

Optical properties of Luteolin: DFT study

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Luteolin is one of the most common flavonoids that can be found in many kinds of plants, including some fruits, vegetables and medicinal herbs. Different studies have shown that this flavonoid has pharmacological activities, such as antioxidant, anti-inflammatory, antimicrobial and anticarcinogenic ones. In this work we study Luteolin's absorption and emission properties using the Time Dependent Density Functional Theory with Polarizable Continuum Model method. Calculations showed that the local minima in the excited state exist in both configurations: enol and keto of the Luteolin molecule in methanol as well as in vacuum. On the other hand, in the fundamental state, only for enol configuration an energy minimum was found.

Key words: Luteolin, flavonoids, TDDFT, fluorescence.

Оптические свойства лютеолина: исследование методом DFT

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Лютеолин является одним из наиболее распространенных флавоноидов, который находится во многих видах растений, в том числе в некоторых фруктах, овощах и лекарственных травах. Различные исследования показали, что этот флавоноид обладает фармакологической активностью, имеет антиоксидантное, противовоспалительное, антимикробное и антиканцерогенное действие. В этой работе мы изучаем свойства поглощения и излучения лютеолина с использованием теории функционала плотности, зависящего от времени, с методом модели поляризуемой непрерывной среды. Расчеты показали, что в возбужденном состоянии существуют локальные минимумы, соответствующие как энольной, так и кето-формам лютеолина (в метаноле и в вакууме). С другой стороны, в основном состоянии минимум энергии был получен только для энольной формы.

Ключевые слова: лютеолин, флавоноиды, TDDFT, флуоресценция.

1. Introduction

Luteolin (L), 3',4',5,7-Tetrahydroxyflavone is a flavonoid present in many kinds of comestible plants, also used in traditional medicine due to its preventive and therapeutic properties, making of this flavonoid a possible agent for prevention and treatment of some diseases [1]. L has been present in nature more than we can expect, it was found in 36-Million-Years-Old fossils. Nowadays we can find it in plants such as Aloe vera [2], carrot (*Daucus carota*) [3], olive oil (*Olea europaea*) [4], chocolate (*Theobroma cacao*) [5], cucumber (*Cucumis sativus*) [6], lettuce (*Lactuca sativa*) [7], and many others.

Crystallographic structure of L was studied by J. Cox *et al.* [8] where the L molecule was reported practically planar with a small torsion angle C3-C2-C1'-C6' (Fig. 1.1) of approximately 2°. Molecule of L has an intramolecular hydrogen bond (O5-H5...O4), while its crystal structure is stabilized by O-H...O, C-H...O and C-H... π interactions. Additionally, the L crystal contains disordered water molecules, providing hemihydrate characteristics [8].

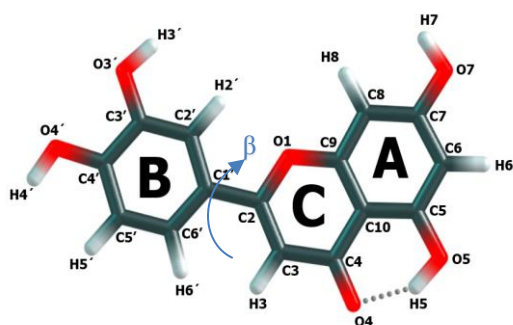


Fig. 1.1. Molecular structure of Luteolin reported in crystals [8].

In order to increase L medical benefits, it is essential to increase the bioavailability of the L molecule. Consequently, it is important to study its optical properties in order to obtain information about the L powder solubility [9].

To describe the experimentally obtained emission and absorption spectra, in Ref. 10 the apigenin and L molecules were studied by means of DFT calculations using TDDFT/B3LYP/6-31+g*. The results of that calculations were not giving the accurate matching with the experimental data, and therefore, here we are using the functional M06-2X, that we used in our previous study of morin and quercetin molecules [9, 11].

2. Computational Methodology

To optimize the geometrical structure of the L molecule and calculate its vibrational frequencies, the Density Functional Theory (DFT) method [12], was used, applying the Minnesota functional M06-2X [13] and 6-31++G** basis set [14, 15]. These calculations were made using Gaussian16 [16].

To calculate the change in the L molecule's energy due to rotation of the B ring around the single bond formed by C2-C1' (Figure 1.1), relaxed scan of the molecular structure was performed with the step of 5°.

