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Article

A Complete and Unambiguous ^{1}H and ^{13}C NMR Signals Assignment of *para*-Naphthoquinones, *ortho*- and *para*-Furanonaphthoquinones

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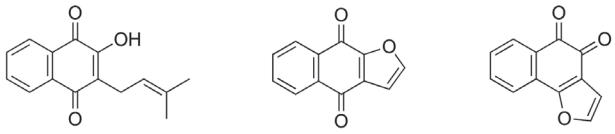
A complete and unambiguous assignment of ^{1}H and ^{13}C nuclear magnetic resonance (NMR) signals of 29 naphthoquinones is reported on the basis of one- and two-dimensional NMR techniques (^{1}H, ^{13}C, ^{1}H-^{1}H correlated spectroscopy (COSY) and ^{1}H-^{13}C heteronuclear multiple-bond correlation (HMBC)). This is the first report distinguishing data between *para*-naphthoquinones, *ortho*- and *para*-furanonaphthoquinones isomers.

Keywords: 1D and 2D NMR, ^{1}H NMR and ^{13}C NMR, naphthoquinones, furanonaphthoquinones

Introduction

Quinones are conjugated cyclic diones oxidatively derived from aromatic compounds. Natural quinones are widespread as plant and microorganisms secondary metabolites disclosing several biological effects such as antitumor, trypanocidal, anti-inflamatory, antifungal and leishmanicidal.[1-7] Lapachol (**1**, Figure 1), a hydroxy prenylnaphthoquinone, was first isolated from *Tabebuia avellanedae*, in 1882, by Paternó.[8] Since then, it has been found in several families as Verbenaceae and Proteaceae, being highly frequent in the Family Bignoniaceae, mainly in representatives of the *Handroanthus* genus (*Tabebuia*) of which some are known as "ipês" in Brazil.[8] Semi-synthetic derivatives and analogs of lapachol are described with antitumor, anti-inflammatory and anti-protozoa activities.[5,9-15] Furanonaphthoquinones such naphtho[2,3-*b*]furan-4,9-dione (**2**), and naphtho[1,2-*b*]furan-4,5-dione (**3**) (Figure 1) are also found in Bignoniaceae and disclose several important biological activities, such as anticancer, antibacterial and anti-inflammatory.[16]

Recently, we described the synthesis of a series of naphthoquinones represented by 2-hydroxy-3-(1'-alkenyl)-1,4-naphthoquinones (NQs) (**4a-h**), *ortho*-furano-naphthoquinones (*ortho*-FNQs) (**5a-h**) and *para*-furano-naphthoquinones (*para*-FNQs) (**6a-h**) (Figure 2) that were assayed for antiplasmodial activity against the chloroquine-resistant *Plasmodium falciparum* W2 strain and for cytotoxicity to the human hepatoma cell culture (HepG2). The furanonaphthoquinones (FNQs) were highlighted as interesting new hits of interest for antimalarial drug development.[17]



(**1**) (**2**) (**3**)

Figure 1. Structures of lapachol (**1**), naphtho[2,3-*b*]furan-4,9-dione (**2**) and naphtho[1,2-*b*]furan-4,5-dione (**3**).

Spectral analysis of this naphthoquinones were explored aiming to distinguish between the three structural classes: NQs, *ortho*- and *para*-FNQs as well as the distinction between the two groups of isomeric furanonaphthoquinones. Some data on nuclear magnetic resonance (NMR) spectra of NQs, *ortho*- and *para*-FNQs are found in the literature, although most of them are restricted to only one isomer, *ortho*- or *para*-FNQ[2,3,18-21] and previous assignments are revised here.[6,22] No references were found correlating NQs and FNQs data, as well as no data that allowed the differentiation between *ortho*- and *para*-FNQs isomers.

