Catechin and Epicatechin. What’s the More Reactive?

Essoh Akpa Eugène, N’guessan Boka Robert, Adenidji Ganiyou, Yapo Kicho Denis, Adjou Ané, Bamba El Hadji Sawaliho*

Laboratoire de Constitution et de Réaction de la Matière, UFR SSMT, Université Félix Houphouët-Boigny, Abidjan, Côte d’Ivoire
Email: *bame1901@usherbrooke.ca


Received: December 24, 2021
Accepted: March 8, 2022
Published: March 11, 2022

Copyright © 2022 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0). http://creativecommons.org/licenses/by/4.0/

Abstract
Catechin and epicatechin are two isomeric flavanoids. Despite the vital properties highlighted by numerous scientific studies, very little data is available on the intrinsic reactivity of these compounds. To provide more details on the stability and reactivity of catechin and epicatechin, this study is performed by means of theoretical calculation methods. For this purpose, geometry optimizations and frequency calculations at the B3LYP/6-31 + G (d, p) level of theory has been carried out and Natural Bond Orbital (NBO) analysis and VEDA (Vibrational Energy Distribution Analysis). The geometric and energy parameters and NBO analysis show that catechin appears more stable than epicatechin. The hydroxyl group position on the ring C of the catechol structure represents a factor that influences this relative stability. The global and local reactivity parameters reveal that epicatechin becomes more reactive than catechin. They indicate that their hydroxyl groups correspond to their most receptive sites. Fukui indices, VEDA and acidity study establish that $O_{28}$–$H_{29}$ remains the most reactive.

Keywords
Catechin, Epicatechin, NBO, Acidity, DFT, Normal Modes

1. Introduction
Catechin and epicatechin are two isomeric flavanols. They differ from the R and S configuration linked to the two asymmetric carbons of 2-phenyl-3-chromanol (Figure 1) [1] [2] [3] [4]. In Figure 1, each ball represents an atom. Red is oxygen. A white ball illustrates the carbon. A small one describes hydrogen. Catechin and epicatechin are widespread in the plant kingdom through fruits such as grapes, apples and too many manufactured products such as wine, chocolate,
and tea [2] [5]. With the consumption of these foods, humans benefit from antioxidant properties [6] [7] [8] [9] [10]. These delay cell damage and combat certain chronic diseases including cardiovascular and neurodegenerative diseases ones [6] [7] [11] [12] [13] [14]. These molecules also possess anti-cancer, anti-inflammatory and anti-viral properties [15] [16] [17] [18]. The wide spectrum of polyphenols’ biological activities gives them a great importance in therapeutic processes. Besides, only 2% of these alcohols consumed reach the plasma. This underperformance thus represents a problem of bioavailability [19]. Increasing their proportion in this organism would make them much more efficacious. For better control and improvement of polyphenols’ therapeutic effects, it’s advisable to discover ways to grow their concentration in plasma. The development of medicines incorporating polyphenols would be an asset in providing effective remedies for these illnesses that ruin human populations. Tests to manufacture catechin-specific anti-inflammatory drugs weren’t as conclusive as expected. The reasons are related to the failures of the very limited clinical tests because of their stability, their short half-life in the plasma and their low bioavailability [20] [21].

The properties exhibited by catechin and epicatechin emanate from their many hydroxyl groups [22]. The aromatic rings and their OH associated makes it possible to build several types of interactions. These permit polyphenols to scavenge hydroxyl radicals, inhibit reactions such as lipid peroxidation and

Figure 1. Structure of Catechin and Epicatechin.
prevent oxidation reactions. This process happens in a state of transition [22];
the latter promotes the occupation of their specific molecular orbitals [23]. These
foster some CHO bond at three centres. However, despite the large number of
studies on the biological mechanisms explaining the beneficial effects of poly-
phenols on human health, few quantitative data are available on the polyphene-
hol’s reactivity. This research aims to fill this gap through the following ques-
tion:

Which isomer is the most reactive between catechin and epicatechin?

Its response fulfills the gap in numerical data relating to the reactivity of the
two compounds. But it’s difficult to identify all the factors involved in the insta-
 bility of the two isomers. To correct this shortcoming, the work wants to address
another question:

What are the most receptive sites of isomers?

The research plans to suggest avenues that will contribute to a better integra-
tion of molecular interactions and biological activities. It assimilates catechin
and epicatechin to a polyphenol model. It evaluates their reactivity using physi-
cal and chemical quantities. These include the energy, infrared (IR) and ultra-
violet (UV) spectroscopic parameters. They incorporate electronic properties such
as the HOMO (High Occupied Molecular Orbital)-LUMO (Lowest Unoccupied
Molecular Orbital) energy gap, chemical hardness and chemical potential. They
comprise molecular electrostatic potential (MEP) and Fukui indices. These ana-
lyze the local and global reactivity. Furthermore, the acidity potential (pKa) speci-
ifies that of each hydroxyl group. Natural Bond Orbital (NBO) analysis allows
following charge transfer and intramolecular interactions in catechin and epicate-
chin. This article discusses the calculations relating to these parameters. Pre-
viously, it presented the method and the material used to obtain them.

2. Materials and Methods

This part includes the descriptors of global and local reactivity. It explains those
of acidity. It describes how to assess load transfers using NBO analysis. For the
moment, it specifies the method of calculations. The bond lengths, the bond an-
gles and the standard dihedral angle constitute the initial geometrical parame-
ters. The geometry optimizations and the frequency calculations were carried
out with the Density Functional Theory (DFT) method at the B3LYP/6-31 +
G(d, p) level of theory [24] in gas and aqueous phases.

2.1. Calculation Method

The CPCM (Conductor-like Polarizable Continuum Model) calculation simu-
lates the physiological environment. All calculations were performed with the
GAUSSIAN 09 software [25]. Frequency calculations verify local and global mi-
nima. TD-DFT method permits to analyze the electron transitions in the ultra-
violet (UV) range. The research determines the energies of the frontier molecu-
lar orbitals including the highest occupied one (HOMO) and the lowest unoccu-
pied one (LUMO). It uses NBO calculation [26] examining the NBO. Gaussian’s calculations provide access to the frontier orbitals of a molecule. Their HOMO and LUMO contribute interpreting the reactivity of a molecule [27] [28].

