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Theoretical study of weak interactions between condensed tannins and salivary proteins : Case of catechin and epicatechin with proline

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ABSTRACT: The weak hydrogen bond interactions of two stereorisomeric flavanols (catechin and epicatechin) and proline, one of the most abundant amino acids in salivary proteins, have been theoretically investigated by the DFT methods with bases 6-31 G (d,p) and 6-31 + G (d,p). Geometric, energy and spectroscopic parameters were calculated. These confirm the formation of complexes by moderate hydrogen bonds between the hydroxyl groups of catechin or epicatechin with the heteroatoms Nsp3, Osp2 and Osp3 of proline. Also, this study establishes that the complexes formed with the proline heteroatoms Nsp3 and Osp2 are the most stable.

KEYWORDS: catechin, epicatechin, proline, flavanol, amino acid.

1 INTRODUCTION

Polyphenols are a large family of compounds represented by phenolic acids, hydroxycinnamic acids, phenylacetic acids, acetophenones, coumarins, xanthones, stilbenes and flavonoids. These are the most common secondary metabolites in plants [1],[2],[3],[4]. Several studies have shown the beneficial effects of eating foods rich in polyphenols. Indeed, they have an ability to trap free radicals that can reduce the risk of cardiovascular disease and cancer [5],[6],[7]. They accelerate the healing rate of superficial wounds by 50% [8].

Condensed tannins such as catechin and epicatechin belong to the flavonoid group. They are found in many fruits, vegetables, seeds and spices [9]. The great diversity of their structure gives them properties such as solubility and polarisability. These properties allow them to interact with each other and with other molecules around them. The high number of hydroxyl groups they possess makes them capable of interacting with proteins. However, tannins would act as inhibitors of protein digestion by binding to both digestive enzymes and food bowl proteins [10].

In addition, the physiological roles of saliva are partly attributable to salivary proteins rich in proline [11]. Due to their importance for the taste and nutritional qualities of foods, interactions between proteins and polyphenols have been the subject of much research [12],[13]. However, proteins rich in proline remain poorly studied.

Our objective is therefore to study, with the theoretical method, the weak interactions by hydrogen binding between catechin, epicatechin and proline in order to determine the stability of the resulting complexes. This would put us on the likely complexes that would form in the mouth. This study consists of an optimization of geometry followed by the calculation of gas phase frequencies at the theory levels B3LYP 6-31 G (d,p) and B3LYP 6-31 G + (d,p), initially, catechin, epicatechin and proline, taken individually. Then, in a second step, these calculations will be followed by catechin-proline and epicatechin-proline complexes.

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2 MATERIALS AND METHODS

2.1 PRESENTATION OF THE COMPLEXES

Quantum chemistry calculations are widely used to accurately determine the nature of weak interactions, in this case hydrogen bonds between different molecules [14],[15]. In this work, we considered only cases of hydrogen binding formation between hydrogen binding donor sites from catechin or epicatechin hydroxyl groups and proline hydrogen binding acceptor sites Nsp3 nitrogen, Osp3 oxygen (O-H) and Osp2 oxygen (O=C), because in the case of condensed tannins, complexes are generally formed at hydroxyl groups [16]. The hydrogen binding donor sites are the hydroxyl groups O3-H, O5-H, O7-H, O4'-H and O5'-H (Fig.1). Thus, the hydrogen bond is defined as O-H···N or O-H···O (Fig.2).

