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Synthesis, experimental and theoretical NMR study of 2′-hydroxychalcones bearing a nitro substituent on their B ring

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Abstract—The synthesis of several 2′-hydroxynitrochalcones has been accomplished by an aldol reaction of equimolar amounts of the appropriate 2′-hydroxyacetophenones with nitrobenzaldehydes in alkaline medium. The reaction of 2′-hydroxyacetophenones bearing a 6′-methoxy with 2- or 4-nitrobenzaldehydes gave the expected 2′-hydroxynitrochalcones and also 4-methoxynitroaurones, being the latter ones the unique reaction products when using 2 molar equiv of nitrobenzaldehydes. The reaction mechanisms for the formation of both products are discussed. The ^{13}C NMR chemical shifts have been discussed first by means of an empirical additive model and then by comparison with GIAO/B3LYP calculated absolute shieldings.

1. Introduction

Chalcones (1,3-diaryl-2-propen-1-ones) are an import class of natural compounds belonging to the flavonoid family, which have demonstrated to possess an impressive array of pharmacological and agrochemical activities, namely, anti-protozoal, anti-inflammatory, immunomodulatory, nitric oxide and lipid peroxidation inhibition, antileishmanial, antimalarial, antiulcer, cytotoxic, anticancer, antitumour, antimicrobial and antiviral activities.[1–12] Certain natural and synthetic derivatives bearing a 2′-hydroxy group have also exhibited a wide spectrum of biological activities with potential applications as biocides and pharmaceutical drugs.[1,13–15] The presence of the enone function and the 2′-hydroxy group in these compounds are important structural features for their antibiotic activity.[1]

The importance of 2′-hydroxychalcones is due not only to their important biological activities, but also due to the fact that they are intermediates in the synthesis and biosynthesis of several flavonoids, such as flavanones, flavones, isoflavones and aurones.[1,16–21] As part of our interests in the area of flavonoids[22–24] and having in mind the potential applications of several nitro- and aminoflavonoid-type compounds,[2,10,25–33] we have expand our studies to the synthesis of several new 2′-hydroxynitrochalcone derivatives. Nitroflavones are selective and competitive ligands for central benzodiazepine receptors and possess anxiolytic properties. The presence of nitro groups is essential for these activities.[27,28,33] Flavones bearing amino groups on the A or B ring have been reported to be potential antineoplastic agents[26] and proved to be antimutagenic in the Ames test using different species of mutagens.[31] Some aminoflavones derivatives are also known as specific antitumour agents in breast cancer[29] and are reported by several authors as tyrosine kinases inhibitors[25] and as antimitotic agents.[32] On the other hand, a series of aminochalcones, synthesised as candidate of cytotoxic agents, displayed selective toxicity to certain malignant cell and were well tolerated in mice.[10]

The synthesis of 2′-hydroxychalcones have been extensively studied,[18,34–36] whereas to our knowledge only a few synthetic methods are available for the preparation of their nitro derivatives.[37–41] Taking these facts into consideration, we started a programme on the synthesis and transformation[41] of this type of compounds and on the study of their spectroscopic features which can give some insights about their biological activities. Recently, Lluch et al. studied the inverse dependence of the chemical shift of the hydroxyl proton of 4′-dimethylamino-2′-hydroxychalcone by theoretical calculations.[42] In this communication, we report the experimental and theoretical studies on the ^{1}H and ^{13}C NMR chemical shifts of twelve 2′-hydroxynitrochalcones **3b–m** and the comparison with those of the parent compound **3a**.

Keywords: 2′-Hydroxynitrochalcones; 4′-Methoxynitroaurones; Oxidation reactions; Aldol reaction; NMR; B3LYP; GIAO.
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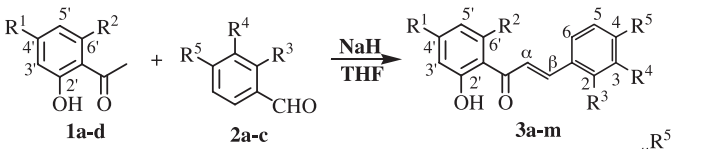
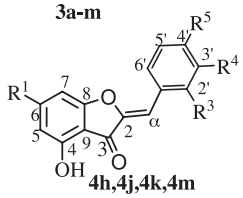


For compounds **1**:
a) $R^1 = R^2 = H$
b) $R^1 = OMe$, $R^2 = H$
c) $R^1 = H$, $R^2 = OMe$
d) $R^1 = R^2 = OMe$

For compounds **2**:
a) $R^3 = R^4 = R^5 = H$
b) $R^3 = NO_2$, $R^4 = R^5 = H$
c) $R^3 = R^5 = H$, $R^4 = NO_2$
d) $R^3 = R^4 = H$, $R^5 = NO_2$


4h,4j,4k,4m

For compounds **3a-m** and **4h**,**4j**,**4k** and **4m**:

	a	b	c	d	e	f	g	h	i	j	k	l	m
R^1	H	H	H	H	OMe	OMe	OMe	H	H	H	OMe	OMe	OMe
R^2	H	H	H	H	H	H	H	OMe	OMe	OMe	OMe	OMe	OMe
R^3	H	NO_2	H	H	NO_2	H	H	NO_2	H	H	NO_2	H	H
R^4	H	H	NO_2	H	H	NO_2	H	H	NO_2	H	H	NO_2	H
R^5	H	H	H	NO_2	H	H	NO_2	H	H	NO_2	H	H	NO_2

Scheme 1.

2. Results and discussion

Initial experiments considered the aldol reaction of 2′-hydroxyacetophenone (**1a**) with 1.1 molar equiv of 2-nitrobenzaldehyde (**2b**) in alkaline medium (2 molar equiv of sodium hydride have been used, since one is consumed by the hydroxyl group) (Scheme 1). After the disappearance of the starting materials, controlled by TLC, the expected 2′-hydroxy-2-nitrochalcone (**3b**) was obtained in 16% yield, after a tedious and hard purification process by preparative thin layer chromatography. In order to increase the yield of the reaction and to avoid some benzaldehyde oxidation, we have deoxygenated the reaction medium before the addition of 2-nitrobenzaldehyde (**2b**) and the expected chalcone (**3b**) was obtained in 24% yield. After this result we carried out the reactions of 2′-hydroxyacetophenones **1a**–**d** with 1.1 equiv of nitrobenzaldehydes (**2b**–**d**) in the same alkaline conditions and the expected 2′-hydroxynitrochalcones **3c**–**m** were obtained in moderate to good yields (Table 1). In the case of chalcones **3h**, **3j** and **3k** a new compound have been obtained in each case. These new compounds were identified as aurones **4h**, **4j** and **4k**. The reaction of 4-nitrobenzaldehyde (**2d**) and 2′-hydroxy-4′,6′-dimethoxyacetophenone (**1d**) does not gave the expected chalcone **3m** but a complex mixture of compounds where there was some starting acetophenone **1d**. Since some starting acetophenone **1d** was recovered in this case, we decided to increase the quantity of 4-nitrobenzaldeyde (**2d**) to 2 molar equiv 2′-Hydroxy-4′,6′-dimethoxy-4-nitrochalcone **3m** were obtained in 17% yield together with 4,6-dimethoxy-4′-nitroaurone (**4m**) (27% yield) after 2 h reaction time and only aurone **4m** (44% yield) after 10 h reaction time (Table 1). Since the yield of the expected chalcone **3m** was not increased after some changes in the experimental procedure, it was decided to perform all the other reactions in these conditions trying to get 2′-hydroxynitrochalcones **3b**–**m** in better yields. The aldol reactions of 2′-hydroxyacetophenones **1a**–**d** with 2 molar equiv of nitrobenzaldehydes **2b**–**d** gave the expected chalcones **3b**–**g**, **3i** and **3l** in better yields than when using 1.1 molar equiv of benzaldehydes **2b**–**d** (Table 1). However, in the cases where some aurones **4h**, **4j** and **4k** have been obtained using 1.1 equiv of benzaldehyde, with 2 equiv only these compounds have been obtained after 2 h reaction time (Table 1). These results indicate that the presence of a 6-methoxy group in the acetophenone moiety and a 2- and 4-nitro group in the benzaldehyde moiety (were there is an electronic conjugation between the nitro substituent and the formyl group) difficult the formation of chalcones, which after to be formed are oxidised (dehydrogenated) into the corresponding aurones **4h**, **4j**, **4k** and **4m**.[43]