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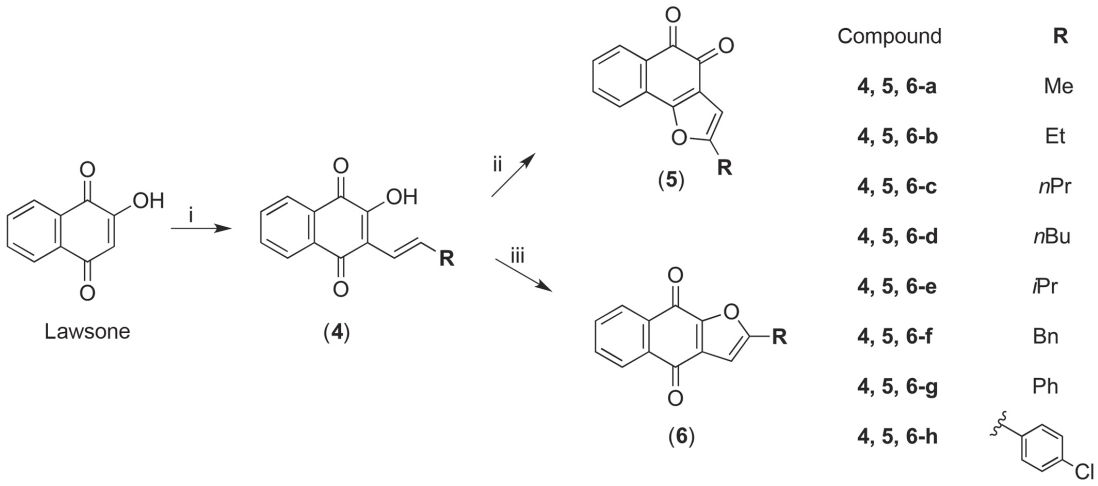

Figure 2. Synthesis of 2-hydroxy-3-(1'-alkenyl)-1,4-naphthoquinones (**4a-h**), *ortho*- (**5a-h**) and *para*-furanonaphthoquinones (**6a-h**). Reagents and conditions: (i) CH_3COOH, RCH_2CHO, $HCl_{conc.}$, reflux 40 min; (ii) (a) $Hg(OAc)_2$, CH_3COOH, room temperature (rt), 30 min, (b) HCl 2 mol L^{-1}, EtOH, reflux 15 min; (iii) (a) $Hg(OAc)_2$, CH_3COOH, rt, 30 min, (b) $HCl_{conc.}$, EtOH, reflux 3 h (adapted from reference 17).

In this article we report signals assignments for lapachol (**1**) and all compounds of the series **4**, **5** and **6** (Figure 2). A detailed discussion is presented for compounds 2-hydroxy-3-(1'-hexenyl)-1,4-naphthoquinone (**4d**), *ortho*-2-butylnaphtho[1,2-*b*]furan-4,5-dione (**5d**) and *para*-2 butylnaphtho[2,3-*b*]furan-4,9-dione (**6d**). A complete and unambiguous assignment of ^1H and ^{13}C NMR chemical shifts was based in a combination of one- and two-dimensional techniques (^1H, ^{13}C, ^1H-^1H correlated spectroscopy (COSY) and ^1H-^{13}C heteronuclear multiple-bond correlation (HMBC)).

Experimental

The synthesis have been published elsewhere.[17] The 2-hydroxy-3-(1'-alkenyl)-1,4-naphthoquinones (**4a**-**h**) were obtained by aldol condensation between commercial lawsone (Sigma-Aldrich) and different aldehydes (Figure 2). The furanonaphthoquinones (**5a**-**h** and **6a**-**h**) were formed by oxidative cyclization of the 2-hydroxy-3-(1'-alkenyl)-1,4-naphthoquinone with $Hg(OAc)_2$ (Figure 2).

The NMR experiments were performed in $CDCl_3$ solution at 25 ºC on a Bruker Avance DRX400 spectrometer. Tetramethylsilane (TMS) was used as internal reference and the program the Bruker's TopSpin 3.5™ software package was used to process the NMR row data.

