



# Theoretical Study of Coumarins Molecules in the Epoxidation Reactions: Chalepine and Gravelliferone

## KEYWORDS

Ab initio, B3LYP, chalepine, gravelliferone, coumarins

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**ABSTRACT** The coumarins have an important biological character. These molecules are natural substances which found in the plant *Ruta*. In this work, we theoretical study the epoxidation reactions on coumarins such as acetate chalepine **1** and Gravelliferone methyl ether **2**. Using the two calculation methods DFT/B3LYP and ab-initio with the standard basis set 6-31G\*, we discuss from thermodynamic and orbital point of view the possibility and the stereoselectivity of these reactions.

## 1/ Introduction

Coumarins are natural organic substance. Generally, they are found in some plant families such as Fabaceae, Asteraceae, Rutaceae and Umbelliferae [1-3]. They are situated in all the parts of plant and especially in fruits and seeds essential oils [3]. Coumarins families are formed by phenolic compounds and they are characterized by the presence of a benzopyran [4] (Figure 1). They formed many substances with flavonoids, chromes and isocoumarins [4-8].

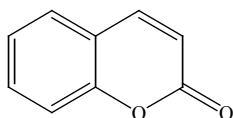


Figure 1

In this work, we found interesting to study the epoxidation reactions of coumarins molecules such as acetate chalepine **1** and gravelliferone methyl ether **2** by Meta chloroperbenzoic acid **3** (Figure 2). We chose the two molecules **1** and **2**, which have three double bonds. A monosubstituted double bond type A, a second double bond type B and a trisubstituted third double bond from molecule **1** type C and from molecule **2** type C'. Our work is to compare the reactivity of these molecules **1** and **2** with Meta chloroperbenzoic acid **3**. Thereafter, we compare the reactivity of these three double bonds belonging to the same molecule with Meta chloroperbenzoic acid **3**.

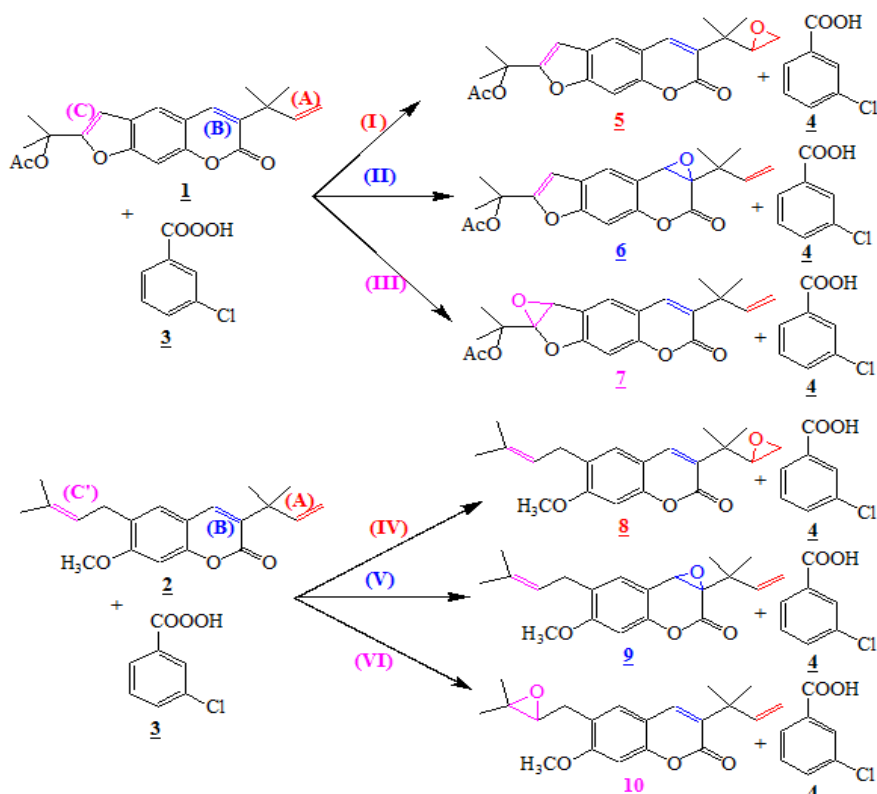


Figure - 2

## II/ Calculation methods

This study was carried out using the Gaussian 03 program [9]. The calculations were performed at DFT and ab-initio methods with the standard basis set 6-31G\*. We used the B3LYP functional in all of the exchange energy which calculated by Becke's three parameters method and the correlation method of Lee, Yang and Parr [10-12]. The choice of the DFT method is justified by its efficiency in the treatment of these systems type (organic molecules) [13-21].

## III/ Results and Discussion

### III.1/ Thermodynamic Study

Based on the two calculation methods ab-initio and DFT/B3LYP with the standard basis set 6-31G\*, we determine under standard conditions of temperature and pressure ( $T = 298,15\text{K}$  and  $P = 1\text{atm}$ ), the thermodynamic values  $\Delta G_r$ ,  $\Delta H_r$ ,  $\Delta E_r$  and ZPE (Zero point energy) corresponding to reactions (I), (II), (III), (IV), (V) and (VI) [14-21] (Figure 2). Our results show that these reactions are possible and thermodynamically favorable. After, we found that the reaction between Meta chloroperbenzoic acid **3** and gravelliferone methyl ether **2** is more favorable from thermodynamic point of view than the reaction between Meta chloroperbenzoic acid **3** and acetate chalepine **1** (Table 1). In the case of the reaction between peroxyacid **3** and molecule **1**, we found that the epoxide **6** formed on the double bond (B) is thermodynamically more favorable as the epoxide **7** formed on the double bond (C). While the epoxide **5** is thermodynamically less favorable than products **6** and **7**. Similarly, in the case of reaction between peroxyacid **3** and compound **2**, the products **9** and **10** are the most thermodynamically favorable than product **8**. These results are due to the influence of double bond substitution. Indeed, the reactivity of alkenes (coumarins) with peroxyacid increases with double bond substitution. Then, we observed selective oxidations. Indeed, the formation of the epoxide **9** on the trisubstituted double bond (B) belonging to molecule **2** is more favorable than the epoxide **10** formed on the trisubstituted double bond (C').