In order to explain the formation of aurones **4h**, **4j**, **4k** and **4m**, we analysed by preparative tlc the reaction mixture of 2′-hydroxy-4′,6′-dimethoxyacetophenone (**1d**) with 2 molar equiv of 4-nitrobenzaldehyde **2d** and 4-nitrobenzyl alcohol have been identified (vide experimental). This result indicates that one can envisage the dehydrogenation

Table 1. Yields obtained in the synthesis of 2′-hydroxynitrochalcones **3b**–**m**

Equiv. nitrobenzaldehydes	Yield of 2′-hydroxynitrochalcones **3b**–**m** (%)											
	3b	**3c**	**3d**	**3e**	**3f**	**3g**	**3h**	**3i**	**3j**	**3k**	**3l**	**3m**
1.1	24	68	80	21	60	64	15[a]	64	19[b]	21[c]	60	—
2	44	75	89	40	72	74	—[d]	81	—[e]	—[f]	73	17[g]

[a] Plus 41% of **4h**.
[b] Plus 48% of **4j**.
[c] Plus 47% of **4k**.
[d] Only 89% of **4h**.
[e] Only 74% of **4j**.
[f] Only 78% of **4k**.
[g] Plus 27% of **4m**.

Table 2. ^{1}H and ^{13}C chemical shifts (δ, ppm, in DMSO-d_6) and matrix of substituents

Compound	H-α	H-β	OH	C-α	C-β	4′-OMe	6′-OMe	2-NO_2	3-NO_2	4-NO_2
3a	8.05	7.84	12.50	121.8	144.9	0	0	0	0	0
3b	7.98	8.06	12.11	126.6	138.8	0	0	1	0	0
3c	8.23	7.92	12.35	124.7	142.0	0	0	0	1	0
3d	8.15	7.85	12.15	126.2	141.3	0	0	0	0	1
3e	8.00	8.07	13.13	125.3	139.6	1	0	1	0	0
3f	8.22	7.91	13.31	124.1	141.6	1	0	0	1	0
3g	8.20	7.88	13.23	125.5	141.1	1	0	0	0	1
3h	7.15	7.64	10.41	132.3	138.2	0	1	1	0	0
3i	7.34	7.48	10.42	131.0	140.9	0	1	0	1	0
3j	7.35	7.45	10.41	132.0	140.3	0	1	0	0	1
3k	7.69	7.87	13.15	131.8	136.6	1	1	1	0	0
3l	7.85	7.71	13.22	130.4	139.3	1	1	0	1	0
3m	7.70	7.59	13.21	131.7	139.0	1	1	0	0	1

of 2′-hydroxychalcones **3h**, **3j**, **3k** and **3m** into the corresponding aurones **4h**, **4j**, **4k** and **4m** by hydrogen transfer to the corresponding benzaldehyde used in excess which is transformed into the obtained benzyl alcohol.

We report here the full characterisation of all synthesised 2′-hydroxynitrochalcones **3b**–**m** since a major part of them are new compounds and the references found for the others are old and do not report these data. The NMR data of 2′-hydroxychalcone **3a** are reported for the comparison study with the nitro derivatives (vide infra).

The main features of the NMR data of 2′-hydroxychalcones **3a**–**m** are the resonances of: (i) the hydroxyl groups at δ 10.41–13.23 ppm. The high frequency resonances of these protons are due to the intramolecular hydrogen bond formed with the carbonyl group; (ii) the vinylic protons appearing as doublets at $\delta_{H\alpha}$ 7.15–8.23 ppm and $\delta_{H\beta}$ 7.45–8.07 ppm. The coupling constants $^{3}J_{H\alpha-H\beta}$ ~15–16 Hz indicate the *trans* configuration of these vinylic system; (iii) the vinylic carbons which appear at $\delta_{C\alpha}$ 121.8–132.3 ppm and $\delta_{C\beta}$ 136.6–144.9 ppm. The resonances of C-β atoms appear at higher frequency values than those of C-α due to deshielding mesomeric effect of the carbonyl group; (iv) the carbonyl group appearing at δ 191.1–194.0 ppm, and (v) the aromatic carbons bonded to oxygen atoms, which appear at δ~157–166 ppm. The resonances of the hydroxyl proton and of the vinylic proton and carbon atoms are very sensitive to the substituents of both aryl rings of 2′-hydroxychalcones **3a**–**m** (vide infra).

The main NMR features of aurones **4h**, **4j**, **4k** and **4m** are the resonances of their vinylic proton, which appear at $\delta_{H\alpha}$ 6.75–7.00 ppm. These resonance frequency are consistent with a *Z* configuration of the olefinic bond of aurones, the thermodynamically more stable isomers of these compounds.[44] Another important resonances to support the structure of aurones are the carbon resonances of C-α (δ 103.4–107.4 ppm), C-2 (δ 147.7–149.2 ppm) and C=O (δ 180.1–180.5 ppm).

The comparison of the ^{1}H and ^{13}C chemical shifts of the parent compound 2′-hydroxychalcone **3a** with those of the twelve methoxy/nitro derivatives **3b**–**m**, shed some light in the effect of these substituents. The most sensitive signals are those belonging to H-α, H-β, OH, C-α and C-β. We have reported these values together with a presence/absence matrix in Table 2.

2.1. Empirical analysis of Table 2 chemical shifts

Using the presence/absence matrix the following correlations are obtained (n=13 points):

$$\delta\text{H-}\alpha = 8.05 + 0.24^{*}(4'\text{-OMe}) - 0.62^{*}(6'\text{-OMe}) - 0.16^{*}(2\text{-NO}_2) + 0.05^{*}(3\text{-NO}_2) - 0.01^{*}(4\text{-NO}_2),\ r^2 = 0.90 \quad (1)$$

$$\delta\text{H-}\beta = 7.84 + 0.10^{*}(4'\text{-OMe}) - 0.32^{*}(6'\text{-OMe}) + 0.18^{*}(2\text{-NO}_2) + 0.02^{*}(3\text{-NO}_2) - 0.04^{*}(4\text{-NO}_2),\ \pi^2 = 0.94 \quad (2)$$

$$\delta\text{OH} = 12.5 + 1.9^{*}(4'\text{-OMe}) - 0.91^{*}(6'\text{-OMe}) - 0.80^{*}(2\text{-NO}_2) - 0.67^{*}(3\text{-NO}_2) - 0.74^{*}(4\text{-NO}_2),\ r^2 = 0.94 \quad (3)$$

$$\delta\text{C-}\alpha = 121.8 - 0.7^{*}(4'\text{-OMe}) + 6.1^{*}(6'\text{-OMe}) + 4.5^{*}(2\text{-NO}_2) + 3.0^{*}(3\text{-NO}_2) + 4.3^{*}(4\text{-NO}_2),\ r^2 = 0.998 \quad (4)$$

$$\delta\text{C-}\beta = 144.9 - 0.7^{*}(4'\text{-OMe}) - 1.7^{*}(6'\text{-OMe}) - 5.4^{*}(2\text{-NO2}) - 2.8^{*}(3\text{-NO}_2) - 3.3^{*}(4\text{-NO}_2),\ r^2 = 0.95 \quad (5)$$