2.2. Global Reactivity Descriptors

The energies of these two frontier orbitals lead to the determination of several reactivity parameters. According to Koopmans theorem [29], the ionization energy $I$ and the electronic affinity $A$ are directly related to the energy of the HOMO and the LUMO respectively.

$$ I = -E_{\text{HOMO}} $$

(1)

$$ A = -E_{\text{LUMO}} $$

(2)

The chemical electron potential $\mu$ and chemical hardness $\eta$ are defined in terms of ionization energy and electron affinity [30]:

$$ \mu = \frac{A + I}{2} $$

(3)

$$ \eta = \frac{I - A}{2} $$

(4)

Also, global index of electrophilicity $\omega$, introduced by Parr [31], is defined by the following formula:

$$ \omega = \frac{\mu^2}{\eta} $$

(5)

Local reactivity index is also accessible by calculation. While the global reactivity parameters evaluate that of a molecule, Fukui [32] introduces indices (Fukui parameters) to describe the reactivity of each atom.

2.3. Local Reactivity Descriptors

These parameters denote either a nucleophilic attack ($f_k^+$), an electrophilic attack ($f_k^-$), or a radical attack ($f_k^0$). The following equations [33] help to determine them:

$$ f_k^+ = q_k(N+1) - q_k(N) $$

(6)

$$ f_k^- = q_k(N) - q_k(N-1) $$

(7)

$$ f_k^0 = \left[ q_k(N+1) - q_k(N-1) \right]/2 $$

(8)

With

$q_k(N)$: the electron population of atom $k$ in the neutral molecule.

$q_k(N+1)$: the electron population of atom $k$ in the cationic molecule.

$q_k(N-1)$: the electron population of atom $k$ in the anionic molecule.

The acidity represents an important parameter to integrate the intermolecular interactions. The calculations give access to the pKa.

2.4. Acidity

Catechin and epicatechin represent polyphenols with both five hydroxyl groups.
They’re therefore likely to exchange one or more protons with other molecules, either during hydrogen bonding interactions or “antiradical” mechanisms [34]. The pKa of each hydroxyl group evaluates the proton transfer reactions between catechin and epicatechin and additional molecules. It helps classifying their acidity. The thermodynamic cycle below allows calculating it by considering the effect of solvation due to the presence of H2O [35].

The free energy of solvation $\Delta G_{\text{sol}}$ becomes:

$$
\Delta G_{\text{sol}} = \Delta G_g + \Delta G_{\text{solv}}(\text{H}^+^-) + \Delta G_{\text{solv}}(\text{H}_2\text{O}^-) - \Delta G_{\text{solv}}(\text{AH}) - \Delta G_{\text{solv}}(\text{H}_2\text{O})
$$

The value of $\Delta G_{\text{solv}}(\text{H}_2\text{O}^-)$ equals −110.2 kcal/mol. Pliego and Riveros [36] determined it experimentally.

$$
pKa = \frac{\Delta G_{\text{sol}}}{1.364} + \log[\text{H}_2\text{O}]
$$

where $[\text{H}_2\text{O}] = 55.5$ M. However, since the free energy of the hydronium ion constitutes a source of error. According to Pliego [35], the corrected formula for pKa is written as follows. On the other hand, this calculation of Pka leads to the NBO analysis.

$$
pKa(\text{corrected}) = pKa - 4.54
$$

2.5. NBO Analysis

NBO analysis [26] evaluates the charge transfer properties in molecules. It provides a deep understanding of intramolecular and intermolecular orbital interactions between occupied NBO donors and empty NBO acceptors [37] [38]. The charge transfer involves delocalization of electrons from an electron donor site Lewis-type orbital: lone pairs (n), natural bond (σ and π) to an electron acceptor one (anti-Lewis orbital: σ* and π*). This electron delocalization is with a decrease in the donor electronic density and an increase in the acceptor one. For each donor NBO (i) and acceptor NBO (j), the electron delocalization $i \rightarrow j$ is evaluated by the stabilization energy $E^{(2)}$ using second-order perturbation theory [39]. This latter is expressed as:

$$
E^{(2)} = \Delta E_{ij} = q_i \frac{F(i,j)^2}{\epsilon_i - \epsilon_j}
$$

where $q_i$ denotes the electronic density in the donor orbital, $F(i,j)$ designs a non-diagonal element of the Fock matrix, $\epsilon_i$ and $\epsilon_j$ correspond to the energies of the occupied $i$ and empty $j$ orbitals respectively. The higher $E^{(2)}$, the more redistribution of electrons between donor and acceptor confers stability. This affirmation introduces the presentation of the results and their analysis.

3. Results and Discussion

This section discusses those related to indicators of global and local responsiveness. Its analysis concerns acidity and NBO comprise results of calcula-
tions associated with spectral quantities. Catechin or epicatechin is composed of 35 atoms. Vibration mode analysis suggests 99 normal vibrations for both molecules.

### 3.1. Spectroscopic Parameters

These vibrations are divided into 34 stretching, 33 deformations and 32 torsions. The 34 stretching is repartitioned into five O–H, nine C–H, 13 C–C and seven C–O. This agrees with the structure of the two molecules (Figure 1). The analysis of the potential energy distribution (PED) by VEDA can efficiently assign the calculated normal modes of vibration. Table 1 presents the O–H elongation vibration frequencies of catechin and epicatechin. It indicates that the catechin and epicatechin O–H elongation frequencies vary from 3788 to 3845 cm⁻¹. These agree with the experimental values of the O–H bonds of aromatic rings [40].

The first three O–H elongation frequencies stay at 3845 cm⁻¹, 3833 cm⁻¹, and 3830 cm⁻¹ correspond to \( \nu_{O28-H28} \), \( \nu_{O32-H32} \), and \( \nu_{O34-H34} \), respectively, of the two molecules. Their intensities are approximately the same. The ranking of the –H bonds by their elongation frequencies is:

\[
\nu_{O28-H28} > \nu_{O32-H32} > \nu_{O34-H34} > \nu_{O36-H36} > \nu_{O38-H38} \quad \text{for epicatechin and} \\
\nu_{O28-H28} > \nu_{O32-H32} > \nu_{O34-H34} > \nu_{O36-H36} > \nu_{O38-H38} \quad \text{for catechin.} \\
\nu_{O30-H31} \text{ changes from 3803 cm}\text{⁻¹ in catechin to 3788 cm}\text{⁻¹ in epicatechin. Their intensities of this vibration also change. They increase from 28.44 km/mole in the catechin to 61.35 km/mole. O}_{30}-H_{31} \text{ is affected by the asymmetry of carbon C}_{12}.
\]

### 3.2. UV-Visible Spectral Analysis

The TD-DFT method at the level of the theory B3LYP/6-31 + G (d, p), in the gas phase evaluates the electron transitions of catechin or epicatechin in the ultraviolet and visible regions. It gives molecule excitation energy. This latter quantity permits comparing the reactivity of two molecules. Its higher value corresponds to the more stable compound. Table 2 shows the results of the TD-DFT calculations. It displays the first three excited states of both molecules as presented in Figure 2.