The ^1H spectra were acquired using the spectrometer frequency of 400 MHz, spectrum resolution of 0.12 Hz, zg 30 pulse program with ns 16, d1 1s, acquisition time 4.0894465 s and spectral width 20.0264 ppm. The phase and baseline were manually corrected and the TMS signal calibrated at 0.00 ppm. Integration regions of signal were selected manually.

The ^{13}C spectra were acquired using the spectrometer frequency of 100 MHz, spectrum resolution of 0.73 Hz, zgpg 30 pulse program with ns 1024, d1 2s, acquisition time 0.6815744 s and spectral width 238.9086 ppm.

The ^1H-^1H COSY contour maps were obtained with a 2 s relaxation delay, acquisition time 0.1024000 s and spectral width 24.9930 ppm. The ^1H-^{13}C HMBC contour maps were recorded with a 1.5 s relaxation delay in a 24.9930 ppm spectral width in F2 and 260.0000 ppm in F1 and acquisition time 0.1024000 s (F2) and 0.0048928 s (F1).

Results and Discussion

The ^1H and ^{13}C NMR spectra of all the naphthoquinones were registered at 400 and 100 MHz, respectively. Signals assignments were based on chemical shifts (δ, ppm) of ^1H and ^{13}C, on the multiplicity patterns of proton resonances depicted by the *J* couplings (Hz), and on data of homonuclear ^1H-^1H COSY and heteronuclear ^1H-^{13}C HMBC. The NMR experiments and the signals assignments were made for all compounds (**1**, **4a**-**h**, **5a**-**h** and **6a**-**h**), and the naphthoquinones **4d**, **5d** and **6d** were focused for illustrating the ^1H and ^{13}C assignments.

The hydrogen signals in the alkenyl chain of compound **4d** (Figure 3) were assigned in the ^1H NMR spectrum and confirmed by the ^1H-^1H COSY (Figure 4). A multiplet at δ 7.10-7.03 corresponding to H-2' that couple to H-1' (δ 6.60, d, $^3J_{H,H}$ 16.00), and to H-3' (δ 2.30, q, 2H, $^3J_{H,H}$ 7.00). H-4' and H-5' are disclosed as a quintet at δ 1.49 (2H, $^3J_{H,H}$ 7.20) and a sextet at δ 1.38 (2H, $^3J_{H,H}$ 7.20), respectively. As expected, H-6' appears as a triplet at δ 0.93 (3H, $^3J_{H,H}$ 7.20).

To assess more information about the structure of naphthoquinone **4d**, an ^1H-^{13}C HMBC (Figures 5 and 6)