Since the goodness-of-fit, as represented by r^2, are not good, except in the case of δC-α, we suspect that the effect of the methoxy groups was not independent. We introduced a supplementary dummy when both are present simultaneously (compounds **3k**–**m**), (4′,6′-diOMe).

$$\begin{aligned}\delta\text{H-}\alpha &= 8.05 + 0.02^{*}(4'\text{-OMe}) - 0.84^{*}(6'\text{-MeO}) \\ &\quad - 0.05^{*}(2\text{-NO}_2) + 0.16^{*}(3\text{-NO}_2) \\ &\quad - 0.10^{*}(4\text{-NO}_2) + 0.45(4',6'\text{-diOMe}), \\ r^2 &= 0.991\end{aligned} \tag{6}$$

$$\begin{aligned}\delta\text{H-}\beta &= 7.84 + 0.01^{*}(4'\text{-OMe}) - 0.42^{*}(6'\text{-MeO}) \\ &\quad + 0.23^{*}(2\text{-NO}_2) + 0.07^{*}(3\text{-NO}_2) \\ &\quad + 0.01^{*}(4\text{-NO}_2) + 0.19(4',6'\text{-diOMe}), \\ r^2 &= 0.992\end{aligned} \tag{7}$$

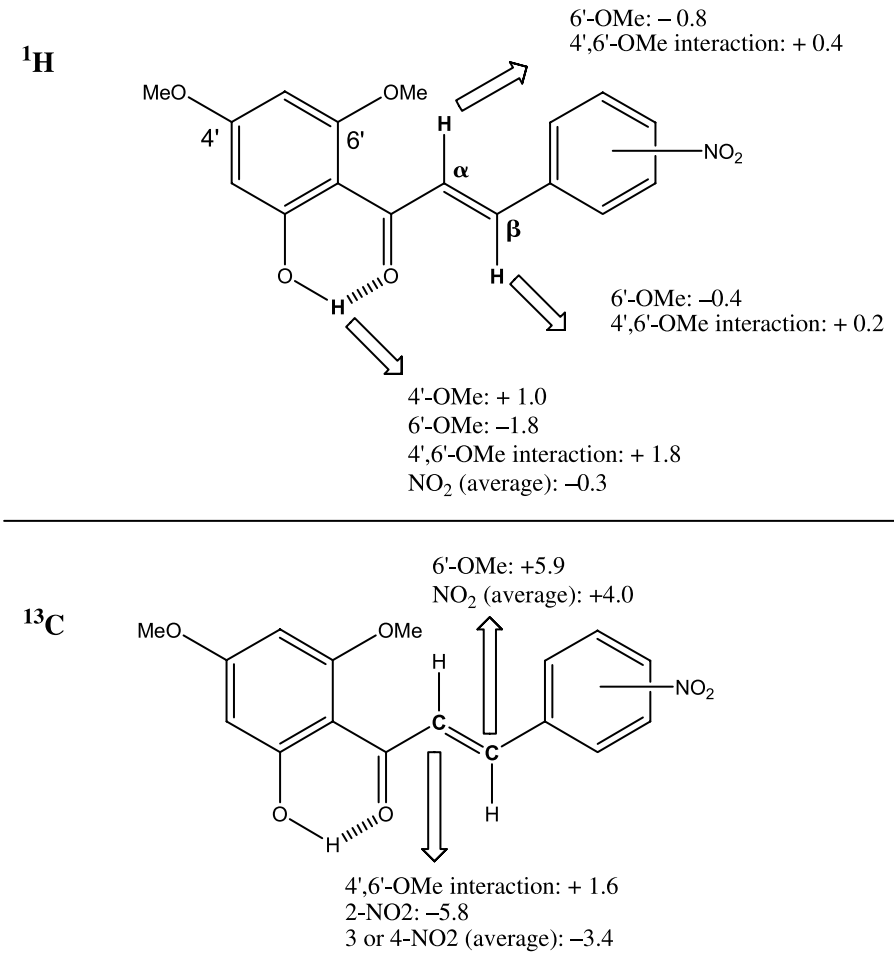
$$\begin{aligned}\delta\text{OH} &= 12.5 + 1.01^{*}(4'\text{-OMe}) - 1.79^{*}(6'\text{-MeO}) \\ &\quad - 0.33^{*}(2\text{-NO}_2) - 0.25^{*}(3\text{-NO}_2) \\ &\quad - 0.30^{*}(4\text{-NO}_2) + 1.77(4',6'\text{-diOMe}), \\ r^2 &= 0.999\end{aligned} \tag{8}$$

$$\begin{aligned}\delta\text{C-}\alpha &= 121.8 - 0.9^{*}(4'\text{-OMe}) + 5.9^{*}(6'\text{-MeO}) \\ &\quad + 4.6^{*}(2\text{-NO}_2) + 3.1^{*}(3\text{-NO}_2) \\ &\quad + 4.4^{*}(4\text{-NO}_2) + 0.4(4',6'\text{-diOMe}), \\ r^2 &= 0.999\end{aligned} \tag{9}$$

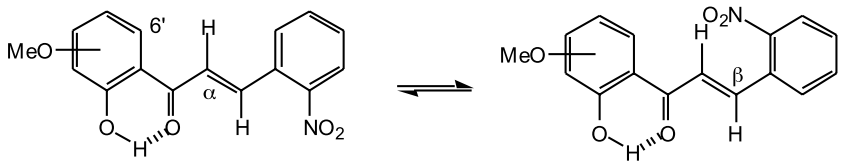
$$\begin{aligned}\delta\text{C-}\beta &= 144.9 - 0.1^{*}(4'\text{-OMe}) - 0.9^{*}(6'\text{-MeO}) \\ &\quad - 5.8^{*}(2\text{-NO}_2) - 3.1^{*}(3\text{-NO}_2) \\ &\quad - 3.7^{*}(4\text{-NO}_2) - 1.6(4',6'\text{-diOMe}), \\ r^2 &= 0.991\end{aligned} \tag{10}$$

Eqs. (6)–(10) can be summarised graphically as represented in Scheme 2.

Concerning the OH proton, the presence of a methoxy group at position 4′ produces a strengthening of the O–H···O hydrogen bond while a 6′-methoxy group weakens the HB. The first effect is electronic in origin, making the carbonyl group, in *para* position, a better HB acceptor. The *ortho* methoxy group should produce a similar effect but its steric effect counterbalanced it, the torsion about the CO-Cα bond weakens the HB. The presence of two methoxy groups has a strong positive effect on the HB, and somewhat



Scheme 2. Effects of the substituents (SCS, ppm) on ^{1}H and ^{13}C signals.



Scheme 3. Conformation of the *o*-nitrophenyl group.

counterbalances the steric effect of the 6′-methoxy group. The same effects, although attenuated, are observed on H-α and H-β, besides H-α is more sensitive to the closer by 6′-OMe while H-β is more sensitive to the *ortho* nitro group (this implies that the conformation of the nitrophenyl group has the NO_2 group close to H-β and not to H-α) (Scheme 3).