**Table 1.** Vibrational frequencies (cm⁻¹), IR intensity (km/mol) and vibrational assignation (PED) of Catechin and Epicatechin.

<table>
<thead>
<tr>
<th>( \nu (\text{cm}^{-1}) )</th>
<th>IR intensity</th>
<th>Vibrational assign. (PED)</th>
<th>( \nu (\text{cm}^{-1}) )</th>
<th>IR intensity</th>
<th>Vibrational assignation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catechin</td>
<td></td>
<td></td>
<td>Epicatechin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3845</td>
<td>86.99</td>
<td>( \nu_{O30H30} ) (100)</td>
<td>3844</td>
<td>87.95</td>
<td>( \nu_{O30H30} ) (100)</td>
</tr>
<tr>
<td>3833</td>
<td>68.90</td>
<td>( \nu_{O32H32} ) (100)</td>
<td>3833</td>
<td>67.91</td>
<td>( \nu_{O32H32} ) (100)</td>
</tr>
<tr>
<td>3830</td>
<td>67.31</td>
<td>( \nu_{O34H34} ) (100)</td>
<td>3830</td>
<td>66.91</td>
<td>( \nu_{O34H34} ) (100)</td>
</tr>
<tr>
<td>3803</td>
<td>28.44</td>
<td>( \nu_{O36H36} ) (100)</td>
<td>3789</td>
<td>86.13</td>
<td>( \nu_{O36H36} ) (94)</td>
</tr>
<tr>
<td>3788</td>
<td>118.71</td>
<td>( \nu_{O38H38} ) (100)</td>
<td>3788</td>
<td>61.35</td>
<td>( \nu_{O38H38} ) (94)</td>
</tr>
</tbody>
</table>
Figure 2. UV-visible spectra of catechin and epicatechin.

Table 2. Main transitions calculated for Catechin and Epicatechin.

<table>
<thead>
<tr>
<th>Excited State</th>
<th>∆E (eV)</th>
<th>λ (nm)</th>
<th>f (a.u.)</th>
<th>Transition</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Catechin</td>
<td>4.7453</td>
<td>261.28</td>
<td>0.0032</td>
<td>HOMO → LUMO + 1</td>
<td>54.03</td>
</tr>
<tr>
<td>Second Catechin</td>
<td>4.7851</td>
<td>259.11</td>
<td>0.0902</td>
<td>HOMO → LUMO</td>
<td>60.56</td>
</tr>
<tr>
<td>Third Catechin</td>
<td>4.8871</td>
<td>253.70</td>
<td>0.0081</td>
<td>HOMO−1 → LUMO</td>
<td>50.35</td>
</tr>
<tr>
<td>First Epicatechin</td>
<td>4.7355</td>
<td>261.82</td>
<td>0.0479</td>
<td>HOMO → LUMO</td>
<td>61.19</td>
</tr>
<tr>
<td>Second Epicatechin</td>
<td>4.7650</td>
<td>260.20</td>
<td>0.0087</td>
<td>HOMO → LUMO + 1</td>
<td>44.24</td>
</tr>
<tr>
<td>Third Epicatechin</td>
<td>4.8607</td>
<td>255.08</td>
<td>0.0269</td>
<td>HOMO−1 → LUMO</td>
<td>47.40</td>
</tr>
</tbody>
</table>

For epicatechin, the first excited state wavelength is 262 nm. This is the most intense excitation. Its main component refers to the HOMO → LUMO transition with a weight of 61%. Its excitation energy is 4.7355 eV. The second one relates to the band with a wavelength equals 260.20 nm. It associates with the HOMO − 2 → LUMO + 1 transition. Its excitation energy is 4.7453 eV. The latter is greater
than that of the first excited state. This result means that epicatechin is more reactive than catechin.

3.3. Global Reactivity Descriptors

To access the chemical reactivity of catechin or epicatechin, it’s necessary to determine their molecular border orbital HOMO and LUMO [27]. More, the first orbitals can explain the physical and chemical properties of molecules [23]. Here, they help to provide insight into intramolecular charge transfers; an electron-rich HOMO orbital acts as a donor; an electron-poor LUMO functions as an acceptor. Figure 3 and Figure 4 illustrate the HOMO − 3 to LUMO + 3 boundary orbitals of catechin and epicatechin. These molecular orbitals have a π character.

For HOMO, the π character is distributed over all the catechin and epicatechin. This means that the delocalization of electrons occurs through the molecules of catechin and epicatechin. Unlike LUMO, the π character of these molecules is concentrated on the B-cycle with a residual contribution of its oxygen atoms. The global reactivity indices are presented in Table 3. The smaller the energy gap (ΔE) between HOMO and LUMO is, the more reactive is the molecule [27]. The energy gap of epicatechin (5.347 eV) is the lowest. It indicates that this molecule is most receptive. The global electrophilicity indices ω confirms this observation. Its epicatechin’s value is slightly higher than those of catechin. The epicatechin is more able to acquire electronic charges. The chemical hardness of epicatechin η (2.674 eV) is lower than that of catechin (2.720 eV). The epicatechin is softer than catechin. The Fukui indices \( f_i^+ \), \( f_i^- \), and \( f_i^0 \) represents the local reactivity descriptors.

Figure 3. Frontier orbitals of the catechin’s main calculated transitions.
Table 3. Global reactivity parameters of catechin and epicatechin.