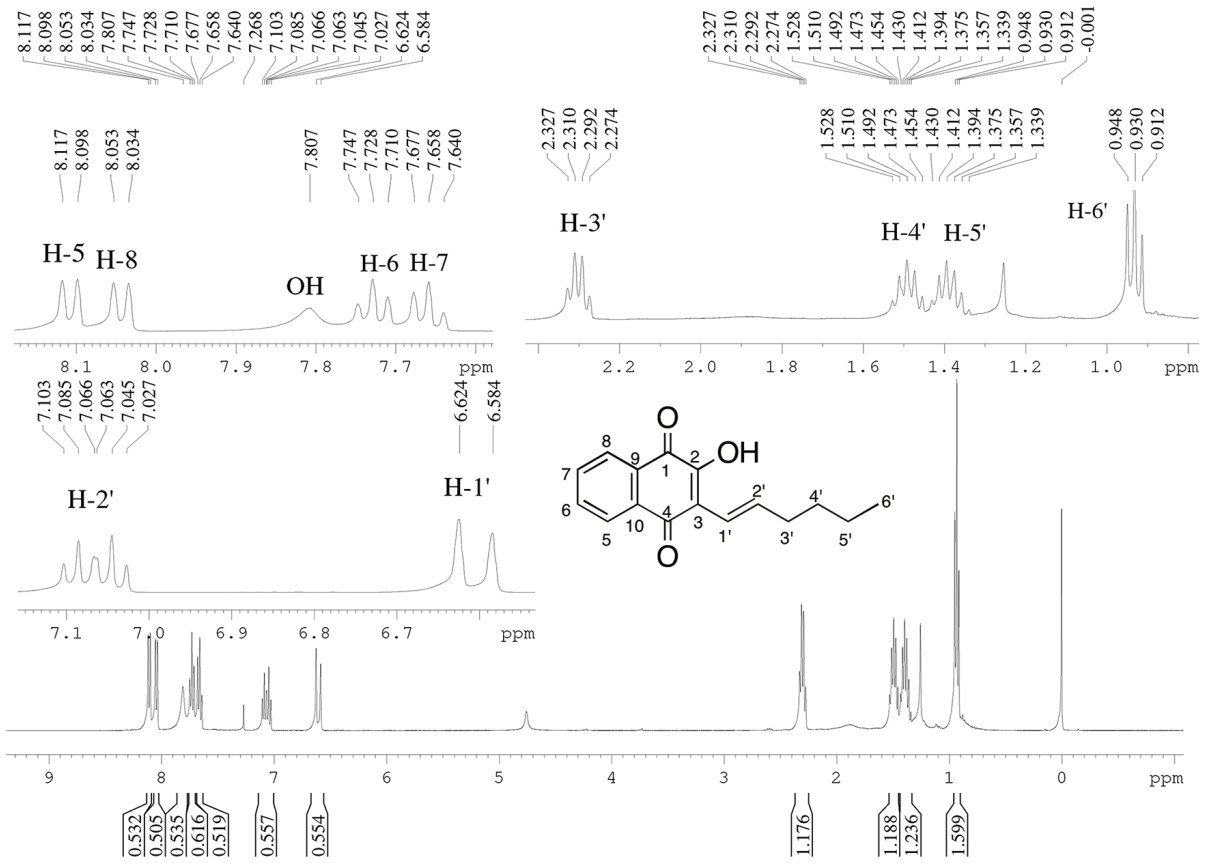

Figure 3. [1]H NMR spectrum of NQ **4d**.