3. Results

3.1. Energy profile of the of B-ring rotation

The relaxed scan of the B-ring torsion angle rotation by 360° was performed using M06-2X/6-31++G** computations. The resulting angular dependence is shown in Figure 3.1. Four minima, at 20°, 155°, 205° and 335° can be observed. Therefore, for the L molecule, four stable configurations with different B-ring positions and with the same energy value are possible. It is important to notice that the completely plane positions at 0° and 180° corresponds to the local maxima with 0.39 kcal/mol, while the much higher barriers (4.26 kcal/mol) are observed at almost perpendicular positions of the B-ring respect to the AC-rings plane (at 90° and 180°).

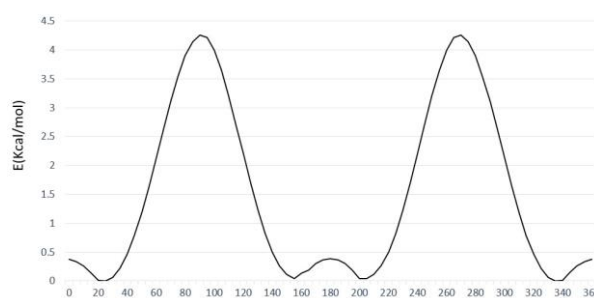


Fig. 3.1. Angular dependence of the relative energy obtained via the changing of the dihedral angle C3-C2-C1'-C6' of the Luteolin molecule, calculated using M06-2X/6-31++G**.

3.2. Enol and keto configurations of the Luteolin molecule.

Two tautomers of the L molecule are possible: enol (Figure 1.1) and keto (Figure 3.2), the last one is formed when -H5 proton of the -OH5 hydroxyl group is transferred towards the O4. Our calculations show that only the enol configuration has the energy minimum in the ground state. In the first excited state both keto and enol configurations exist.

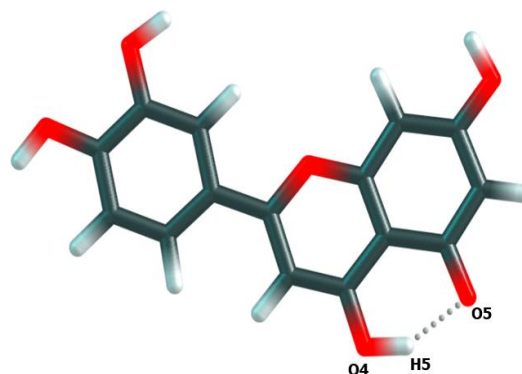


Fig. 3.2. Keto configuration of the Luteolin molecule.

3.3. Absorption of the enol configuration of the Luteolin molecule.

As mentioned before, only enol configuration is stable at the ground state, therefore, for the evaluation of absorption spectra only this configuration was used. In Table 1, we present the main characteristics of the enol configuration of the L molecule in the ground state, including the value of the energy of the minimum, zero-point corrected energy and free energy, geometrical characteristics of the internal H-bond, and, finally, energy and characteristic wavelength of the absorption.

As shown in Table 3.1, the dipole moment of enol configuration of the L molecule changes significantly (from 5.5 to 7.5 D) when the molecule is considered to be within a solvent. Additionally, there is a small variation of the torsion angle of the B-ring of about 2°, and the characteristic wavelength increases in approximately 10 nm.

Table 3.1. Main characteristics obtained for the optimized geometry of enol configuration of Luteolin molecule in the ground state in vacuum and in methanol, found using M06-2X/6-31++G**

	Vacuum	Methanol
Ground state energy, E (a.u.)	-1028.6216	-1028.6458
Zero-point corrected energy, Z_E (a.u.)	-1028.3938	-1028.4183
Free energy, ΔG (a.u.)	-1028.4385	-1028.4629
First Frequency, F (Hz)	28	27
Distance O5-H5, R_{OH} (Å)	0.99	0.99
Distance O4...O5, R_{OO} (Å)	2.61	2.60
Angle O5-H5...O4, α_{OHO} (°)	147.64	149.03
Torsion angle C3-C2-C1'-C6', β (°)	22.96	20.54
Dipole moment, P (Debye)	5.46	7.52
First excited state energy, E (a.u.)	-1028.4655	-1028.4955
Absorption, ΔE (eV)	4.25	4.09
Characteristic wavelength of absorption, λ_{abs} (nm)	291.84	303.04
Oscillator strength of absorption, f_{ab}	0.3954	0.6991