<table>
<thead>
<tr>
<th>molecules</th>
<th>$E_{\text{HOMO}}$ (eV)</th>
<th>$E_{\text{LUMO}}$ (eV)</th>
<th>$\Delta E$ (eV)</th>
<th>$\eta$ (eV)</th>
<th>$\mu$ (eV)</th>
<th>$\omega$ (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catechin</td>
<td>-6.054</td>
<td>-0.614</td>
<td>5.440</td>
<td>2.720</td>
<td>-3.334</td>
<td>2.0433</td>
</tr>
<tr>
<td>Epicatechin</td>
<td>-6.008</td>
<td>-0.661</td>
<td>5.347</td>
<td>2.674</td>
<td>-3.335</td>
<td>2.0791</td>
</tr>
</tbody>
</table>

3.4. Local Reactivity Descriptors

Fukui indices are used to assess the reactivity of atoms or functional groups (nucleophilic or electrophilic attack site) of a molecule [33]. This work is based on a natural population analysis (NPA) in gas and aqueous phase to estimate the electron population [41]. This leads to the Fukui indices, reported in Tables 4-6. The Molecular Electrostatic Potential (MEP) map displays the electron density of a molecule as a function of colour. It constitutes a descriptor of the local reactivity for a molecule. Colours indicate the electron density of areas of the molecule [42]. A red region illustrates an electron-rich site. A blue zone describes an electron-poor site. A green area is a neutral site. Figure 5 gives the plots of the catechin and epicatechin electrostatic potential.

These tables data show that the highest $f_k^+$ values in both the aqueous and gas phases link to the hydrogen atoms H$_{27}$, H$_{29}$, H$_{31}$, H$_{33}$, and H$_{35}$ of catechin and epicatechin. These constitute the preferential sites of nucleophilic attack. On the other hand, some are favoured on the oxygen atoms and the carbon atoms of the aromatic rings. The properties are preserved when the molecule passing from the gas phase of the aqueous phase.

Figure 4. Frontier orbitals of the epicatechin’s main calculated transitions.
Table 4. Global reactivity parameters of catechin and epicatechin (atoms 1 to 12).

<table>
<thead>
<tr>
<th>Atom</th>
<th>$f_i^+$</th>
<th>$f_i^-$</th>
<th>$f_i^+$</th>
<th>$f_i^-$</th>
<th>$f_i^+$</th>
<th>$f_i^-$</th>
<th>$f_i^+$</th>
<th>$f_i^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_1</td>
<td>-0.200</td>
<td>0.085</td>
<td>-0.195</td>
<td>0.154</td>
<td>-0.132</td>
<td>0.064</td>
<td>-0.192</td>
<td>0.062</td>
</tr>
<tr>
<td>C_2</td>
<td>0.172</td>
<td>-0.020</td>
<td>0.174</td>
<td>-0.150</td>
<td>0.256</td>
<td>-0.012</td>
<td>0.178</td>
<td>-0.008</td>
</tr>
<tr>
<td>C_3</td>
<td>-0.092</td>
<td>0.141</td>
<td>-0.095</td>
<td>-0.002</td>
<td>-0.094</td>
<td>0.159</td>
<td>-0.103</td>
<td>0.136</td>
</tr>
<tr>
<td>C_4</td>
<td>0.175</td>
<td>0.025</td>
<td>0.167</td>
<td>-0.166</td>
<td>0.174</td>
<td>0.014</td>
<td>0.166</td>
<td>0.012</td>
</tr>
<tr>
<td>C_5</td>
<td>-0.191</td>
<td>-0.005</td>
<td>-0.192</td>
<td>0.207</td>
<td>-0.148</td>
<td>0.000</td>
<td>-0.189</td>
<td>0.007</td>
</tr>
<tr>
<td>C_6</td>
<td>0.168</td>
<td>0.055</td>
<td>0.168</td>
<td>-0.170</td>
<td>0.195</td>
<td>0.061</td>
<td>0.168</td>
<td>0.054</td>
</tr>
<tr>
<td>H_7</td>
<td>0.125</td>
<td>0.026</td>
<td>0.131</td>
<td>-0.112</td>
<td>0.134</td>
<td>0.027</td>
<td>0.131</td>
<td>0.016</td>
</tr>
<tr>
<td>H_8</td>
<td>0.127</td>
<td>0.025</td>
<td>0.132</td>
<td>-0.115</td>
<td>0.134</td>
<td>0.024</td>
<td>0.132</td>
<td>0.017</td>
</tr>
<tr>
<td>H_9</td>
<td>-0.253</td>
<td>-0.027</td>
<td>-0.254</td>
<td>0.236</td>
<td>-0.243</td>
<td>-0.029</td>
<td>-0.254</td>
<td>-0.022</td>
</tr>
<tr>
<td>H_{10}</td>
<td>0.143</td>
<td>0.026</td>
<td>0.142</td>
<td>-0.128</td>
<td>0.144</td>
<td>0.029</td>
<td>0.142</td>
<td>0.021</td>
</tr>
<tr>
<td>H_{11}</td>
<td>0.124</td>
<td>0.023</td>
<td>0.129</td>
<td>-0.122</td>
<td>0.135</td>
<td>0.024</td>
<td>0.137</td>
<td>0.022</td>
</tr>
<tr>
<td>H_{12}</td>
<td>0.027</td>
<td>-0.003</td>
<td>0.025</td>
<td>-0.030</td>
<td>0.033</td>
<td>-0.002</td>
<td>0.030</td>
<td>-0.001</td>
</tr>
</tbody>
</table>

Table 5. Global reactivity parameters of catechin and epicatechin (atoms 13 to 24).