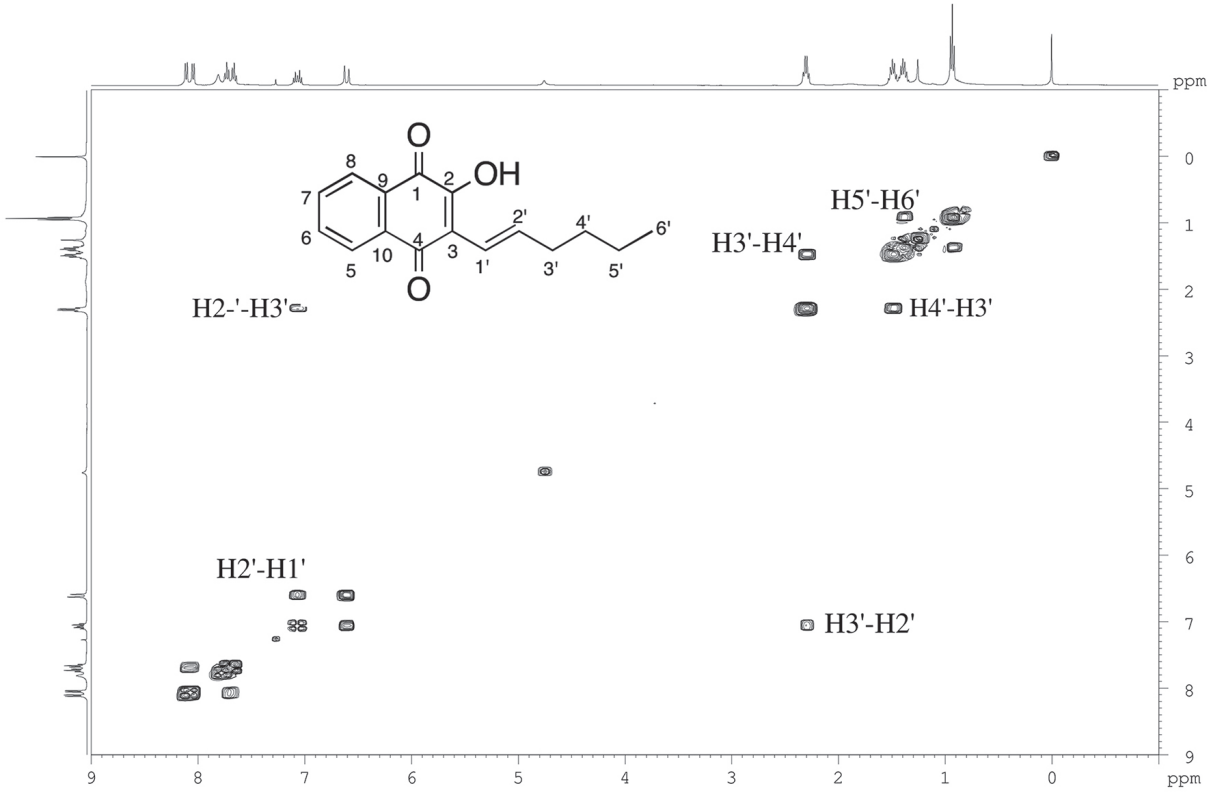

Figure 4. [1]H-[1]H COSY contour map of compound **4d**.

contour map was recorded. From that we can conclude the following: H-1' (δ 6.60, d, $^3J_{H,H}$ 16.00) shows long-range couplings to C-4 at δ 184.50, C-2 at δ 151.47 and C-3' at δ 34.95 ($^3J_{C,H}$). H-2' (δ 7.10-7.03, m) is coupled to C-4' at 31.45 and to C-3 at δ 120.18 ($^3J_{C,H}$) (Figure 5). The H-3' signal (δ 2.30, q, $^3J_{H,H}$ 7.00) shows long-range correlations with C-1' at δ 118.80, C-5' at δ 22.55 ($^3J_{C,H}$), C-2' at δ 144.40 and C-4' at δ 31.45 ($^2J_{C,H}$). H-4' (δ 1.49, quint, $^3J_{H,H}$ 7.20) is coupled to C-2' at δ 144.40, C-6' at δ 14.14 ($^3J_{C,H}$), C-5' at δ 22.55 and C-3' at δ 34.95 ($^2J_{C,H}$). H-5' (δ 1.38, st, $^3J_{H,H}$ 7.20) shows long-range couplings to C-3' at δ 34.95 ($^3J_{C,H}$) and C-6' at δ 14.14 ($^2J_{C,H}$). Finally, H-6' signal (δ 0.93, t, $^3J_{H,H}$ 7.20) is correlated to those of C-4' at δ 31.45 ($^3J_{C,H}$) and C-5' at δ 22.55 ($^2J_{C,H}$) (Figure 6).

Although carbonyl carbon signals are close they were assigned with ^{1}H-^{13}C HMBC support (Figure 5) once H-1' (δ 6.60) shows a long-range coupling to the carbonyl carbon at δ 184.50 which is thus attributed to C-4 and, therefore, the other carbonyl carbon signal at δ 181.56 corresponds undoubtedly to C-1. Opposite assignments were previously proposed for lapachol (**1**) that discloses similar situation on the naphthoquinone moiety.[6,22] Long range couplings of the carbonyl carbons C-1 and C-4 supported the assignment of the aromatic hydrogens. There is a clear coupling of C-1 to H-8 (δ 8.04, d, $^3J_{H,H}$ 7.60), and of C-4 to H-5 (δ 8.11, d, $^3J_{H,H}$ 7.60) ($^3J_{C,H}$). Furthermore the H-8 signal shows a correlation with the carbon resonances of C-10 at δ 132.87 ($^3J_{C,H}$). H-5 is coupled to C-7 at 133.16 and to C-9 at δ 129.62 ($^3J_{C,H}$). The two apparent triplets at δ 7.73 and 7.64 were assigned to H-6 and H-7, in this order. The H-6 signal shows long-range correlation with the carbon resonances of C-10 at δ 132.87 and C-8 at δ 126.08 ($^3J_{C,H}$), while the H-7 signal is correlated with the ones of C-9 at δ 129.62 and C-5 at 127.19 ($^3J_{C,H}$) (Figure 5).