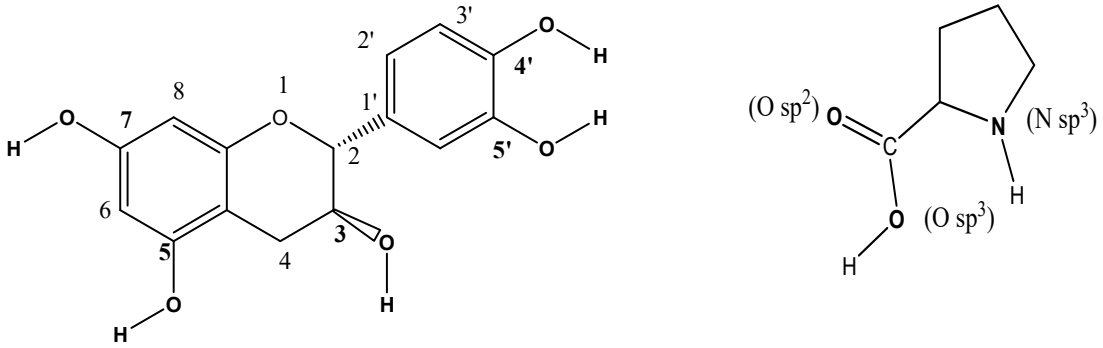

Fig. 1. Hydrogen binding donor and acceptor sites

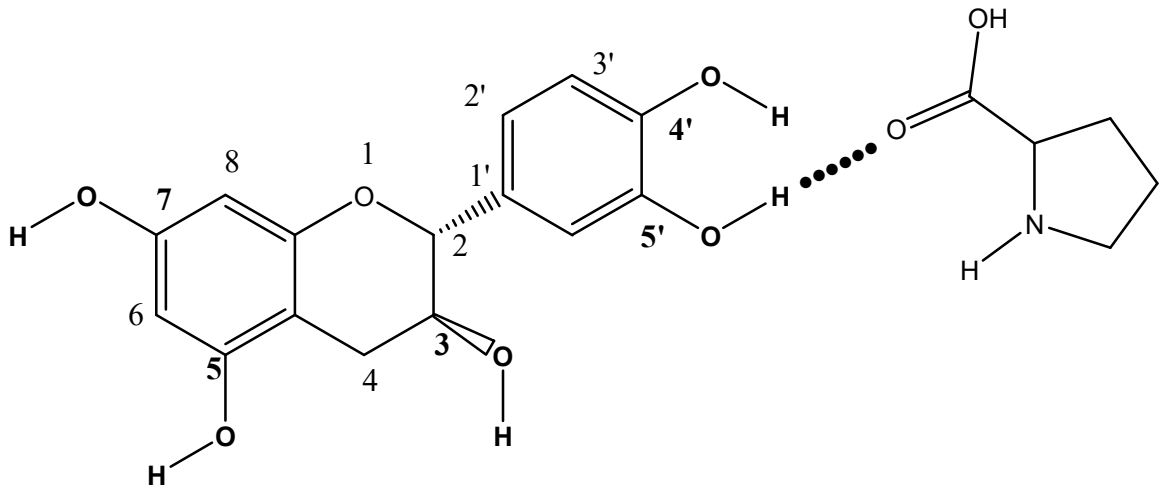

Fig. 2. Interaction by hydrogen bonding between an O5'-H catechin donor site and an Osp2 proline acceptor site rated O5'-H.....Osp2

2.2 CALCULATION METHODS

Studying all these complexes at the same level of theory allows us to analyze their relative stability in terms of binding site properties. This theoretical study was carried out using the GAUSSIAN 09 software. The calculations were carried out in the gas phase at the theory levels B3LYP/ 6-31 G (d,p) and B3LYP/ 6-31 + G (d,p) in order to evaluate whether or not a diffuse function was taken into account during these interactions. Thus, we were interested in geometric and energetic parameters, as well as infrared (IR) vibration frequencies and their intensities.

3 RESULTS AND DISCUSSION

3.1 GEOMETRIC PARAMETERS

We determined the lengths of the intramolecular O-H bonds in catechin and epicatechin on the one hand, and in the complexes on the other hand in order to evaluate the effect of the hydrogen bond on these bonds. This parameter is noted d_{intra}.

We also evaluated the length of the different hydrogen bonds (d_{inter}) which play an important role in the stability of the complexes.

In addition, we examined the binding angle between the donor atom, the hydrogen atom H and the accepting atom. This angle, noted α, is called the linearity angle. The hydrogen bond will be all the more stable if the donor and acceptor atoms are aligned, i. e. α = 180° [17].

Before the complex optimization, the intermolecular distance and linearity angle were set at 2 Å and 180° respectively. These values correspond to the average distance and angle that characterize a strong hydrogen bond [17].