In ^{13}C NMR, the SCS of Scheme 2 show the sensibility to proximity effects (C-α to 6′-OMe group and C-β to all NO_2 groups but especially to the *ortho* one).

2.2. Theoretical analysis of Table 2 chemical shifts

It should be possible to verify the conclusions of the previous empirical discussion carrying GIAO/DFT calculations. We decided to calculate, as the most representative compounds, **3a**, **3b**, **3c**, **3d**, **3g**, **3j** and **3m**. Initially the structures have been optimised at the B3LYP/6-31G* level and its minimum nature has been confirmed by frequency calculations. A further optimisation has been carried out at the B3LYP/6-311++G** level and these structures have been used to obtain the theoretical absolute chemical shielding with the GIAO method. As this implies in a first step the optimisation (B3LYP/6-31G*), the first result is that of the two conformations of Scheme 3, that of the left side is the only one stable (compound **3b**). The geometrical characteristics of the O–H···O hydrogen bonds in the different compounds are gathered in Table 3.

Table 3. Distance (Å) and angle (°) of the structures optimised at the B3LYP/6-311++G** computational level

Compound	H···O	O–H···O
3a	1.638	148.0
3b	1.653	147.4
3c	1.652	147.4
3d	1.650	147.4
3g	1.646	148.1
3j	1.611	147.7
3m	1.598	149.1

The $\delta\,^{13}C$ are relatively well correlated with the calculated absolute shielding, σ. Although all nuclei of each molecule are calculated, we will limit ourselves to those corresponding to Table 1. For carbon atoms C-α and C-β, Eq. (11) is obtained.

$$\delta^{13}\mathrm{C(ppm)} = 162\ \mathrm{ppm} - 0.63\sigma^{13}\mathrm{C(ppm)}, n = 14, r^2 = 0.96 \quad (11)$$

The slope is far from 1 but the correlation coefficient is acceptable taking into account that the experimental (23 ppm) and calculated (33 ppm) ranges are quite narrow. An analysis of the calculated values similar to Eqs. (9) and (10) is possible but not interesting due to the proportionality between δ and σ (Eq. (11)). The theoretical calculated values do not need an empirical partition into contributing terms: they show that the experimental results are consistent with the optimised geometries and there are no large anomalies. Two points show the largest deviations both C-β carbons: **3b** (2-NO_2) fitted 143.0, experimental 138.8 ($\Delta\delta$=−4.2 ppm) and **3g** (4-NO_2) fitted 138.1, experimental 141.1 ($\Delta\delta$=+3.0 ppm). The NMR spectra have been recorded again and the experimental values do not change: we have no explanation for these differences that reflect some factor not well taken into account by the calculations, a rather unusual observation.

Concerning the ^1H chemical shifts, the CH and the OH cannot be treated together. This is an usual observation: protons linked to heteroatoms are different, not from the calculations, but from the experimental data. The calculations correspond to the isolated molecule and the experimental data are from DMSO-d_6 solutions. Obviously, the solvent plays an important role on the acidic proton.

3. Computational details

The structure of the molecules have been optimised with the hybrid B3LYP functional[45,46] and the 6-31G*[47] using the Gaussian-98 program.[48] At the same computational level, the minimum nature of the structures has been confirmed by frequency calculation. A further geometry optimisation has been carried out at the B3LYP/6-311++G**[49] computational level. The absolute chemical shieldings have been calculated using the GIAO method[50,51] at the B3LYP/6-311++G** level.

4. Experimental

Melting points were measured in a Büchi 535 apparatus and are uncorrected. NMR spectra were recorded on a Bruker DRX 300 spectrometer (300.13 for ^1H and 75.47 MHz for ^{13}C), with DMSO-d_6 as a solvent. Chemical shifts (δ) are reported in ppm and coupling constants (J) in Hz. The internal standard was TMS. Unequivocal ^{13}C assignments were made with the aid of 2D *g*HSQC and *g*HMBC (delays for one bond and long-range J C/H couplings were optimised for 147 and 7 Hz, respectively) experiments. Electron impact (EI, 70 eV) MS were recorded on VG Autospec Q spectrometer. Elemental Analyses were obtained on a Carlo Erba 1108 CHNS analyser. Preparative thin-layer chromatography was performed with Merck silica gel 60 DGF_{254}. Column chromatography was performed with Merck silica gel 60, 70–230 mesh. All other chemicals

and solvents used were obtained from commercial sources and used as received or dried using standard procedures.

4.1. Synthesis of 2′-hydroxychalcone (3a)

An aqueous solution of sodium hydroxide (60%, 160 mL) was added to a methanolic solution (160 mL) of 2′-hydroxyacetophenone (**1a**) (4 mL, 33 mmol). The obtained solution was cooled to room temperature, benzaldehyde (**2a**) (40 mmol) was added and the reaction mixture was stirred for 4 h. After this period, the reaction mixture was poured into a mixture of water (100 mL), ice and hydrochloric acid (pH adjusted to 2). The obtained solid was filtered, taken in chloroform (300 mL) and washed with a 5% aqueous solution of sodium hydrogen carbonate (2×200 mL). The organic layer was collected, dried and evaporated to dryness. The residue was crystallised from ethanol; giving 2′-hydroxychalcone **3a** (75%). Mp 81–83 °C (recrystallised from ethanol, lit.[40] 88 °C). ^{1}H NMR: δ 6.98–7.04 (m, 2H, H-3′ and H-5′), 7.57 (dt, 1H, H-4′, J=1.6, 7.8 Hz), 7.45–7.50 (m, 3H, H-3, H-4 and H-5), 7.84 (d, 1H, H-β, J=15.6 Hz), 7.91–7.93 (m, 1H, H-2,6), 8.05 (d, 1H, H-α, J=15.6 Hz), 8.25 (dd, 1H, H-6′, J=1.6, 8.3 Hz), 12.50 (s, 1H, 2′-O*H*). ^{13}C NMR: δ 117.8 (C-3′), 119.2 (C-5′), 120.9 (C-1′), 121.8 (C-α), 129.0 (C-3,5), 130.9 (C-6′), 129.2 (C-2,6), 134.4 (C-1), 131.0 (C-4), 136.4 (C-4′), 144.9 (C-β), 161.9 (C-2′), 193.7 (C═O).

4.2. Synthesis of 2′-hydroxynitrochalcones 3b–m

Method A. Sodium hydride (0.88 g, 36.5 mmol) was slowly added to a solution of the appropriate 2′-hydroxyacetophenone **1a–d** (16.6 mmol) in dry tetrahydrofuran (10 mL) and the reaction mixture stirred at room temperature for 20 min. After this period the adequate nitrobenzaldehyde **2b–d** (18.3 mmol) dissolved in tetrahydrofuran (10 mL) was added. The solution was stirred, under nitrogen, at room temperature until the disappearance of the starting materials (~8 h). The solution was poured into ice and water, and the pH adjusted to 3 with hydrochloric acid. The obtained solid was removed by filtration, dissolved in chloroform (30 mL) and washed with water (2×20 mL). The organic layer was dried over Na_2SO_4 and evaporated to dryness. In the case of 2′-hydroxynitrochalcones **3b–g**, **3i** and **3l**, the residue was crystallised from ethanol, ethyl acetate or ethanol:acetone. 2′-Hydroxynitrochalcones **3h**, **3j** and **3k** and the corresponding nitroaurones **4h**, **4j** and **4k** have been isolated from the reaction mixture by by column chromatography using different mixtures of chloroform:*n*-hexane as eluent. Finally all the synthesised compounds were recrystallised from ethanol, ethyl acetate or ethanol:acetone, and collected in the following yields: **3b**, 24%; **3c**, 68%; **3d**, 80%; **3e**, 21%; **3f**, 60%; **3g**, 64%; **3h**, 15% and **4h**, 41%; **3i**, 64%; **3j**, 19% and **4j**, 48%; **3k**, 21% and **4k**, 47%; **3l**, 60%.