<table>
<thead>
<tr>
<th>Atom</th>
<th>$f_i^+$</th>
<th>$f_i^-$</th>
<th>$f_i^+$</th>
<th>$f_i^-$</th>
<th>$f_i^+$</th>
<th>$f_i^-$</th>
<th>$f_i^+$</th>
<th>$f_i^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>H_{13}</td>
<td>0.129</td>
<td>0.015</td>
<td>0.133</td>
<td>-0.118</td>
<td>0.130</td>
<td>0.015</td>
<td>0.133</td>
<td>0.011</td>
</tr>
<tr>
<td>H_{14}</td>
<td>0.027</td>
<td>-0.013</td>
<td>0.019</td>
<td>-0.027</td>
<td>0.029</td>
<td>-0.016</td>
<td>0.027</td>
<td>-0.015</td>
</tr>
<tr>
<td>H_{15}</td>
<td>0.137</td>
<td>0.030</td>
<td>0.143</td>
<td>-0.124</td>
<td>0.143</td>
<td>0.028</td>
<td>0.157</td>
<td>0.026</td>
</tr>
<tr>
<td>O_{16}</td>
<td>-0.267</td>
<td>0.058</td>
<td>-0.273</td>
<td>0.267</td>
<td>-0.270</td>
<td>0.042</td>
<td>-0.274</td>
<td>0.038</td>
</tr>
<tr>
<td>C_{17}</td>
<td>-0.033</td>
<td>0.042</td>
<td>-0.065</td>
<td>0.040</td>
<td>-0.011</td>
<td>0.037</td>
<td>0.061</td>
<td>0.062</td>
</tr>
<tr>
<td>C_{18}</td>
<td>-0.148</td>
<td>0.000</td>
<td>-0.188</td>
<td>0.144</td>
<td>-0.099</td>
<td>-0.003</td>
<td>0.042</td>
<td>-0.001</td>
</tr>
<tr>
<td>C_{19}</td>
<td>-0.122</td>
<td>0.052</td>
<td>-0.101</td>
<td>0.121</td>
<td>-0.116</td>
<td>0.055</td>
<td>-0.133</td>
<td>0.075</td>
</tr>
<tr>
<td>C_{20}</td>
<td>0.146</td>
<td>0.063</td>
<td>0.138</td>
<td>-0.134</td>
<td>0.155</td>
<td>0.066</td>
<td>0.136</td>
<td>0.082</td>
</tr>
<tr>
<td>H_{21}</td>
<td>0.140</td>
<td>0.023</td>
<td>0.149</td>
<td>-0.128</td>
<td>0.136</td>
<td>0.021</td>
<td>0.139</td>
<td>0.019</td>
</tr>
<tr>
<td>C_{22}</td>
<td>-0.159</td>
<td>-0.007</td>
<td>-0.183</td>
<td>0.152</td>
<td>-0.025</td>
<td>-0.005</td>
<td>0.080</td>
<td>-0.003</td>
</tr>
<tr>
<td>H_{23}</td>
<td>0.131</td>
<td>0.005</td>
<td>0.140</td>
<td>-0.129</td>
<td>0.135</td>
<td>0.008</td>
<td>0.139</td>
<td>0.015</td>
</tr>
<tr>
<td>C_{24}</td>
<td>0.112</td>
<td>0.064</td>
<td>0.105</td>
<td>-0.125</td>
<td>0.246</td>
<td>0.064</td>
<td>0.343</td>
<td>0.080</td>
</tr>
</tbody>
</table>
Figure 5. Molecular electrostatic potential of Catechin and Epicatechin.

Table 6. Global reactivity parameters of catechin and epicatechin (atoms 25 to 35).

<table>
<thead>
<tr>
<th>Atom</th>
<th>$f_i^+$</th>
<th>$f_i^-$</th>
<th>$f_i^+$</th>
<th>$f_i^-$</th>
<th>$f_i^+$</th>
<th>$f_i^-$</th>
<th>$f_i^+$</th>
<th>$f_i^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>H_{25}</td>
<td>0.119</td>
<td>0.023</td>
<td>0.148</td>
<td>-0.127</td>
<td>0.124</td>
<td>0.024</td>
<td>0.139</td>
<td>0.020</td>
</tr>
<tr>
<td>O_{26}</td>
<td>-0.350</td>
<td>0.064</td>
<td>-0.355</td>
<td>0.368</td>
<td>-0.342</td>
<td>0.068</td>
<td>-0.351</td>
<td>0.072</td>
</tr>
<tr>
<td>H_{27}</td>
<td>0.263</td>
<td>0.016</td>
<td>0.273</td>
<td>-0.267</td>
<td>0.277</td>
<td>0.017</td>
<td>0.284</td>
<td>0.014</td>
</tr>
<tr>
<td>O_{28}</td>
<td>-0.376</td>
<td>0.049</td>
<td>-0.364</td>
<td>0.374</td>
<td>-0.295</td>
<td>0.049</td>
<td>-0.318</td>
<td>0.060</td>
</tr>
<tr>
<td>H_{29}</td>
<td>0.256</td>
<td>0.020</td>
<td>0.278</td>
<td>-0.269</td>
<td>0.377</td>
<td>0.021</td>
<td>0.380</td>
<td>0.017</td>
</tr>
<tr>
<td>O_{30}</td>
<td>-0.379</td>
<td>0.018</td>
<td>-0.393</td>
<td>0.401</td>
<td>-0.381</td>
<td>0.019</td>
<td>-0.397</td>
<td>0.011</td>
</tr>
<tr>
<td>H_{31}</td>
<td>0.249</td>
<td>0.005</td>
<td>0.256</td>
<td>-0.254</td>
<td>0.254</td>
<td>0.002</td>
<td>0.259</td>
<td>0.003</td>
</tr>
<tr>
<td>O_{32}</td>
<td>-0.360</td>
<td>0.021</td>
<td>-0.363</td>
<td>0.383</td>
<td>-0.311</td>
<td>0.025</td>
<td>-0.362</td>
<td>0.020</td>
</tr>
<tr>
<td>H_{33}</td>
<td>0.257</td>
<td>0.020</td>
<td>0.268</td>
<td>-0.258</td>
<td>0.315</td>
<td>0.020</td>
<td>0.268</td>
<td>0.010</td>
</tr>
<tr>
<td>O_{34}</td>
<td>-0.356</td>
<td>0.061</td>
<td>-0.365</td>
<td>0.365</td>
<td>-0.343</td>
<td>0.064</td>
<td>-0.364</td>
<td>0.052</td>
</tr>
<tr>
<td>H_{35}</td>
<td>0.257</td>
<td>0.021</td>
<td>0.267</td>
<td>-0.253</td>
<td>0.282</td>
<td>0.021</td>
<td>0.266</td>
<td>0.012</td>
</tr>
</tbody>
</table>
This map indicates that the hydroxyl groups $O_{28}-H_{29}$, $O_{32}-H_{33}$, and $O_{34}-H_{35}$, are more depleted in electrons than those of $O_{30}-H_{31}$, $O_{26}-H_{27}$ and of the different $C_i-H_j$ bonds. These hydrogen atoms of the $O_i-H_j$ hydroxyl groups and $C_i-H_j$ bonds of catechin and epicatechin are sites conducive to nucleophilic attack on the following decreasing order of reactivity: $O_{28}-H_{29} > O_{32}-H_{33} > O_{34}-H_{35} > O_{26}-H_{27} > O_{30}-H_{31} > C_i-H_j$. The regions of the oxygen atoms and the aromatic rings are, on the other hand, favourable sites for electrophilic attacks.