3.1.1 INTRAMOLECULAR BONDS

The lengths of the intramolecular bonds calculated for catechin and epicatechin for the different levels of theory (B3LYP/6-31 G (d,p) and B3LYP/6-31 G+ (d,p)) are contained in Table 1. In comparison with the complex values, for catechin (Table 1), all O-H bonds increase for each of the two levels of theory. Table 1 shows that the hydrogen bond formed with the heteroatom Nsp3 has the highest O-H bond lengths. This increasing is further enhanced with the level of theory B3LYP/6-31 G + (d,p). Then comes the heteroatom Osp2 and finally Osp3. This corresponds to the following order of magnitude: Nsp3 > Osp2 > Osp3. At the Nsp3 heteroatom, the deviations are 0.012 Å for the O3-H bond, 0.031 Å for the O5-H bond, 0.025 Å for the O7-H bond, and 0.033 Å for the O4'-H and O5'-H bonds, at the B3LYP/6-31 G (d,p) theory level. However, these deviations are 0.028 Å for the O3-H bond, 0.033 Å for the O5-H bond, 0.025 Å for the O7-H bond, 0.035 Å for the O4'-H bond and 0.036 Å for the O5'-H bond, at B3LYP/6-31 G + (d,p) theory level.This indicates that the O4'-H and O5'-H bonds are increasing significantly.

The same observations are made in the case of epicatechin. For the heteroatom Nsp3, the deviations are 0.015 Å for the O3-H bond, 0.030 Å for the O5-H and O5'-H bonds, 0.031 Å for the O7-H bond, and 0.039 Å for the O4'-H bond, at the B3LYP/6-31 G (d,p) theory level. These deviations, at the level of theory B3LYP/6-31 G + (d,p) are 0.017 Å for the O3-H bond, 0.033 Å for the O5-H and O7-H bonds, 0.040 Å for the O4' -H bond and 0.032 Å for the O5' -H bond. Thus, the O5-H, O7-H and O4'-H bonds are the highest.

Table 1. Lengths of intramolecular bonds in Å

	B3LYP 6-31 G (d,p)				B3LYP 6-31+ G (d,p)			
Bond O-H	d_{intra} **monomer**	d_{intra} **Complexe** Nsp^3 Osp^3 Osp^2			d_{intra} **monomer**	d_{intra} **Complexe** Nsp^3 Osp^3 Osp^2		
Catechin								
O_3—H	0,968	0,980	0,970	0,981	0,968	0,990	0,980	0,978
O_5—H	0,966	0,997	0,971	0,986	0,966	0,999	0,971	0,983
O_7—H	0,966	0,991	0,973	0,979	0,966	0,991	0,972	0,979
$O_{4'}$—H	0,965	0,998	0,972	0,986	0,965	1,000	0.972	0,983
$O_{5'}$—H	0,969	1,002	0,971	0,982	0,969	1,005	0,971	0,982
Epicatechin								
O_3—H	0,968	0,983	0,973	0,975	0,968	0,985	0,973	0,975
O_5—H	0,966	0,996	0,972	0,984	0,966	0,999	0,969	0,982
O_7—H	0,966	0,997	0,971	0,979	0,966	0,999	0,971	0,978
$O_{4'}$—H	0,965	1,004	0,974	0,979	0,965	1,005	0,973	0,978
$O_{5'}$—H	0,969	0,999	0,974	0,983	0,969	1.001	0,973	0,978

3.1.2 INTERMOLECULAR BOND (HYDROGEN BOND) AND BINDING ANGLES

The lengths of the intermolecular bond and the values of the binding angles are contained in Tables 2 and 3. The values of the lengths of the intermolecular bonds are between 1.734 and 2.274 Å for catechin, and between 1.746 and 2.030 Å for epicatechin at the B3LYP/6-31 G (d,p) theory level. However, they are between 1.742 and 3.162 Å for catechin, and between 1.745 and 2.052 Å for epicatechin for calculations at the B3LYP/6-31+G (d,p) theory level (Table 3). They indicate that hydrogen bonds are indeed established between catechin and proline, also between epicatechin and proline. Most of these hydrogen bonds can be considered moderate because they are located between 1.5 and 2.2 Å [17.18]. Compared to the two levels of theory, the intermolecular distances are approximately equal for interactions with the Nsp3 and Osp3 sites of proline while differences are observed with the Osp2 site. These values also reveal that for the same hydrogen donor site, the Nsp3 acceptor site gives a shorter distance than the Osp3 and Osp2 acceptor sites for both catechin and epicatechin. This corresponds to the following order of magnitude: Nsp3 < Osp2 < Osp3. The complexes formed by catechin and epicatechin with proline at the nitrogen level will therefore be more stable compared to the others. Indeed, the shorter the hydrogen bond, the more stable the complex formed [15].