Assignments of the heteronuclear correlations observed in the ^{1}H-^{13}C HMBC contour map for compound **4d** are shown in Table 1.

The main difference between NQ and FNQ is the change of spectral features in ^{1}H NMR spectra around δ 7-6. In the NQ's (**4d**) ^{1}H NMR spectra the signal of H-1', a hydrogen of alkenyl moiety, is a doublet, while in the FNQs H-1' (**5d** and **6d**), the only hydrogen in the furan ring, is a singlet (Figure 7).

The *ortho*-FNQ ^{1}H NMR spectrum of **5d** (Figure 8) exhibits a triplet at δ 2.71 related to 2H-3' ($^3J_{H,H}$ 7.60), a quintet at δ 1.70 refers to 2H-4' ($^3J_{H,H}$ 7.60), a sextet at δ 1.44 relative to 2H-5' ($^3J_{H,H}$ 7.60) and a triplet at δ 0.97 corresponds to methyl hydrogens 3H-6' ($^3J_{H,H}$ 7.60).

All these hydrogens were assigned on the basis of the ^{1}H-^{1}H COSY spectrum (Figure 9), where can be observed that H-3' is coupled to H-4', H-4' to H-5', and H-5' to H-6'. A apparent doublet at δ 8.00 and a apparent triplet

