C(7)-C(8)-C(9) | 117.3 | 118.9 | C(14)-C(15)-C(16) | 123.0 | 120.2 |
| O(1)-C(9)-C(8 | 114.7 | 115.3 | C(I l)-C(16)-C(15 | 118.7 | 120.4 |

$R^2$=0.60

Table 2: Selected calculated and experimental vibrational frequencies (cm$^{-1}$) and, assignments. Experimental values are obtained from the IR spectrum of (-)- epicatechin [21].

| Assinments | Exp.[21] | Calculated |
|---|---|---|
| νOH(100) | 3603 | 3690 |
| νOH(100) | 3455 | 3689 |
| νOH(100) | 3409 | 3647 |
| νCH(99) | 3169 | 3091 |
| νCH(98) | 3151 | 3090 |
| νCH(98) | 2923 | 2929 |
| νCH(98) | 2868 | 2920 |
| νCH(99) | 2864 | 2889 |
| νCH(90) | 2727 | 2885 |
| νCC(51)+δHCC(10) | 1627 | 1604 |
| νCC(56) | 1608 | 1597 |
| νCC(53) | 1522 | 1573 |
| δHCC(21)+δCCC(12) | 1457 | 1468 |
| νCC(15)+δHOC(15)+δHCH(11) | 1444 | 1435 |
| δHOC(18)+δHCO(17)+τHCOH(16)+τHCCC(11) | 1378 | 1381 |
| δHCO(18) +τHCCC(14)+νCC(12) | 1349 | 1355 |
| νCC(16)+νOC(12) | 1313 | 1310 |
| δHCC(14)+δHOC(13) | 1296 | 1299 |
| δHOC(22) | 1289 | 1287 |
| νOC(29)+δHCC(12)+νCC(11) | 1261 | 1253 |
| νOC(18)+δHCC(15) | 1225 | 1232 |
| δHOC(38) | 1182 | 1187 |
| δHCC(33)+δHOC(26) | 1144 | 1148 |
| δHCC(13)+ νCC(10) | 1112 | 1115 |
| νOC(30)+δHOC(42)+δHCC(12) | 1096 | 1108 |
| νOC(33)+δCCC(13) | 1070 | 1068 |

Table 2: Continued

| Assinments | Exp.[21] | Calculated |
|---|---|---|
| νCC(22)+νOC(19) | 1045 | 1047 |
| νOC(33) | 1017 | 1028 |
| νCC(30)+δHCC(15)+τHCCC(12) | 979 | 973 |
| τHCCC(24) | 875 | 871 |
| τHCCC(46)+τCCCC(14) | 862 | 843 |
| τHCCC(68)+ γOCCC(22) | 833 | 806 |
| δCCC(15) | 808 | 792 |
| τHCCC(52) | 795 | 778 |
| δOCC(15)+γOCCC(12)+δCOC(11) | 627 | 636 |