The calculated binding angles are between 138 and 172º for catechin and between 135 and 171º for epicatechin, at the B3LYP/6-31 G (d,p) theory level. These angles are between 120 and 173º for catechin and between 135 and 173º for epicatechin, at the B3LYP/6-31 + G (d,p) theory level. In general, the binding angle for strong hydrogen bonding varies from 170 to 180° [15],[17],[18] and for moderate bonding from 130 to 180°. This confirms that the hydrogen bonds between catechin and proline, and between epicatechin and proline are indeed moderate hydrogen bonds. The binding angles at the Nsp3 acceptor site are almost linear, so they will give the most stable binding.

Table 2. Lengths of intermolecular bonds (Å) and angles of bond (º) of catechin complexes

Catechin-proline Complexe	B3LYP 6-31 G (d,p)		B3LYP 6-31+ G (d,p)	
	d_{inter}	α	d_{inter}	α
O_3—H……Nsp^3	1,989	154	1,862	161
O_5—H……Nsp^3	1,786	168	1,779	171
O_7—H……Nsp^3	1,929	166	1,850	167
$O_{4'}$—H……Nsp^3	1,800	166	1,794	171
$O_{5'}$—H……Nsp^3	1,734	166	1,742	165
O_3—H……Osp^3	2,274	149	3,162	120
O_5—H……Osp^3	1,957	168	1,978	170
O_7—H……Osp^3	1,925	164	1,969	170
$O_{4'}$—H……Osp^3	1,914	172	1,943	172
$O_{5'}$—H……Osp^3	1,979	159	2,009	173
O_3—H……Osp2	1,957	138	3,162	131
O_5—H……Osp2	1,807	148	1,978	145
O_7—H……Osp2	1,849	159	1,877	159
$O_{4'}$—H……Osp2	1,811	147	1,943	145
$O_{5'}$—H……Osp2	1,830	156	2,009	156

Table 3. Lengths of intermolecular bonds (Å) and angles of bond (º) of epicatechin complexes

Epicatechin-proline Complexe	B3LYP 6-31 G (d,p)		B3LYP 6-31+ G (d,p)	
	d_{inter}	α	d_{inter}	α
O_3—H……Nsp^3	1.935	154	1.934	167
O_5—H……Nsp^3	1.792	168	1.785	171
O_7—H……Nsp^3	1.774	164	1.774	164
$O_{4'}$—H……Nsp^3	1.746	163	1.745	167
$O_{5'}$—H……Nsp^3	1.764	169	1.764	171
O_3—H……Osp^3	1.984	167	2.027	157
O_5—H……Osp^3	1.955	171	2.001	171
O_7—H……Osp^3	1.959	165	1.981	171
$O_{4'}$—H……Osp^3	1.882	168	1.930	173
$O_{5'}$—H……Osp^3	2.030	161	2.052	160
O_3—H……Osp^2	1.912	156	1.940	156
O_5—H……Osp^2	1.828	147	1.879	143
O_7—H……Osp^2	1.842	160	1.874	159
$O_{4'}$—H……Osp^2	1.789	169	1.811	169
$O_{5'}$—H……Osp^2	1.927	135	1.927	135

3.2 ENERGY PARAMETERS

The energy parameters determined are the variations of the thermodynamic enthalpy quantities related to the complexing by hydrogen bonding of the sites considered and the interaction energy.

3.2.1 VARIATIONS IN THERMODYNAMIC ENTHALPY BQUANTITIES

These variations are calculated from the following relationship:

$$\Delta H = H(\text{Complexe}) - \sum H\ (\text{monomer}) \qquad (1)$$

The results are contained in Table 4. All enthalpy values (ΔH) are negative, meaning that the complexing reactions of catechin and epicatechin with proline are exothermic for each of the theory levels B3LYP/6-31 G (d,p) and B3LYP/6-31 + G (d,p). The complexes formed will therefore be thermodynamically stable. The more negative the complexing energy, the more thermodynamically stable (favourable). Thus the calculations at the level of theory B3LYP/6-31 + G (d,p) show that the complexes formed between catechin and proline will be more stable with Nsp3 and Osp2 atoms (Table 4). The complexation enthalpies for these Nsp3 and Osp2 sites are in the range of 20 to 35 kJ/mol. Interactions with these two acceptance sites are moderate hydrogen bonds [19]. With the Nsp3 heteroatom, the lowest value is observed with the hydroxyl group O5-H (-34.77 kJ/mol), followed by the hydroxyl groups O5'-H (-28.99 kJ/mol) and O4'-H (-28.36 kJ/mol). These same observations are made with calculations at the theory level B3LYP/6-31 G (d,p). However, the complexation enthalpies are lower with the theory level B3LYP/6-31 G (d,p).