3.4. Emission of the enol and keto configurations of the Luteolin molecule.

Table 3.2. Main characteristics obtained for optimized geometry of enol configuration of Luteolin molecule in the first excited state in methanol, found using M06-2X/6-31++G**

	Methanol
Ground state energy, E (a.u.)	-1028.6340
Zero-point corrected energy, Z_E (a.u.)	-1028.2918
Free energy, ΔG (a.u.)	-1028.3375
First Frequency, F (Hz)	21
Distance O5-H5, R_{OH} (Å)	1.05
Distance O4...O5, R_{OO} (Å)	2.45
Angle O5-H5...O4, α_{OHO} (°)	156.98
Torsion angle C3-C2-C1'-C6', β (°)	0.01
Dipole moment, P (Debye)	10.31
First excited state energy, E (a.u.)	-1028.5142
Emission, ΔE (eV)	3.26
Characteristic wavelength of emission, λ_{em} (nm)	380.49
Oscillator strength of emission, f_{em}	1.01

In the process of geometric optimization of the enol configuration of the L molecule in the first excited state in vacuum, the proton H5 is transferred within the L molecule, and it moves from O5 to O4 position. In methanol, however, the minimum of enol configuration exists and its characteristics are listed in the Table 3.2.

We can observe, that the O5-H5 distance slightly increases in the excited state, while the O4...O5 distance decreases. More pronounced change happens in the C3-C2-C1'-C6' torsion angle: the enol configuration in the first excited state is practically planar. The dipole moment increases from 7.5 D in the ground state to the 10.3 D in the excited state. The characteristic wavelength of the emission is 380 nm, therefore, the Stokes shift for enol configuration in methanol is about 77 nm.

The data for the keto configuration of L is presented in the Table 3.3.

Table 3.3. Main characteristics obtained for the optimized geometry of the keto configuration of Luteolin molecule in the first excited state in vacuum and in methanol, using M06-2X/6-31++G**

	Vacuum	Methanol
Ground state energy, E (a.u.)	-1028.5813	-1028.6199
Zero-point corrected energy, Z_E (a.u.)	-1028.2838	-1028.3028
Free energy, ΔG (a.u.)	-1028.3297	-1028.3490
First Frequency, F (Hz)	24	22
Distance O4-H5, R_{OH} (Å)	0.98	0.98
Distance O4...O5, R_{OO} (Å)	2.68	2.65
Angle O5-H5...O4, α_{OHO} (°)	146.00	146.44
Torsion angle C3-C2-C1'-C6', β (°)	0.06	0.03
Dipole moment, P (Debye)	9.77	12.03
First excited state energy, E (a.u.)	-1028.5081	-1028.5264
Emission, ΔE (eV)	1.99	2.54
Characteristic wavelength of emission, λ_{em} (nm)	623.18	487.40
Oscillator strength of emission, f_{em}	0.04	0.30

As in the case of enol configuration, in the excited state of keto configuration is practically plane. The dipole moment is significantly larger in methanol than in vacuum. The characteristic wavelength of the emission is 623 nm for vacuum and 487 nm for methanol. For the last one, the difference with respect to the enol configuration is more than 100 nm.