Method B. This method is similar to method A, except the quantity of the adequate nitrobenzaldehyde **2b–d**, which was 33.2 mmol. The obtained yields were as follows: **3b**, 44%; **3c**, 75%; **3d**, 89%; **3e**, 40%; **3f**, 72%; **3g**, 74%; **4h**, 89%; **3i**, 81%; **4j**, 74%; **4k**, 78%; **3l**, 78%; **3m**, 17% and **4m**, 27%.

4.2.1. 2′-Hydroxy-2-nitrochalcone (3b). Mp 160.2–161.0 °C (recrystallised from ethanol). ^{1}H NMR: δ 7.00 (d, 2H, H-3′ and H-5′, J=7.9 Hz), 7.58 (dt, 1H, H-4′, J=1.7, 7.9 Hz), 7.71 (dt, 1H, H-4, J=1.4, 8.2 Hz), 7.84 (dt, 1H, H-5, J=1.2, 8.2 Hz), 7.98 (d, 1H, H-α, J=15.4 Hz), 8.06 (d, 1H, H-β, J=15.4 Hz), 8.11 (dd, 1H, H-3, J=1.2, 8.2 Hz), 8.16 (dd, 1H, H-6, J=1.4, 8.2 Hz), 8.19 (dd, 1H, H-6′, J=1.7, 7.9 Hz), 12.11 (s, 1H, 2′-O*H*). ^{13}C NMR: δ 117.8 (C-3′), 119.4 (C-5′), 121.1 (C-1′), 126.6 (C-α), 124.8 (C-3), 131.1 (C-6′), 129.6 (C-1 and C-6), 131.3 (C-4), 133.9 (C-5), 136.5 (C-4′), 138.8 (C-β), 148.8 (C-2), 161.5 (C-2′), 193.0 (C═O). EI-MS: *m*/*z* (rel. intensity) 269 ($M^{+\cdot}$, 10), 252 (55), 222 (38), 165 (7), 132 (5), 121 (100), 102 (8), 93 (18), 77 (10), 65 (32). IR ν 1643, 1589, 1513, 1438, 1342, 1267, 1205, 1018 cm^{-1}. Anal. calcd for $C_{15}H_{11}NO_4$: C 66.91, H 4.09, N 5.20. Found: C 66.70, H 4.03, N 5.12.

4.2.2. 2′-Hydroxy-3-nitrochalcone (3c). Mp 163.5–163.9 °C (recrystallised from ethyl acetate, lit.[40] 163.0 °C). ^{1}H NMR: δ 7.02 (d, 2H, H-3′ and H-5′, J=8.0 Hz), 7.58 (dt, 1H, H-4′, J=1.4, 8.0 Hz), 7.75 (t, 1H, H-5, J=9.0 Hz), 7.92 (d, 1H, H-β, J=15.6 Hz), 8.23 (d, 1H, H-α, J=15.6 Hz), 8.27 (d, 1H, H-6, J=9.0 Hz), 8.31–8.35 (m, 2H, H-4 and H-6′), 8.78 (d, 1H, H-2, J=1.6 Hz), 12.35 (s, 1H, 2′-O*H*). ^{13}C NMR: δ 117.7 (C-3′), 119.2 (C-5′), 120.7 (C-1′), 123.1 (C-2), 124.7 (C-α), 124.9 (C-6), 130.3 (C-5), 131.1 (C-6′), 135.2 (C-4), 136.3 (C-1), 136.5 (C-4′), 142.0 (C-β), 148.4 (C-3), 161.8 (C-2′), 193.3 (C═O). EI-MS: *m*/*z* (rel. intensity) 269 ($M^{+\cdot}$, 60), 268 (44), 252 (10), 222 (9), 194 (8), 176 (7), 152 (3), 147 (100), 121 (55), 102 (22), 93 (15), 76 (12), 65 (30). IR ν 1644, 1589, 1523, 1486, 1438, 1357, 1288, 1211, 1157 cm^{-1}. Anal. calcd for $C_{15}H_{11}NO_4$: C 66.91, H 4.09, N 5.20. Found: C 66.78, H 3.97, N 5.12.

4.2.3. 2′-Hydroxy-4-nitrochalcone (3d). Mp 141.8–142.1 °C (recrystallised from ethyl acetate, lit.[40] 206–207 °C, lit.[37] 153–154 °C). ^{1}H NMR: δ 6.99–7.04 (m, 2H, H-3′ and H-5′), 7.58 (dt, 1H, H-4′, J=1.5, 7.8 Hz), 7.86 (d, 1H, H-β, J=15.5 Hz), 8.14 (d, 2H, H-2,6, J=9.1 Hz), 8.15 (d, 1H, H-α, J=15.5 Hz), 8.20 (dd, 1H, H-6′, J=1.5, 8.3 Hz), 8.27 (d, 2H, H-3,5, J=9.1 Hz), 12.15 (s, 1H, 2′-O*H*). ^{13}C NMR: δ 117.6 (C-3′), 119.1 (C-5′), 120.9 (C-1′), 123.8 (C-3,5), 126.2 (C-α), 129.8 (C-2,6), 130.9 (C-6′), 136.5 (C-4′), 140.8 (C-1), 141.3 (C-β), 148.1 (C-4), 161.5 (C-2′), 193.1 (C═O). EI-MS: *m*/*z* (rel. intensity) 269 ($M^{+\cdot}$, 82), 268 (60), 252 (16), 222 (15), 194 (6), 176 (10), 165 (13), 147 (100), 121 (62), 102 (19), 93 (15), 93 (17), 76 (9), 65 (27). IR ν 1644, 1590, 1515, 1490, 1440, 1340, 1270, 1209, 1157 cm^{-1}. Anal. calcd for $C_{15}H_{11}NO_4$: C 66.91, H 4.09, N 5.20. Found: C 66.64, H 3.97, N 5.17.

4.2.4. 2′-Hydroxy-4′-methoxy-2-nitrochalcone (3e). Mp 149.9–150.3 °C (recrystallised from ethanol). ^{1}H NMR: δ 3.87 (s, 3H, OC*H*$_3$), 6.55 (d, 1H, H-3′, J=2.5 Hz), 6.59 (dd, 1H, H-5′, J=2.5, 9.0 Hz), 7.72 (ddd, 1H, H-4, J=1.2, 7.6, 8.0 Hz), 7.85 (ddd, 1H, H-5, J=1.0, 7.6, 7.7 Hz), 8.00 (d, 1H, H-α, J=15.5 Hz), 8.07 (d, 1H, H-β, J=15.5 Hz), 8.11 (dd, 1H, H-3, J=1.0, 8.0 Hz), 8.22 (dd, 1H, H-6, J=1.2, 7.7 Hz), 8.27 (d, 1H, H-6′, J=9.0 Hz), 13.13 (s, 1H, 2′-O*H*). ^{13}C NMR: δ 55.9 (O*C*H$_3$), 101.0 (C-3′), 107.7 (C-5′), 113.9 (C-1′), 124.8 (C-3), 125.8 (C-α), 129.6 (C-1), 129.7 (C-6), 131.2 (C-4), 133.0 (C-6′), 133.8 (C-5), 138.3 (C-β), 148.8 (C-2), 165.7 (C-2′), 166.4 (C-4′), 191.3 (C═O). EI-MS: *m*/*z* (rel. intensity) 299 ($M^{+\cdot}$, 22), 282 (54), 252 (46), 226 (10),

177 (9), 164 (8), 151 (100), 120 (5), 108 (12), 102 (7), 95 (11), 77 (6), 65 (7). IR ν 1639, 1579, 1517, 1344, 1228, 1201, 1135 cm^{-1}. Anal. calcd for $C_{16}H_{13}NO_5$: C 64.21, H 4.35, N 4.68. Found: C 64.12, H 4.34, N 4.60.