At the epicatechin level, the smallest values are observed with the Nsp3 heteroatom for both calculation levels: they are O4'-H (-39.03 kJ/mol), O7-H (-34.43 kJ/mol), after O5-H (-34.08 kJ/mol) at the theory level B3LYP/6-31 + G (d,p).

These statements are confirmed by the values of the complexation enthalpies obtained at the B3LYP/6-31 G (d,p) theory level. These complexation enthalpies are lower compared to those obtained at the B3LYP/6-31 + G (d,p) theory level.

Table 4. Complexation enthalpies of catechin complexes

Complexation enthalpies ΔH (kJ/mol)		
Catechin- proline Complexes	**B3LYP 6-31 G (d,p)**	**B3LYP 6-31+ G (d,p)**
O_3—H……Nsp^3	-43.09	-23.13
O_5—H……Nsp^3	-52.12	-34.77
O_7—H……Nsp^3	-39.08	-20.15
$O_{4'}$—H……Nsp^3	-56.72	-28.36
$O_{5'}$—H……Nsp^3	-45.85	-28.99
O_3—H……Osp^3	-30.31	-19.37
O_5—H……Osp^3	-27.67	-9.44
O_7—H……Osp^3	-25.46	-10.78
$O_{4'}$—H……Osp^3	-29.18	-10.46
$O_{5'}$—H……Osp^3	-33.69	-12.89
O_3—H……Osp^2	-44.60	-21.70
O_5—H……Osp^2	-47.94	-25.45
O_7—H……Osp^2	-47.44	-24.71
$O_{4'}$—H……Osp^2	-55.68	-30.46
$O_{5'}$—H……Osp^2	-41.80	-20.79

Table 5. Complexing enthalpies of epicatechin complexes

Complexation enthalpies ΔH (kJ/mol)		
Epicatechin-proline Complexes	**B3LYP 6-31 G (d,p)**	**B3LYP 6-31 + G (d,p)**
O_3—H……Nsp^3	-25.22	-9.33
O_5—H……Nsp^3	-50.84	-34.08
O_7—H……Nsp^3	-51.24	-34.43
$O_{4'}$—H……Nsp^3	-56.56	-39.03
$O_{5'}$—H……Nsp^3	-30.33	-11.84
O_3—H……Osp^3	-29.66	-7.19
O_5—H……Osp^3	-29.99	-10.72
O_7—H……Osp^3	-27.00	-8.04
$O_{4'}$—H……Osp^3	-28.80	-12.62
$O_{5'}$—H……Osp^3	-45.50	-21.30
O_3—H……Osp^2	-34.41	-14.10
O_5—H……Osp^2	-57.71	-31.38
O_7—H……Osp^2	-48.54	-25.35
$O_{4'}$—H……Osp^2	-40.82	-21.01
$O_{5'}$—H……Osp^2	-39.10	-8.31

3.2.2 INTERACTION ENERGY

Since in the complex each molecular orbital is developed in a broader base than that of monomers, this results in excessive stabilization of the complex. This excessive stabilization has been corrected by taking into account" the overlay error of the bases" or BSSE (Basis Set Superposition Error) [20]. The interaction energy E_int is calculated from the relationship :

$$E_{int} = E(complex) - \sum E(monomer) + E_{BSSE} \quad (2)$$

The results are reported in Tables 6 and 7. The interaction energies are all negative. In the case of interactions between catechin and proline, they range from -53.92 and -22.17 kJ/mol in base 6-31G(d,p), and from -41.5 to -15.84 kJ/mol in base 6-31+G(d,p). For epicatechin-proline complexes, the interaction energies are between -53.70 and -21.14 kJ/mol for calculations in the 6-31G(d,p) base; they vary from -46.16 to -13.42 kJ/mol in the 6-31G(d,p) base. In the case of both catechins and epicatechins, taking into account the diffuse function leads to an increase in the energy of interaction. This justifies the effects of free heteroatom doublets on weak interactions, in this case hydrogen bonds. The interaction energies of the Nsp3 and Osp2 accepting sites give lower interaction energies, compared to those of the Osp3 site. The complexes formed with Nsp3 and Osp2 sites are more stable than those formed with Osp3 site. The sites of catechins and epicatechins giving more stable complexes are in increasing order O4'-H, O5-H and O7-H.