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5. References

1. Lopez-Lazaro M. Distribution and Biological Activities of the Flavonoid Luteolin. *Mini-Rev. Med. Chem.* 2009. V. 9. P. 31–59. doi: [10.2174/138955709787001712](https://doi.org/10.2174/138955709787001712)
2. Keyhanian S., Stahl-Biskup E. Phenolic Constituents in Dried Flowers of Aloe Vera (*Aloe Barbadosensis*) and Their in Vitro Antioxidative Capacity. *Planta Med.* 2007. V. 73. P. 599–602. doi: [10.1055/s-2007-967202](https://doi.org/10.1055/s-2007-967202)
3. Shalaby N.M.M., Maghraby A.S., El-Hagrassy A.M. Effect Of *Daucus Carota* Var. *Boissieri* Extracts on Immune Response Of *Schistosoma Mansoni* Infected Mice. *Folia Microbiol. (Praha)* 1999. V. 44. P. 441–448. doi: [10.1007/BF02903720](https://doi.org/10.1007/BF02903720)
4. Pieroni A., Heimler D., Pieters L., van Poel B., Vlietinck A.J. In Vitro Anti-Complementary Activity of Flavonoids from Olive (*Olea Europaea* L.) Leaves. *Pharm.* 1996. V. 51. P. 765–768.
5. Sánchez-Rabaneda F., Jáuregui O., Casals I., Andrés-Lacueva C., Izquierdo-Pulido M., Lamuela-Raventós R.M. Liquid Chromatographic/Electrospray Ionization Tandem Mass Spectrometric Study of the Phenolic Composition of Cocoa (*Theobroma Cacao*). *J. Mass Spectrom.* 2003. V. 38. P. 35–42. doi: [10.1002/jms.395](https://doi.org/10.1002/jms.395)
6. McNally D.J., Wurms K.V., Labbé C., Quideau S., Bélanger R.R. Complex C-Glycosyl Flavonoid Phytoalexins from *Cucumis Sativus*. *J. Nat. Prod.* 2003. V. 66. P. 1280–1283. doi: [10.1021/np030150y](https://doi.org/10.1021/np030150y)
7. DuPont M.S., Mondin Z., Williamson G., Price K.R. Effect of Variety, Processing, and Storage on the Flavonoid Glycoside Content and Composition of Lettuce and Endive. *J. Agric. Food Chem.* 2000. V. 48. P. 3957–3964. doi: [10.1021/jf0002387](https://doi.org/10.1021/jf0002387)
8. Cox P.J., Kumarasamy Y., Nahar L., Sarker S.D., Shoeb M. Luteolin. *Acta Crystallogr. Sect. E Struct. Rep.* 2003. V. 59. P. o975–o977. doi: [10.1107/S1600536803013229](https://doi.org/10.1107/S1600536803013229)
9. Deriabina A., Prutskij T., Castillo Trejo L., Sanchez Gutierrez M.P., Gonzalez Jimenez E. Experimental and Theoretical Study of Fluorescent Properties of Morin. *Molecules.* 2022. V. 27. P. 4965. doi: [10.3390/molecules27154965](https://doi.org/10.3390/molecules27154965)
10. Amat A., Clementi C., De Angelis F., Sgamellotti A., Fantacci S. Absorption and Emission of the Apigenin and Luteolin Flavonoids: A TDDFT Investigation. *J. Phys. Chem. A.* 2009. V. 113. P. 15118–15126. doi: [10.1021/jp9052538](https://doi.org/10.1021/jp9052538)
11. Prutskij T., Deriabina A., Melendez F.J., Castro M.E., Castillo Trejo L., Vazquez Leon G.D., Gonzalez E., Perova T.S. Concentration-Dependent Fluorescence Emission of Quercetin. *Chemosensors.* 2021. V. 9. P. 315. doi: [10.3390/chemosensors9110315](https://doi.org/10.3390/chemosensors9110315)
12. Parr R.G. Density Functional Theory of Atoms and Molecules. In: *Proceedings of the Horizons of Quantum Chemistry*. Eds. Fukui K., Pullman B. Springer Netherlands: Dordrecht, 1980. P. 5–15.
13. Zhao Y., Truhlar D.G. The M06 Suite of Density Functionals for Main Group Thermochemistry, Thermochemical Kinetics, Noncovalent Interactions, Excited States, and Transition Elements: Two New Functionals and Systematic Testing of Four M06-Class Functionals and 12 Other Functionals. *Theor. Chem. Acc.* 2008. V. 120. P. 215–241. doi: [10.1007/s00214-007-0310-x](https://doi.org/10.1007/s00214-007-0310-x)
14. Ditchfield R., Hehre W.J., Pople J.A. Self-Consistent Molecular-Orbital Methods. IX. An Extended Gaussian-Type Basis for Molecular-Orbital Studies of Organic Molecules. *J. Chem. Phys.* 1971. V. 54. P. 724–728. doi: [10.1063/1.1674902](https://doi.org/10.1063/1.1674902)
15. Frisch M.J., Pople J.A., Binkley J.S. Self-consistent Molecular Orbital Methods 25. Supplementary Functions for Gaussian Basis Sets. *J. Chem. Phys.* 1984. V. 80. P. 3265–3269. doi: [10.1063/1.447079](https://doi.org/10.1063/1.447079)
16. Frisch M.J., Trucks G.W., Schlegel H.B., Scuseria G.E., Robb M.A., Cheeseman J.R., Scalmani G., Barone V., Petersson G.A., Nakatsuji H., et al. Gaussian~16 Revision A.01 2016.