**Table 1: Thermodynamic results of  $\Delta E_r$ ,  $\Delta G_r$ ,  $\Delta H_r$  and ZPE for reactions (I-VI) ( $\text{kcal.mol}^{-1}$ ).**

Reactions	products	$\Delta G_r$	$\Delta E_r + \text{ZPE}$	$\Delta H_r$
Ab-initio / 6-31G*				
Reaction (I)	<b>5</b> + <b>4</b>	-50.37	-31.48	21.37
Reaction (II)	<b>6</b> + <b>4</b>	-86.51	-65.35	30.13
Reaction (III)	<b>7</b> + <b>4</b>	-71.32	-52.10	28.54
Reaction (IV)	<b>8</b> + <b>4</b>	-73.97	-57.11	24.22
Reaction (V)	<b>9</b> + <b>4</b>	-115.18	-82.47	37.91
Reaction (VI)	<b>10</b> + <b>4</b>	-90.71	-69.89	31.07
B3LYP / 6-31G*				
Reaction (I)	<b>5</b> + <b>4</b>	-47.12	-29.75	19.37
Reaction (II)	<b>6</b> + <b>4</b>	-72.97	-51.34	26.33
Reaction (III)	<b>7</b> + <b>4</b>	-65.34	-42.16	24.99
Reaction (IV)	<b>8</b> + <b>4</b>	-69.34	-47.91	18.37
Reaction (V)	<b>9</b> + <b>4</b>	-103.13	-78.10	32.19
Reaction (VI)	<b>10</b> + <b>4</b>	-81.89	-58.37	28.18

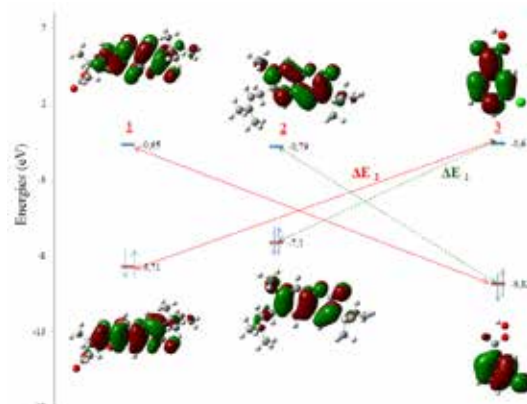
### III.2/ Study of the frontier orbitals

We determine by the two calculation methods, the energies of the HOMO and the LUMO of molecules **1**, **2** and **3** (Table 2) [14-21]. We have subsequently shown the orbital diagram between these molecules (Figure 3). This orbital diagram gives a good qualitative indication in our

system. Indeed, the preferential interactions are between the HOMO energy of molecules **1** and **2** and the LUMO energy of Meta chloroperbenzoic acid **3**. Furthermore, we found that the energy difference  $\Delta E_1$  is shorter than  $\Delta E_2$ . These results show that the reaction between Meta chloroperbenzoic acid **3** and gravelliferone methyl ether **2** is more favorable than the reaction between Meta chloroperbenzoic acid **3** and acetate chalepine **1**. This confirms the results found by the thermodynamic study.

**Table 2: Energy (eV) of frontier orbitals of **1**, **2** and **3** molecules. (1a.u = 27.21 eV)**

	LUMO (eV)	HOMO (eV)	$\mu = (E_{\text{HOMO}} + E_{\text{LUMO}})/2$ [14, 17, 18, 20]	$\eta = E_{\text{LUMO}} - E_{\text{HOMO}}$ [14, 17, 18, 20]	$\omega = \mu^2/2\eta$ [14, 17, 18, 20]
Ab-initio / 6-31G*					
1	-0.77	-9.01	-4.89	8.24	1.45
2	-0.81	-8.93	-4.87	8.12	1.46
3	-0.69	-10.23	-5.46	9.54	1.56
B3LYP / 6-31G*					
1	-0.65	-8.71	-4.68	8.06	1.35
2	-0.79	-7.10	-3.94	6.31	1.23
3	-0.60	-9.82	-5.21	9.22	1.47



**Figure 3: Orbital diagram between Meta chloroperbenzoic acid **3** and gravelliferone methyl ether **2** and interaction between Meta chloroperbenzoic acid **3** and acetate chalepine **1**. Energies in (eV), value of the isocontour = (0.02 a.u). B3LYP (6-31G\*)**

## IV/ Conclusion

We discussed from thermodynamic and orbital point of view the epoxidation reactions between Meta chloroperbenzoic acid **3** and molecules such as acetate chalepine **1** and gravelliferone methyl ether **2**. Using both calculation methods ab-initio and DFT with B3LYP functional and 6-31G\* standard basis set, we have shown that the reaction between peroxyacid **3** and molecule **2** is easier than the reaction between peroxyacid **3** and molecule **1**. Moreover we found that the reactivity of alkenes (coumarins) with peroxyacid **3** increases with the trisubstituted double bond belonging to molecules **1** and **2**.

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