Table 6. Interaction energy of catechin complexes

Interaction energy E_{int} (kJ/mol)		
Catechin - proline Complexes	**B3LYP 6-31G(d,p)**	**B3LYP 6-31+G(d,p)**
O_3—H……Nsp^3	-40.12	-23.78
O_5—H……Nsp^3	-49.01	-41.95
O_7—H……Nsp^3	-36.21	-27.65
$O_{4'}$—H……Nsp^3	-53.92	-35.58
$O_{5'}$—H……Nsp^3	-41.76	-35.05
O_3—H……Osp^3	-26.22	-21.78
O_5—H……Osp^3	-24.12	-15.84
O_7—H……Osp^3	-22.17	-16.60
$O_{4'}$—H……Osp^3	-25.62	-17.33
$O_{5'}$—H……Osp^3	-29.57	-18.50
O_3—H……Osp^2	-42.08	-24.58
O_5—H……Osp^2	-22.37	-31.79
O_7—H……Osp^2	-43.89	-31.34
$O_{4'}$—H……Osp^2	-53.00	-37.66
$O_{5'}$—H……Osp^2	-38.28	-27.24

Table 7. Interaction energy of epicatechin complexes

Interaction energy E_{int} (kJ/mol)		
Epicatechin- proline Complexes	**B3LYP 6-31G(d.p)**	**B3LYP 6-31+G(d.p)**
O_3—H……Nsp^3	-22.53	-16.97
O_5—H……Nsp^3	-47.85	-41.14
O_7—H……Nsp^3	-48.43	-41.71
$O_{4'}$—H……Nsp^3	-53.70	-46.16
$O_{5'}$—H……Nsp^3	-26.56	-18.58
O_3—H……Osp^3	-25.60	-13.42
O_5—H……Osp^3	-26.01	-16.91
O_7—H……Osp^3	-23.44	-14.83
$O_{4'}$—H……Osp^3	-21.14	-18.95
$O_{5'}$—H……Osp^3	-42.95	-28.72
O_3—H……Osp^2	-30.94	-20.39
O_5—H……Osp^2	-52.12	-38.27
O_7—H……Osp^2	-44.84	-32.07
$O_{4'}$—H……Osp^2	-38.63	-28.55
$O_{5'}$—H……Osp^2	-35.35	-14.02

3.3 IR VIBRATION FREQUENCIES AND THEIR INTENSITIES

The extension of a covalent bond is often used as an indicator of the presence of hydrogen bond in complexes [21]. Indeed when the spectroscopic parameters of the free X-H group and those of the X-H group in a hydrogen bond (X-H⋯Y) are compared. we generally observe a decrease in elongation frequency and an increase in vibration intensity [22].

Catechin and epicatechin are made up of 35 atoms. they have 3N-6 = 99 normal modes of vibration. The proline has 17 atoms. which gives 45 normal vibration modes. All calculated vibration frequencies are positive. which corresponds to the minimum potential for molecules and complexes. We were particularly interested in the O-H elongations (νO-H) of catechin and epicatechin because they are involved in complexing with proline. The results are presented in Tables 8 and 9.

In the catechin molecule the vO-H elongations are between 3783 cm^{-1} and 3843 cm^{-1}. In the catechin-proline complex. they range from 3103 cm^{-1} to 3754 cm^{-1}. So there is a decrease in frequency when you go from the catechin molecule to the complex. In addition. we are seeing a significant increase in IR intensities. These variations are due to the presence of hydrogen bonds [23].

The same remarks are made in the case of epicatechin. Indeed. the vO-H elongations are between 3782 cm^{-1} and 3843 cm^{-1}. in the epicatechin molecule and between 3076 cm^{-1} and 3729 cm^{-1} in the complexes.