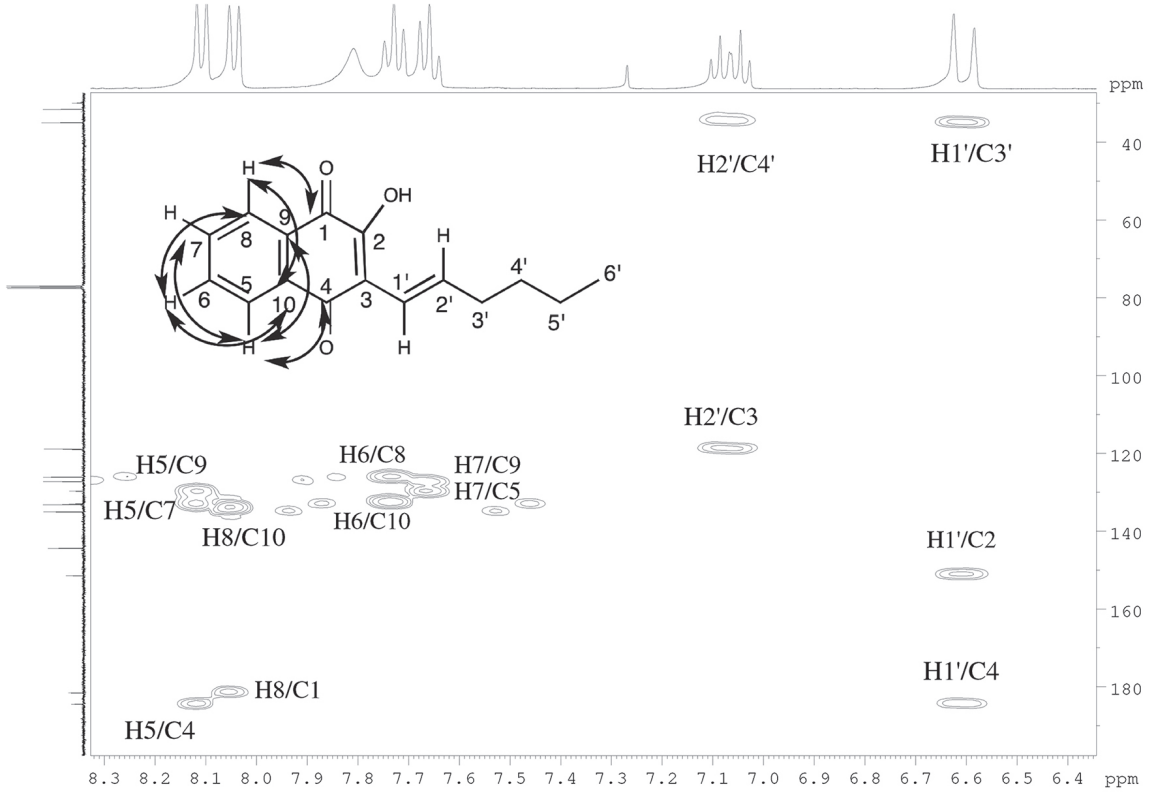

Figure 5. Expansion of ^{1}H-^{13}C HMBC contour map (δ 6.4-8.3 ppm) of compound **4d**.

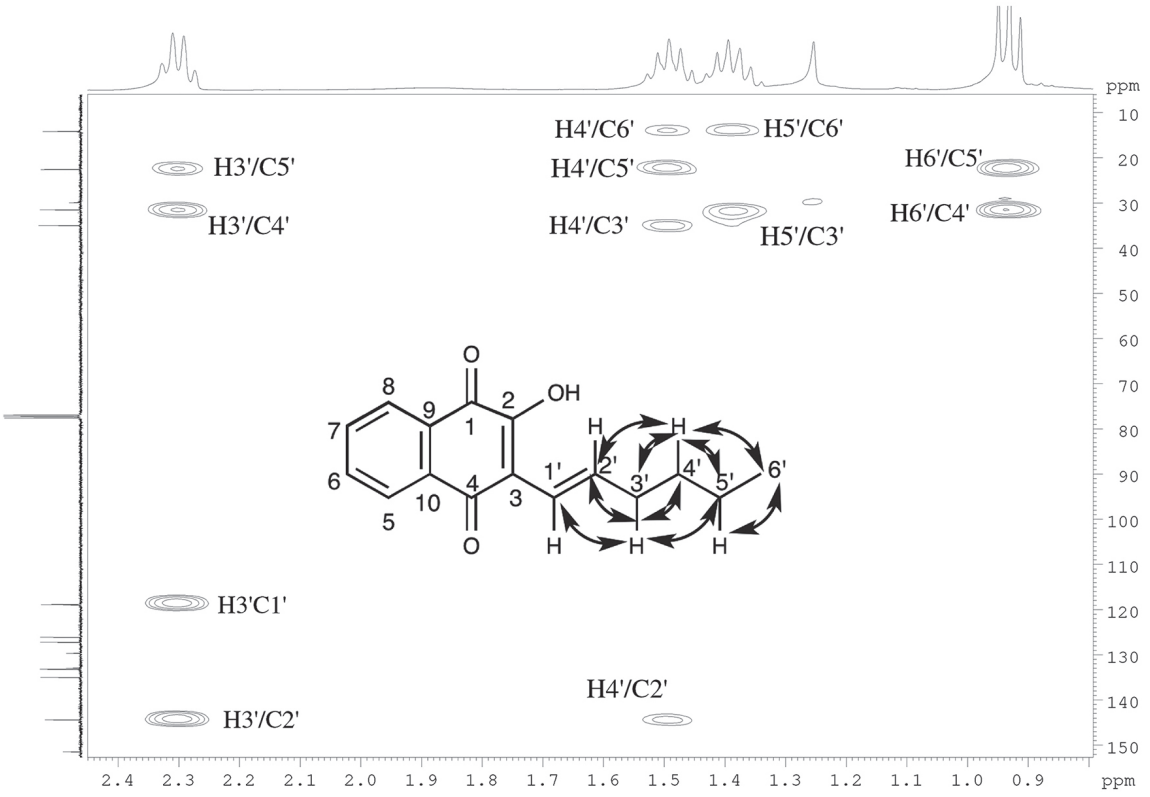

Figure 6. Expansion of ^{1}H-^{13}C HMBC contour map (δ 0.9-2.4 ppm) of compound **4d**.