### 3.5. Acidity

Table 7 shows the theoretical values of pKa for each hydroxyl group of the catechin and its isomer. This statistic varies from 6.77 to 21.77 for catechin and from 6.77 to 21.70 for epicatechin. The pka of the hydroxyl group’s $O_{32}-H_{33}$, $O_{34}-H_{35}$ and $O_{26}-H_{27}$ are respectively 9.92, 10.47, 11.47 for catechin. For epicatechin, they’re 10.56, 11.21, 1171. These values are close to the pka experimental value of the phenol’s hydroxyl; the latter is equal to 9.95 [43]. The pKa values of the hydroxyl group $O_{28}-H_{29}$ are 7.53 in catechin and 6.77 in epicatechin. These values remain inferior to 9.85. Therefore, the hydroxyl group $O_{28}-H_{29}$ of catechin or epicatechin is more acidic than the phenol’s hydroxyl group and those of catechin or epicatechin. The difference between the pKa of the hydroxyl group $O_{30}-H_{31}$ and that of the phenol is great. It shows that the hydroxyl group isn’t on an aromatic ring. Its acidic character is very weak compared to the other hydroxyl groups of catechin and epicatechin.

The hydroxyl group acidity becomes: $O_{28}-H_{29} > O_{32}-H_{33} > O_{34}-H_{35} > O_{26}-H_{27} > O_{30}-H_{31}$. The hydroxyl groups $O_{26}-H_{27}$, $O_{32}-H_{33}$, $O_{34}-H_{35}$ are much more acidic. They’re more favourable to the anti-radical processes than the hydroxyl groups $O_{26}-H_{27}$ or $O_{30}-H_{31}$.

### 3.6. NBO Analysis

Table 8 and Table 9 collate the second-order perturbation energies $E^{(2)}$, the electron density (ED), the energy difference $E(j) - E(i)$ of the donor NBO ($i$) and of the acceptor NBO ($j$) related to catechin and epicatechin. They show their elements of the Fock matrix $H(i, j)$. These results indicate that for catechin and epicatechin, the main interactions are of two types. They’re intramolecular interactions of the types $\pi(i)_{C\alpha-C\beta} \rightarrow \pi(\alpha_{C7-C8})$ and $n(i)_{O\alpha} \rightarrow \pi(\alpha_{C7-C8})$ where $\pi(\alpha_{C\alpha-C\beta})$, $n(\alpha_{O\alpha})$, and

**Table 7.** pKa values of catechin and epicatechin.

<table>
<thead>
<tr>
<th>hydroxyl group</th>
<th>pKa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Catechin</td>
</tr>
<tr>
<td>$O_{30}-H_{31}$</td>
<td>21.77</td>
</tr>
<tr>
<td>$O_{32}-H_{33}$</td>
<td>9.92</td>
</tr>
<tr>
<td>$O_{34}-H_{35}$</td>
<td>10.47</td>
</tr>
<tr>
<td>$O_{26}-H_{27}$</td>
<td>11.78</td>
</tr>
<tr>
<td>$O_{28}-H_{29}$</td>
<td>7.53</td>
</tr>
</tbody>
</table>
### Table 8. The catechin’s NBO parameters.

<table>
<thead>
<tr>
<th>Donor</th>
<th>Acceptor</th>
<th>$E^{(2)}$ (kcal/mol)</th>
<th>$E(j) - E(i)$ (a.u.)</th>
<th>$F(i, j)$ (a.u.)</th>
<th>$R(i, j)$ (a.u.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi_{C1-C2}^{(2)}$</td>
<td>$\pi_{C3-C4}^{(2)}$</td>
<td>1.71091</td>
<td>0.42126</td>
<td>12.52</td>
<td>0.29</td>
</tr>
<tr>
<td>$\pi_{C1-C2}^{(2)}$</td>
<td>$\pi_{C5-C6}^{(2)}$</td>
<td>1.71091</td>
<td>0.40712</td>
<td>25.81</td>
<td>0.28</td>
</tr>
<tr>
<td>$\pi_{C3-C4}^{(2)}$</td>
<td>$\pi_{C1-C2}^{(2)}$</td>
<td>1.69169</td>
<td>0.40662</td>
<td>25.41</td>
<td>0.28</td>
</tr>
<tr>
<td>$\pi_{C3-C4}^{(2)}$</td>
<td>$\pi_{C5-C6}^{(2)}$</td>
<td>1.71003</td>
<td>0.40662</td>
<td>12.26</td>
<td>0.28</td>
</tr>
<tr>
<td>$\pi_{C1-C2}^{(2)}$</td>
<td>$\pi_{C3-C4}^{(2)}$</td>
<td>1.71003</td>
<td>0.42126</td>
<td>24.64</td>
<td>0.29</td>
</tr>
<tr>
<td>$\pi_{C1-C19}^{(2)}$</td>
<td>$\pi_{C16-C20}^{(2)}$</td>
<td>1.68580</td>
<td>0.37976</td>
<td>18.65</td>
<td>0.27</td>
</tr>
<tr>
<td>$\pi_{C1-C19}^{(2)}$</td>
<td>$\pi_{C22-C24}^{(2)}$</td>
<td>1.68580</td>
<td>0.39742</td>
<td>19.91</td>
<td>0.27</td>
</tr>
<tr>
<td>$\pi_{C18-C20}^{(2)}$</td>
<td>$\pi_{C1-C19}^{(2)}$</td>
<td>1.67554</td>
<td>0.36492</td>
<td>20.33</td>
<td>0.30</td>
</tr>
<tr>
<td>$\pi_{C18-C20}^{(2)}$</td>
<td>$\pi_{C22-C24}^{(2)}$</td>
<td>1.67554</td>
<td>0.39742</td>
<td>19.32</td>
<td>0.28</td>
</tr>
<tr>
<td>$\pi_{C22-C24}^{(2)}$</td>
<td>$\pi_{C17-C19}^{(2)}$</td>
<td>1.70705</td>
<td>0.39742</td>
<td>17.47</td>
<td>0.31</td>
</tr>
<tr>
<td>$\pi_{C22-C24}^{(2)}$</td>
<td>$\pi_{C18-C20}^{(2)}$</td>
<td>1.70705</td>
<td>0.37976</td>
<td>18.42</td>
<td>0.29</td>
</tr>
<tr>
<td>$n_{O16}^{(2)}$</td>
<td>$\pi_{C3-C4}^{(2)}$</td>
<td>1.84295</td>
<td>0.42126</td>
<td>29.69</td>
<td>0.34</td>
</tr>
<tr>
<td>$n_{O26}^{(2)}$</td>
<td>$\pi_{C3-C4}^{(2)}$</td>
<td>1.87435</td>
<td>0.37976</td>
<td>27.75</td>
<td>0.35</td>
</tr>
<tr>
<td>$n_{O28}^{(2)}$</td>
<td>$\pi_{C5-C6}^{(2)}$</td>
<td>1.89789</td>
<td>0.39742</td>
<td>24.07</td>
<td>0.36</td>
</tr>
<tr>
<td>$n_{O32}^{(2)}$</td>
<td>$\pi_{C1-C2}^{(2)}$</td>
<td>1.87678</td>
<td>0.40662</td>
<td>22.50</td>
<td>0.35</td>
</tr>
<tr>
<td>$n_{O34}^{(2)}$</td>
<td>$\pi_{C3-C4}^{(2)}$</td>
<td>1.87887</td>
<td>0.40712</td>
<td>28.65</td>
<td>0.35</td>
</tr>
</tbody>
</table>