Specifically. the Nsp3 and Osp2 acceptor sites have the lowest frequencies and highest IR intensities (Figure 9) for both catechin and epicatechin.

Table 8. IR vibration frequencies (cm^{-1}) and their intensity (in brackets) in catechin and catechin-proline complexes

	Elongations O-H	**Catechin**	**Catechin-Proline Complex**		
			Nsp^3	Osp^3	Osp^2
B3LYP 6-31 G (d.p)	vO_3—H	3797 (20)	3532 (555)	3754 (115)	3583 (519)
	vO_5—H	3827 (52)	3194 (1927)	3725 (542)	3517 (1712)
	vO_7—H	3825 (51)	3306 (1865)	3699 (574)	3580 (1146)
	$vO_{4'}$—H	3843 (70)	3191 (1022)	3708 (656)	3505 (1910)
	$vO_{5'}$—H	3783 (96)	3103 (2051)	3729 (625)	3531 (2099)
B3LYP 6-31 G + (d.p)	vO_3—H	3803 (28)	3347 (1101)	3805 (35)	3647 (361)
	vO_5—H	3833 (69)	3149 (2379)	3725 (614)	3547 (1773)
	vO_7—H	3830 (67)	3307 (1857)	3720 (570)	3600 (1095)
	$vO_{4'}$—H	3845 (87)	3143 (2288)	3717 (700)	3538 (1574)
	$vO_{5'}$—H	3788 (119)	3058 (1473)	3747 (824)	3529 (2149)

Table 9. IR vibration frequencies (cm^{-1}) and their intensity (in brackets) in epicatechin and epicatechin-proline complexes

	Elongations O-H	**Epicatechin**	**Epicatechin-Proline Complex**		
			Nsp^3	Osp^3	Osp^2
B3LYP 6-31 G (d.p)	vO_3—H	3782 (54)	3485 (763)	3698 (144)	3663 (372)
	vO_5—H	3827 (51)	3209 (2057)	3719 (572)	3512 (1921)
	vO_7—H	3825 (50)	3192 (1904)	3728 (488)	3581 (1149)
	$vO_{4'}$—H	3843 (71)	3076 (1661)	3682 (748)	3562 (1176)
	$vO_{5'}$—H	3783 (67)	3173 (2772)	3693 (423)	3549 (1620)
B3LYP 6-31G + (d.p)	vO_3—H	3788 (61)	3442 (885)	3709 (229)	3674 (362)
	vO_5—H	3833 (68)	3163 (2388)	3721 (641)	3551 (1651)
	vO_7—H	3830 (67)	3153 (2201)	3730 (540)	3601 (1088)
	$vO_{4'}$—H	3844 (88)	3041 (1144)	3704 (750)	3590 (1153)
	$vO_{5'}$—H	3789 (86)	3133 (1523)	3712 (458)	3618 (1119)

4 CONCLUSION

This work consisted in studying weak interactions. in particular hydrogen bonds between catechin and proline on the one hand. and between epicatechin and proline in the gas phase on the other hand using the DFT method. with the functional B3LYP associated with the two bases 6-31G(d.p) and 6-31+G(d.p). The results show that the hydrogen bond has a significant influence on the geometry and stability of catechin-proline and epicatechin-proline complexes.

At the geometry level. we observe an elongation of the intramolecular O-H bonds of catechin and epicatechin in the complexes. The lengths of intermolecular bonds indicate that the bonds that are established in the complexes are moderate hydrogen bonds. Comparison of these lengths with the three proline accepting sites reveals that the Nsp3 heteroatom gives more stable complexes than the Osp2 and Osp3 heteroatoms.

The enthalpy values (ΔH) reveal that all the complexes formed are thermodynamically stable. The most stable are those formed at the Nsp3 heteroatom level.

The values of the IR vibration frequencies and their intensities indicate a decrease in vibration frequencies and an increase in intensities in complexes. The Nsp3 heteroatom has the best values.

All these observations lead us to affirm that the hydrogen bonds between catechin. epicatechin and proline are of a moderate nature. The most likely are those occurring at the Nsp3 heteroatom level.

In perspective. we plan to resume this study in the water phase to confirm or complete this work. We also plan to study strong interactions.

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