4.2.5. 2′-Hydroxy-4′-methoxy-3-nitrochalcone (3f). Mp 177.6–178.3 °C (recrystallised from ethyl acetate, lit.[52] 172–173°C). ^{1}H NMR: δ 3.85 (s, 3H, OCH_3), 6.52 (d, 1H, H-3′, J=2.4 Hz), 6.58 (dd, 1H, H-5′, J=2.4, 9.0 Hz), 7.75 (t, 1H, H-5, J=8.0 Hz), 7.91 (d, 1H, H-β, J=15.7 Hz), 8.22 (d, 1H, H-α, J=15.7 Hz), 8.27 (dd, 1H, H-6′, J=2.4, 9.0 Hz), 8.31–8.35 (m, 2H, H-4 and H-6), 8.80 (br s, 1H, H-2), 13.31 (s, 1H, 2′-O*H*). ^{13}C NMR: δ 55.9 (O*C*H$_3$), 100.9 (C-3′), 107.7 (C-5′), 113.9 (C-1′), 123.2 (C-2), 124.1 (C-α), 124.9 (C-6), 130.4 (C-5), 133.1 (C-6′), 135.4 (C-4), 136.3 (C-1), 141.6 (C-β), 148.5 (C-3), 165.9 (C-2′), 166.3 (C-4′), 191.7 (C═O). EI-MS: *m*/*z* (rel. intensity) 299 ($M^{+\cdot}$, 100), 298 (38), 282 (8), 252 (6), 224 (10), 177 (97), 151 (53), 120 (9), 102 (9), 95 (7), 76 (5). IR ν 1641, 1581, 1527, 1438, 1353, 1284, 1230, 1132 cm^{-1}. Anal. calcd for $C_{16}H_{13}NO_5$: C 64.21, H 4.35, N 4.68. Found: C 63.88, H 4.33, N 4.61.

4.2.6. 2′-Hydroxy-4′-methoxy-4-nitrochalcone (3g). Mp 191.8–192.7°C (recrystallised from ethyl acetate, lit.[52] 194–195 °C). ^{1}H NMR: δ 3.86 (s, 3H, OCH_3), 6.54 (d, 1H, H-3′, J=2.4 Hz), 6.59 (dd, 1H, H-5′, J=2.4, 9.0 Hz), 7.88 (d, 1H, H-β, J=15.6 Hz), 8.18 (d, 2H, H-2,6, J=8.7 Hz), 8.20 (d, 1H, H-α, J=15.5 Hz), 8.29 (d, 2H, H-3,5, J=8.7 Hz), 8.30 (d, 1H, H-6′, J=9.0 Hz), 13.23 (s, 1H, 2′-O*H*). ^{13}C NMR: δ 55.9 (O*C*H$_3$), 101.0 (C-3′), 107.7 (C-5′), 114.0 (C-1′), 124.0 (C-3,5), 125.5 (C-α), 130.1 (C-2,6), 133.0 (C-6′), 141.0 (C-1), 141.1 (C-β), 148.1 (C-4), 165.8 (C-2′), 166.4 (C-4′), 191.4 (C═O). EI-MS: *m*/*z* (rel. intensity) 299 ($M^{+\cdot}$, 82), 298 (46), 282 (10), 271 (11), 252 (12), 224 (6), 210 (3), 177 (100), 165 (7), 151 (64), 130 (5), 102 (14), 95 (11), 76 (9). IR ν 1637, 1589, 1509, 1340, 1287, 1224, 1209, 1132 cm^{-1}. Anal. calcd for $C_{16}H_{13}NO_5$: C 64.21, H 4.35, N 4.68. Found: C 64.11, H 4.38, N 4.61.

4.2.7. 2′-Hydroxy-6′-methoxy-2-nitrochalcone (3h). Mp 180.2–181.4 °C (recrystallised from acetone:ethanol). ^{1}H NMR: δ 3.76 (s, 3H, OCH_3), 6.55 (d, 1H, H-3′, J=8.3 Hz), 6.58 (d, 1H, H-5′, J=8.3 Hz), 7.15 (d, 1H, H-α, J=15.9 Hz), 7.27 (t, 1H, H-4′, J=8.3 Hz), 7.64 (d, 1H, H-β, J=15.9 Hz), 7.67 (ddd, 1H, H-4, J=1.3, 7.6, 8.1 Hz), 7.78 (t, 1H, H-5, J=7.6 Hz), 7.97 (d, 1H, H-6, J=7.6 Hz), 8.06 (dd, 1H, H-3, J=1.0, 8.1 Hz), 10.41 (s, 1H, 2′-O*H*). ^{13}C NMR: δ 55.8 (O*C*H$_3$), 102.3 (C-5′), 109.0 (C-3′), 115.2 (C-1′), 124.8 (C-3), 129.2 (C-6), 129.6 (C-1), 131.0 (C-4), 132.3 (C-4′ and C-α), 134.0 (C-5), 138.2 (C-β), 148.5 (C-2), 157.2 (C-2′), 158.3 (C-6′), 194.0 (C═O). EI-MS: *m*/*z* (rel. intensity) 299 ($M^{+\cdot}$, 100), 282 (80), 252 (58), 177 (10), 164 (11), 136 (21), 108 (20), 77 (10), 65 (16). IR ν 1633, 1583, 1529, 1473, 1454, 1351, 1236, 1205, 1085 cm^{-1}. Anal. calcd for $C_{16}H_{13}NO_5$: C 64.21, H 4.35, N 4.68. Found: C 64.17, H 4.29, N 4.70.

4.2.8. 2′-Hydroxy-6′-methoxy-3-nitrochalcone (3i). Mp 137.0–138.6 °C (recrystallised from ethyl acetate). ^{1}H NMR: δ 3.74 (s, 3H, OCH_3), 6.55 (d, 1H, H-3′, J=8.3 Hz), 6.58 (d, 1H, H-5′, J=8.3 Hz), 7.27 (t, 1H, H-4′, J=8.3 Hz), 7.34 (d, 1H, H-α, J=16.1 Hz), 7.48 (d, 1H, H-β, J=16.1 Hz), 7.69 (t, 1H, H-5, J=8.0 Hz), 8.19 (d, 1H, H-6, J=8.0 Hz), 8.23 (dd, 1H, H-4, J=1.8, 8.0 Hz), 8.51 (t, 1H, H-2, J=1.8 Hz), 10.42 (s, 1H, 2′-O*H*). ^{13}C NMR: δ 55.9 (O*C*H$_3$), 102.4 (C-5′), 109.1 (C-3′), 115.7 (C-1′), 123.3 (C-2), 124.7 (C-4), 130.5 (C-5), 131.0 (C-α), 132.2 (C-4′), 134.3 (C-6), 136.4 (C-1), 140.9 (C-β), 148.4 (C-3), 157.0 (C-2′), 158.3 (C-6′), 194.0 (C═O). EI-MS: *m*/*z* (rel. intensity) 299 ($M^{+\cdot}$, 55), 298 (39), 282 (7), 252 (6), 224 (5), 210 (3), 177 (100), 162 (7), 151 (33), 136 (8), 107 (9), 102 (11). IR ν 1635, 1583, 1529, 1475, 1436, 1353, 1238, 1209, 1087 cm^{-1}. Anal. calcd for $C_{16}H_{13}NO_5$: C 64.21, H 4.35, N 4.68. Found: C 64.13, H 4.39, N 4.61.