$R^2$=0.996

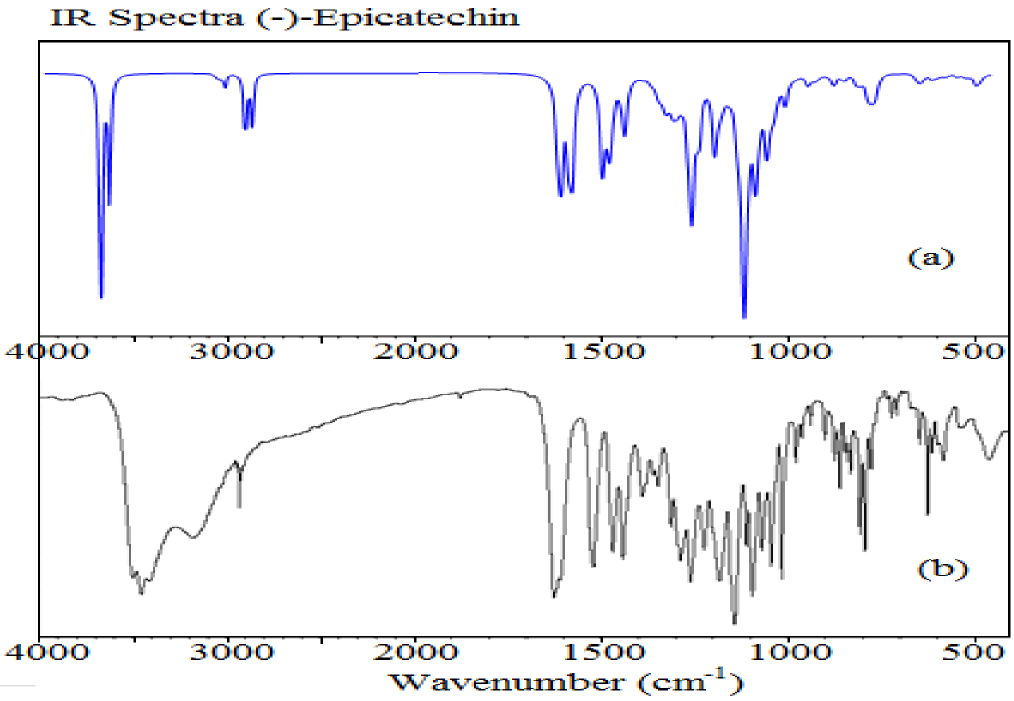

Figure 2: a) Theoretical and b) experimental IR spectrum of (-)-epicatechin

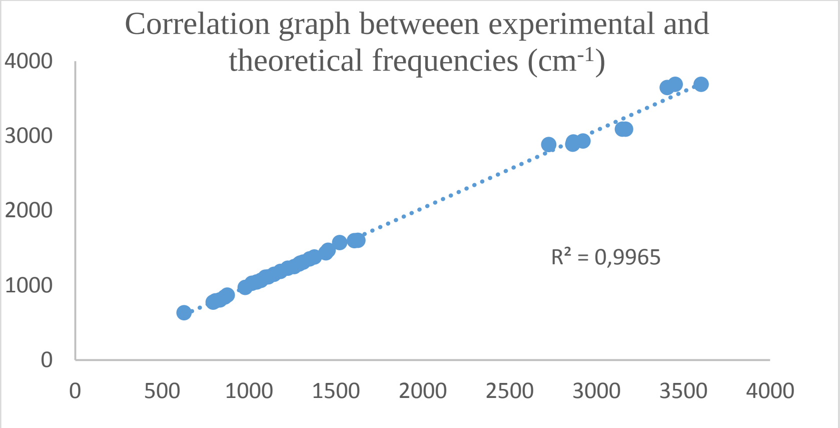

Figure 3: Correlation graph for frequencies**.**

distribution (PED) analysis. The correlation value between the theoretical and experimental frequencies is written at the bottom line of the table. The correlation graph can be seen in Fig.3. Here, from the $R^2$ value we can say that the experimental and theoretical frequencies are in a very good harmony.

As finally in Table 3 the calculated and experimental $^1$H and $^{13}$C NMR isotropic chemical shift values for (-)-epicatechin are given as corresponding to the atom numbering schema given in Fig.4. The experimental values are taken from Ref. [21]. Again, the $R^2$ values are written in the last line of the charts. They show a good agreement with the experimental data.

## 4 Conclusion

As conclusion, the ground state optimized structures of (-)- epicatechin molecule was determined, and its geometric parameters, vibration frequencies and chemical shift values were calculated and, compared with the experimental results. It has been found a good harmony between the experimental and theoretical values. The results determined here for the title molecule having various pharmacological activities will be useful in its future studies.

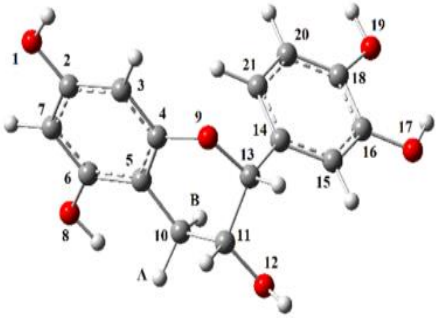

Figure 4: Atom numbering scheme for chemical shifts**.**

Table 3: Calculated and experimental $^1$H experimental and $^{13}$C NMR isotropic chemical shifts for (-)-epicatechin.

| Atoms | Exp. (DMSO-$d_6$) | Calculated (Gas) |
|---|---|---|
| C2 | 156.41 | 165.81 |
| C3 | 94.09 | 97.07 |
| C4 | 155.68 | 162.74 |
| C5 | 98.47 | 101.41 |
| C6 | 156.16 | 163.88 |
| C7 | 95.12 | 99.77 |
| C10 | 28.07 | 25.46 |
| C11 | 64.89 | 73.93 |
| C13 | 78.01 | 85.25 |
| C14 | 130.55 | 138.15 |
| C15 | 114.85 | 121.80 |
| C16 | 144.35 | 151.80 |
| C18 | 144.42 | 148.88 |
| C20 | 114.72 | 115.92 |
| C21 | 117.91 | 122.74 |
| $R^2$=0.995 | | |
| H3 | 5.65 | 5.84 |
| H7 | 5.82 | 6.35 |
| H10A | 2.60 | 2.28 |
| H10B | 2.40 | 1.98 |
| H11 | 3.93 | 4.37 |
| H13 | 4.59 | 5.08 |
| H15 | 6.82 | 6.99 |
| H20 | 6.58 | 6.35 |
| H21 | 6.59 | 6.45 |
| $R^2$=0.964 | | |

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## Conflict of Interest Declaration

The authors declare that there is no conflict of interest statement.

## Ethics Committee Approval and Informed Consent

The authors declare that there is no ethics committee approval and/or informed consent statement.

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