### Table 9. The epicatechin’s NBO parameters.

<table>
<thead>
<tr>
<th>Donor</th>
<th>Acceptor</th>
<th>$E^{(2)}$ (kcal/mol)</th>
<th>$E(j) - E(i)$ (a.u.)</th>
<th>$F(i, j)$ (a.u.)</th>
<th>$R(i, j)$ (a.u.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi_{C1-C2}^{(2)}$</td>
<td>$\pi_{C3-C4}^{(2)}$</td>
<td>1.71167</td>
<td>0.41979</td>
<td>12.40</td>
<td>0.29</td>
</tr>
<tr>
<td>$\pi_{C1-C2}^{(2)}$</td>
<td>$\pi_{C5-C6}^{(2)}$</td>
<td>1.71167</td>
<td>0.40740</td>
<td>25.74</td>
<td>0.28</td>
</tr>
<tr>
<td>$\pi_{C3-C4}^{(2)}$</td>
<td>$\pi_{C1-C2}^{(2)}$</td>
<td>1.68796</td>
<td>0.40993</td>
<td>25.95</td>
<td>0.28</td>
</tr>
<tr>
<td>$\pi_{C3-C4}^{(2)}$</td>
<td>$\pi_{C5-C6}^{(2)}$</td>
<td>1.68796</td>
<td>0.40740</td>
<td>13.01</td>
<td>0.28</td>
</tr>
<tr>
<td>$\pi_{C5-C6}^{(2)}$</td>
<td>$\pi_{C1-C2}^{(2)}$</td>
<td>1.70973</td>
<td>0.40993</td>
<td>12.28</td>
<td>0.28</td>
</tr>
<tr>
<td>$\pi_{C5-C6}^{(2)}$</td>
<td>$\pi_{C3-C4}^{(2)}$</td>
<td>1.70973</td>
<td>0.41979</td>
<td>24.71</td>
<td>0.29</td>
</tr>
</tbody>
</table>
Continued

<table>
<thead>
<tr>
<th></th>
<th>$\pi^{(2)}<em>{C</em>{17}-C_{19}}$</th>
<th>$\pi^{(4)}<em>{C</em>{18}-C_{20}}$</th>
<th>0.38557</th>
<th>19.08</th>
<th>0.27</th>
<th>0.065</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^{(2)}<em>{C</em>{17}-C_{19}}$</td>
<td>1.67829</td>
<td>$\pi^{(4)}<em>{C</em>{18}-C_{20}}$</td>
<td>0.40148</td>
<td>20.07</td>
<td>0.27</td>
<td>0.067</td>
</tr>
<tr>
<td>$\pi^{(2)}<em>{C</em>{18}-C_{20}}$</td>
<td>1.66656</td>
<td>$\pi^{(4)}<em>{C</em>{17}-C_{19}}$</td>
<td>0.37121</td>
<td>20.25</td>
<td>0.29</td>
<td>0.070</td>
</tr>
<tr>
<td>$\pi^{(2)}<em>{C</em>{18}-C_{20}}$</td>
<td>1.66656</td>
<td>$\pi^{(4)}<em>{C</em>{17}-C_{19}}$</td>
<td>0.40148</td>
<td>19.61</td>
<td>0.28</td>
<td>0.067</td>
</tr>
<tr>
<td>$\pi^{(2)}<em>{C</em>{17}-C_{19}}$</td>
<td>1.69886</td>
<td>$\pi^{(4)}<em>{C</em>{17}-C_{19}}$</td>
<td>0.37121</td>
<td>17.87</td>
<td>0.30</td>
<td>0.067</td>
</tr>
<tr>
<td>$\pi^{(2)}<em>{C</em>{18}-C_{20}}$</td>
<td>1.69886</td>
<td>$\pi^{(4)}<em>{C</em>{17}-C_{19}}$</td>
<td>0.38557</td>
<td>18.56</td>
<td>0.29</td>
<td>0.067</td>
</tr>
<tr>
<td>$\pi^{(2)}<em>{C</em>{18}-C_{20}}$</td>
<td>1.84377</td>
<td>$\pi^{(4)}<em>{C</em>{17}-C_{19}}$</td>
<td>0.41979</td>
<td>29.65</td>
<td>0.34</td>
<td>0.097</td>
</tr>
<tr>
<td>$\pi^{(2)}<em>{C</em>{17}-C_{19}}$</td>
<td>1.87363</td>
<td>$\pi^{(4)}<em>{C</em>{17}-C_{19}}$</td>
<td>0.38557</td>
<td>27.66</td>
<td>0.34</td>
<td>0.093</td>
</tr>
<tr>
<td>$\pi^{(2)}<em>{C</em>{17}-C_{19}}$</td>
<td>1.89676</td>
<td>$\pi^{(4)}<em>{C</em>{17}-C_{19}}$</td>
<td>0.40148</td>
<td>24.13</td>
<td>0.36</td>
<td>0.090</td>
</tr>
<tr>
<td>$\pi^{(2)}<em>{C</em>{17}-C_{19}}$</td>
<td>1.87803</td>
<td>$\pi^{(4)}<em>{C</em>{17}-C_{19}}$</td>
<td>0.40993</td>
<td>28.25</td>
<td>0.35</td>
<td>0.096</td>
</tr>
<tr>
<td>$\pi^{(2)}<em>{C</em>{17}-C_{19}}$</td>
<td>1.87952</td>
<td>$\pi^{(4)}<em>{C</em>{17}-C_{19}}$</td>
<td>0.40740</td>
<td>28.50</td>
<td>0.35</td>
<td>0.096</td>
</tr>
</tbody>
</table>