4.2.9. 2′-Hydroxy-6′-methoxy-4-nitrochalcone (3j). Mp 160.3–161.0 °C (recrystallised from acetone:ethanol). ^{1}H NMR: δ 3.75 (s, 3H, OCH_3), 6.55 (d, 1H, H-3′, J=8.3 Hz), 6.59 (d, 1H, H-5′, J=8.3 Hz), 7.28 (t, 1H, H-4′, J=8.3 Hz), 7.35 (d, 1H, H-α, J=16.2 Hz), 7.45 (d, 1H, H-β, J=16.2 Hz), 8.00 (d, 2H, H-2,6, J=8.7 Hz), 8.23 (d, 2H, H-3,5, J=8.7 Hz), 10.41 (s, 1H, 2′-O*H*). ^{13}C NMR: δ 55.8 (O*C*H$_3$), 102.4 (C-5′), 109.0 (C-3′), 115.5 (C-1′), 124.0 (C-3,5), 129.6 (C-2,6), 132.0 (C-α), 132.2 (C-4′), 140.3 (C-β), 141.0 (C-1), 148.0 (C-4), 157.1 (C-2′), 158.2 (C-6′), 194.0 (C═O). EI-MS: *m*/*z* (rel. intensity) 299 ($M^{+\cdot}$, 70), 298 (56), 282 (7), 252 (9), 177 (100), 162 (6) 151 (40), 136 (10), 130 (5), 122 (7), 107 (8), 102 (12). IR ν 1633, 1581, 1515, 1440, 1344, 1226, 1133 cm^{-1}. Anal. calcd for $C_{16}H_{13}NO_5$: C 64.21, H 4.35, N 4.68. Found: C 64.22, H 4.33, N 4.77.

4.2.10. 2′-Hydroxy-4′,6′-dimethoxy-2-nitrochalcone (3k). Mp 173.0–173.9 °C (recrystallised from acetone:ethanol). ^{1}H NMR: δ 3.86 (s, 3H, OCH_3), 3.90 (s, 3H, OCH_3), 6.16 (d, 1H, H-3′, J=2.2 Hz), 6.18 (d, 1H, H-5′, J=2.2 Hz), 7.66–7.72 (m, 1H, H-4), 7.69 (d, 1H, H-α, J=15.6 Hz), 7.81 (d, 1H, H-5, J=7.5 Hz), 7.87 (d, 1H, H-β, J=15.6 Hz), 7.95 (d, 1H, H-6, J=7.5 Hz), 8.10 (dt, 1H, H-3, J=0.9, 8.1 Hz), 13.15 (s, 1H, 2′-O*H*). ^{13}C NMR: δ 55.9 (O*C*H$_3$), 56.4 (O*C*H$_3$), 91.3 (C-5′), 94.0 (C-3′), 106.3 (C-1′), 124.9 (C-3), 129.3 (C-6), 130.0 (C-1), 131.0 (C-4), 131.8 (C-α), 134.1 (C-5), 136.6 (C-β), 148.7 (C-2), 162.1 (C-6′), 165.5 (C-2′), 166.0 (C-4′), 191.9 (C═O). EI-MS: *m*/*z* (rel. intensity) 329 ($M^{+\cdot}$, 11), 312 (27), 282 (24), 253 (3), 207 (9), 194 (19), 181 (100), 166 (5), 138 (8), 102 (4), 95 (7), 69 (6). IR ν 1631, 1581, 1531, 1438, 1347, 1270, 1155 cm^{-1}. Anal. calcd for $C_{17}H_{15}NO_6$: C 62.01, H 4.56, N 4.26. Found: C 62.32, H 4.56, N 4.19.

4.2.11. 2′-Hydroxy-4′,6′-dimethoxy-3-nitrochalcone (3l). Mp 169.1–170.0 °C (recrystallised from ethyl acetate). ^{1}H NMR: δ 3.82 (s, 3H, OCH_3), 3.89 (s, 3H, OCH_3), 6.14 (d, 1H, H-3′, J=2.1 Hz), 6.16 (d, 1H, H-5′, J=2.1 Hz), 7.71 (d, 1H, H-β, J=15.6 Hz), 7.73 (t, 1H, H-5, J=8.0 Hz), 7.85 (d, 1H, H-α, J=15.6 Hz), 8.20 (d, 1H, H-6, J=8.0 Hz), 8.25 (dd, 1H, H-4, J=1.5, 8.0 Hz), 8.51 (br s, 1H, H-2), 13.22 (s, 1H, 2-O*H*). ^{13}C NMR: δ 55.7 (O*C*H$_3$), 56.0 (O*C*H$_3$), 91.2 (C-5′), 94.0 (C-3′), 106.4 (C-1′), 123.1 (C-2), 124.5 (C-4), 130.4 (C-α), 130.6 (C-5), 134.0 (C-6), 136.8 (C-1), 139.3 (C-β), 148.4 (C-3), 162.0 (C-6′), 165.4 (C-2′), 165.9 (C-4′), 192.1 (C═O). EI-MS: *m*/*z* (rel. intensity) 329 ($M^{+\cdot}$, 61), 328 (39), 312 (13), 301 (15), 282 (5), 254 (9), 207 (100), 181 (46), 166 (7), 138 (8), 102 (10), 95 (6), 69 (7). IR ν 1635, 1581, 1531, 1438, 1347, 1270, 1218, 1159 cm^{-1}. Anal. calcd for $C_{17}H_{15}NO_6$: C 62.01, H 4.56, N 4.26. Found: C 62.18, H 4.51, N 4.13.

4.2.12. 2′-Hydroxy-4′,6′-dimethoxy-4-nitrochalcone (3m). Mp 235.0–236.4 °C (recrystallised from acetone: ethanol). ^{1}H NMR: δ 3.84 (s, 3H, OCH_3), 3.91 (s, 3H, OCH_3), 6.17 (d, 1H, H-3′, J=1.9 Hz), 6.19 (d, 1H, H-5′, J=1.9 Hz), 7.59 (d, 1H, H-β, J=15.7 Hz), 7.70 (d, 1H, H-α, J=15.7 Hz), 8.02 (d, 2H, H-2,6, J=8.6 Hz), 8.29 (d, 2H, H-3,5, J=8.6 Hz), 13.21 (s, 1H, 2′-OH). ^{13}C NMR: δ 55.8 (OCH_3), 56.4 (OCH_3), 91.3 (C-5′), 93.9 (C-3′), 106.4 (C-1′), 124.1 (C-3,5), 129.5 (C-2,6), 131.7 (C-α), 139.0 (C-β), 141.4 (C-1), 148.0 (C-4), 162.0 (C-6′), 165.4 (C-2′), 166.0 (C-4′), 192.0 (C=O). EI-MS: m/z (rel. intensity) 329 ($M^{+\cdot}$, 69), 328 (32), 312 (8), 301 (20), 282 (5), 255 (3), 207 (100), 181 (53), 166 (9), 125 (10), 97 (21), 71 (25), 57 (35). IR ν 1639, 1583, 1519, 1438, 1342, 1216, 1160 cm^{-1}. Anal. calcd for $C_{17}H_{15}NO_6$: C 62.01, H 4.56, N 4.26. Found: C 62.23, H 4.49, N 4.31.

4.2.13. 4-Methoxy-2′-nitroaurone (4h). Mp 194.0–195.0 °C (recrystallised from ethanol). ^{1}H NMR: δ 3.95 (s, 3H, OCH_3), 6.87 (d, 1H, H-5, J=8.3 Hz), 6.97 (d, 1H, H-7, J=8.3 Hz), 7.00 (s, 1H, H-α), 7.67 (t, 1H, H-4′, J=7.9 Hz), 7.72 (t, 1H, H-6, J=8.3 Hz), 7.85 (t, 1H, H-5′, J=7.9 Hz), 8.10 (d, 1H, H-3′, J=7.9 Hz), 8.19 (d, 1H, H-6′, J=7.9 Hz). ^{13}C NMR: δ 56.2 (OCH_3), 104.0 (C-α), 104.4 (C-7), 106.7 (C-5), 109.4 (C-9), 124.8 (C-3′), 125.9 (C-1′), 130.1 (C-4′), 131.9 (C-6′), 133.3 (C-5′), 139.7 (C-6), 147.7 (C-2), 148.7 (C-2′), 158.2 (C-8), 166.3 (C-4), 180.4 (C=O). EI-MS: m/z (rel. intensity) 297 ($M^{+\cdot}$, 7), 280 (22), 267 (25), 251 (71), 236 (100), 221 (13), 208 (47), 180 (47), 165 (48). IR ν 1708, 1656, 1602, 1519, 1496, 1347, 1251, 1193, 1074, 794 cm^{-1}. Anal. calcd for $C_{16}H_{11}NO_5$: C 64.65, H 3.70, N 4.71. Found: C 64.45, H 3.67, N 4.62.

4.2.14. 4-Methoxy-4′-nitroaurone (4j). Mp 201.5–202.3 °C (recrystallised from ethanol). ^{1}H NMR: δ 3.95 (s, 3H, OCH_3), 6.89 (s, 1H, H-α), 7.04 (d, 1H, H-7, J=8.1 Hz), 7.74 (t, 1H, H-6, J=8.1 Hz), 7.88 (d, 1H, H-5, J=8.1 Hz), 8.16 (d, 2H, H-2′,6′, J=8.8 Hz), 8.28 (d, 2H, H-3′,5′, J=8.8 Hz). ^{13}C NMR: δ 56.1 (OCH_3), 104.4 (C-7), 106.7 (C-5), 107.4 (C-α), 109.3 (C-9), 123.6 (C-3′,5′), 131.5 (C-2′,6′), 138.5 (C-1′), 139.5 (C-6), 146.9 (C-4′), 147.8 (C-2), 158.1 (C-8), 166.2 (C-4), 180.5 (C=O). EI-MS: m/z (rel. intensity) 297 ($M^{+\cdot}$, 100), 298 (14), 280 (3), 268 (17), 236 (8), 221 (28), 165 (15), 139 (4), 107 (9), 89 (16), 76 (26), 63 (21). IR ν 1704, 1654, 1604, 1494, 1336, 1255, 1078, 796 cm^{-1}. Anal. calcd for $C_{16}H_{11}NO_5$: C 64.65, H 3.70, N 4.71. Found: C 64.46, H 3.66, N 4.71.

4.2.15. 4,6-Dimethoxy-2′-nitroaurone (4k). Mp 221.7–222.0 °C (recrystallised from ethanol). ^{1}H NMR: δ 3.93 (s, 6H, OCH_3), 6.40 (d, 1H, H-5, J=1.5 Hz), 6.68 (d, 1H, H-7, J=1.5 Hz), 6.95 (s, 1H, H-α), 7.68 (t, 1H, H-4′, J=7.8 Hz), 7.86 (t, 1H, H-5′, J=7.8 Hz), 8.13 (d, 1H, H-3′, J=7.8 Hz), 8.19 (d, 1H, H-6′, J=7.8 Hz). ^{13}C NMR: δ 56.4 (OCH_3), 56.6 (OCH_3), 90.2 (C-7), 94.7 (C-5), 103.4 (C-α), 103.8 (C-9), 124.4 (C-3′), 126.3 (C-1′), 130.1 (C-4′), 132.0 (C-6′), 133.6 (C-5′), 148.7 (C-2′), 148.9 (C-2), 159.7 (C-4), 169.1 (C-8), 169.6 (C-6), 180.1 (C=O). EI-MS: m/z (rel. intensity) 327 ($M^{+\cdot}$, 52), 310 (21), 297 (22), 281 (100), 266 (25), 237 (31), 223 (40), 208 (20), 195 (51). IR ν 1704, 1621, 1594, 1517, 1481, 1346, 1247, 1224, 1160, 1097, 825 cm^{-1}. Anal. calcd for $C_{17}H_{13}NO_6$: C 62.39, H 3.98, N 4.28. Found: C 62.47, H 3.99, N 4.38.

4.2.16. 4,6-Dimethoxy-4′-nitroaurone (4m). Mp 266.7–261.9 °C (recrystallised from ethanol). ^{1}H NMR: δ 3.95 (s, 3H, OCH_3), 3.98 (s, 3H, OCH_3), 6.17 (d, 1H, H-5, J=1.7 Hz), 6.43 (d, 1H, H-7, J=1.7 Hz), 6.75 (s, 1H, H-α), 7.99 (d, 2H, H-2′,6′, J=8.8 Hz), 8.26 (d, 2H, H-3′,5′, J=8.8 Hz). ^{13}C NMR: δ 56.3 (OCH_3), 56.4 (OCH_3), 89.6 (C-7), 94.4 (C-5), 104.7 (C-9), 107.3 (C-α), 123.9 (C-3′,5′), 131.4 (C-2′,6′), 139.1 (C-1′), 147.3 (C-4′), 149.6 (C-2), 159.7 (C-4), 169.1 (C-8), 169.6 (C-6), 180.1 (C=O). EI-MS: m/z (rel. intensity) 327 ($M^{+\cdot}$, 100), 326 (25), 310 (7), 298 (38), 251 (16), 180 (8), 137 (9), 106 (12), 85 (11), 69 (20), 57 (22). IR ν 1695, 1664, 1617, 1585, 1506, 1421, 1338, 1157, 1089, 827 cm^{-1}. Anal. calcd for $C_{17}H_{13}NO_6$: C 62.39, H 3.98, N 4.28. Found: C 62.39, H 4.00, N 4.46.

4.2.17. 4-Nitrobenzyl alcohol. ^{1}H NMR: δ 4.84 (s, 2H, CH_2), 7.54 (d, 2H, H-2,6, J=8.7 Hz), 8.22 (d, 2H, H-3,5, J=8.7 Hz). EI-MS: m/z (rel. intensity) 153 ($M^{+\cdot}$, 54), 137 (100), 120 (45), 92 69), 83 (11), 71 (27), 57 (37).

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