$\pi^{(2)}_{C_{17}-C_{19}}$ are: Lewis $\pi$ orbital of the $C\alpha = C\beta$ double bond, the lone pair 2 of the $O\varepsilon$ atoms, anti-Lewis $\pi$ orbital of the $C\gamma = C\delta$ double bond. $\alpha, \beta, \gamma, \delta, \varepsilon$ are atomic numbers. In the aromatic ring A, the stabilization energies of the

$\pi^{(2)}_{C_{17}-C_{19}} \rightarrow \pi^{(2)}_{C_{18}-C_{20}}$, $\pi^{(2)}_{C_{18}-C_{20}} \rightarrow \pi^{(2)}_{C_{17}-C_{19}}$ and $\pi^{(2)}_{C_{18}-C_{20}} \rightarrow \pi^{(2)}_{C_{16}-C_{17}}$ interactions are 25.81, 25.41, 24.64 kcal/mol respectively for catechin and 25.74, 25.95, 24.71 kcal/mol for epicatechin.

In aromatic ring B, for the same intramolecular interaction

$\pi^{(2)}_{C_{17}-C_{19}} \rightarrow \pi^{(2)}_{C_{18}-C_{20}}$, the maximum stabilization energy is equal to 20.33 kcal/mol for catechin and 20.25 kcal/mol for epicatechin. Thus, the aromatic ring B is less stable than the A one. Regarding the $\pi^{(2)}_{O_{28}} \rightarrow \pi^{(2)}_{C_{22}-C_{24}}$ interactions, the lowest stabilization energy is obtained with $\pi^{(2)}_{O_{28}} \rightarrow \pi^{(2)}_{C_{22}-C_{24}}$. For catechin, it’s worthy 24.07 kcal/mol and 24.13 kcal/mol for epicatechin. The electronic density (ED) of the Lewis orbital $\pi^{(2)}_{C_{17}-C_{19}}$ and $\pi^{(2)}_{O_{28}}$ undergo a decreasing (ED < 2e) while those of the anti-Lewis orbital $\pi^{(2)}_{C_{18}-C_{20}}$ increase (ED > 0).

These results show that intramolecular interactions are associated with the delocalization of $\pi$-electrons from Lewis’s orbitals to anti Lewis’s orbitals. They also indicate that ring A is more stable than ring B in both molecules. The ring B is therefore more reactive than the ring A. Its reactivity influences that of the hydroxyl group O$_{28}$–H$_{29}$. LP(O$_{28}$) $\rightarrow \pi' (C_{22}-C_{24})$ transition is the most active of the LP(O$_{28}$) $\rightarrow \pi' (C_{m}-C_{n})$ transitions. Its delocalization energy (24.07 kcal/mol) is the lowest of the four catechin.

This finding is too valid for epicatechin. More, it contrasts the reactivity priority order of the hydroxyls. Its strong reactivity also enhances that of the hydroxyl O$_{28}$–H$_{29}$. Under these conditions, any electrophilic or nucleophilic attack takes place primarily and respectively on O$_{28}$ and O$_{26}$. In the event of unavailability, hydroxyl O$_{28}$–H$_{29}$ becomes priority; it attaches to ring B. The other two hydrox-
yls of ring A (O32–H33 = O34–H35) follow in order of reactivity. Hydroxyl O30–H31 loops the latter from the ring C. This aspect of the research leads to this article’s conclusion.

4. Conclusions

The research plans to compare the reactivity of two isomers, catechin and epicatechin, using the resources of theoretical chemistry. It’s carried out at the TD-DFT/B3LYP/6-31 + G(d, p) level. It’s interesting in the parameters of global and local responsiveness. The MEP and the Fukui indices make it possible to specify the latter. It also harnesses the distribution of potential energy through VEDA. It contrasts the acidity. It ends with an NBO analysis. These statistics probe that epicatechin remains the more reactive compound of the two. More, the Fukui indices and the analysis of vibration energies establish that hydroxyl group reactivity of two isomers varies in the following order: O28–H29 > O32–H33 = O34–H35 > O30–H31 > O26–H27. In other words, the O28–H29 site remains the least stable of all these OH. The molecular electrostatic potential confirms these results.

The acidity indicated that the hydroxyls O28–H29, O32–H33, O34–H35 remain the most acid in the sense of Brönsted. In other words, the hydroxyl O28–H29 the most favourable site to participate remains in anti-free radical processes. NBO analysis detected that the stabilization energies of the two isomers equal 25 81, 25.41, 24.64 kcal/mol. Besides, it presents the transition \( \pi_{\text{C1-C2}}^{(2)} \rightarrow \pi_{\text{C3-C6}}^{(2)} \), \( \pi_{\text{C3-C4}}^{(2)} \rightarrow \pi_{\text{C1-C2}}^{(2)} \), and \( \pi_{\text{C5-C6}}^{(2)} \rightarrow \pi_{\text{C3-C4}}^{(2)} \). Their energies remain equal to 25.74, 25.95, 24.71 kcal/mol for epicatechin. It appears that ring B is more reactive than A. Its reactivity reinforces that of O28–H29. This hydroxyl becomes the most receptive site of the catechin or epicatechin. As a result, the hydroxyls of ring A (O32–H33 = O34–H35) and of ring B (O26–H27) follow in decreasing order to their reactivity. This research furnishes the team’s next agenda.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References