Table 1. ^{1}H NMR chemical shifts (δ), multiplicities, coupling constants (J) and heteronuclear correlations observed in the HMBC for compound **4d**

^{1}H (δ, multiplicity, $^{3}J_{H,H}$ / Hz)	^{3}J ^{13}C (δ / ppm)	^{2}J ^{13}C (δ / ppm)
H-5 (8.11, d, *J* 7.60)	C-4 (184.50); C-7 (133.16); C-9 (129.62)	–
H-6 (7.73, t, *J* 7.40)	C-8 (126.08); C-10 (132.87)	–
H-7 (7.64, t, *J* 7.40)	C-5 (127.19); C-9 (129.62)	–
H-8 (8.04, d, *J* 7.60)	C-1 (181.56); C-10 (132.87)	–
H-1' (6.60, d, *J* 16.00)	C-2 (151.47); C-3'(34.95); C-4 (184.50)	–
H-2' (7.10-7.03, m)	C-4'(31.45)	C-3 (120.18)
H-3' (2.30, q, *J* 7.00)	C-1'(118.80); C-5'(22.55)	C2'(144.40); C4'(31.45)
H-4' (1.49, quint, *J* 7.20)	C-2' (144.40); C-6'(14.14)	C-3'(34.95); C-5'(22.55)
H-5' (1.38, st, *J* 7.20)	C-3'(34.95)	C-6' (14.14)
H-6' (0.93, t, *J* 7.20)	C-4'(31.45)	C-5' (22.55)

s: singlet; d: doublet; t: triplet; q:quartet; quint: quintet; s: sextet.

at δ 7.40 corresponding to H-8 ($^{3}J_{H,H}$ 7.70) and H-7 ($^{3}J_{H,H}$ 7.70), respectively, (Figure 8) and from ^{1}H-^{1}H COSY contour map these hydrogens are coupling to each other (Figure 9). A multiplet at δ 7.64-7.58 is related to H-5 and H-6.

Aiming to confirm the **5d** chemical shifts assignments a heteronuclear correlation contour map ^{1}H-^{13}C HMBC was recorded (Figure 10) and the following informations were derived from it. From the singlet at δ 6.42 corresponding to H-1', the only hydrogen in the furan ring, it is possible to differentiate between the two carbonyl carbons because H-1' shows long-range coupling to C-2 at δ 174.60 ($^{3}J_{C,H}$). So, the other carbonyl carbon signal is related to C-1 (δ 180.89). Besides, H-1' is coupled to C-4 at δ 159.65 ($^{3}J_{C,H}$) and C-3 at δ 122.68 ($^{2}J_{C,H}$), allowing to distinguish them from aromatic carbons. H-3' (δ 2.71, t, $^{3}J_{H,H}$ 7.60) shows long-range couplings to C-2' at δ 160.49, C-4' at δ 29.71 ($^{2}J_{C,H}$), C-1' at δ 103.84 and C-5' at δ 22.28 ($^{3}J_{C,H}$). The signal of H-4' (δ 1.70, quint, $^{3}J_{H,H}$ 7.60) is correlated with the carbon resonances of C-2' at δ 160.49, C-6' at

δ 13.85 ($^3J_{C,H}$), C-3' at δ 27.70 and C-5' at δ 22.28 ($^2J_{C,H}$). H-5' (δ 1.44, st, $^3J_{H,H}$ 7.60) shows long-range couplings to C-4' at δ 29.71 and C-6' at δ 13.85 ($^2J_{C,H}$). The signal of H-6' (δ 0.97, t, $^3J_{H,H}$ 7.60) is correlated with the carbon resonances of C-4' at δ 29.71 ($^3J_{C,H}$) and C-5' at δ 22.28 ($^2J_{C,H}$) (Figure 11).

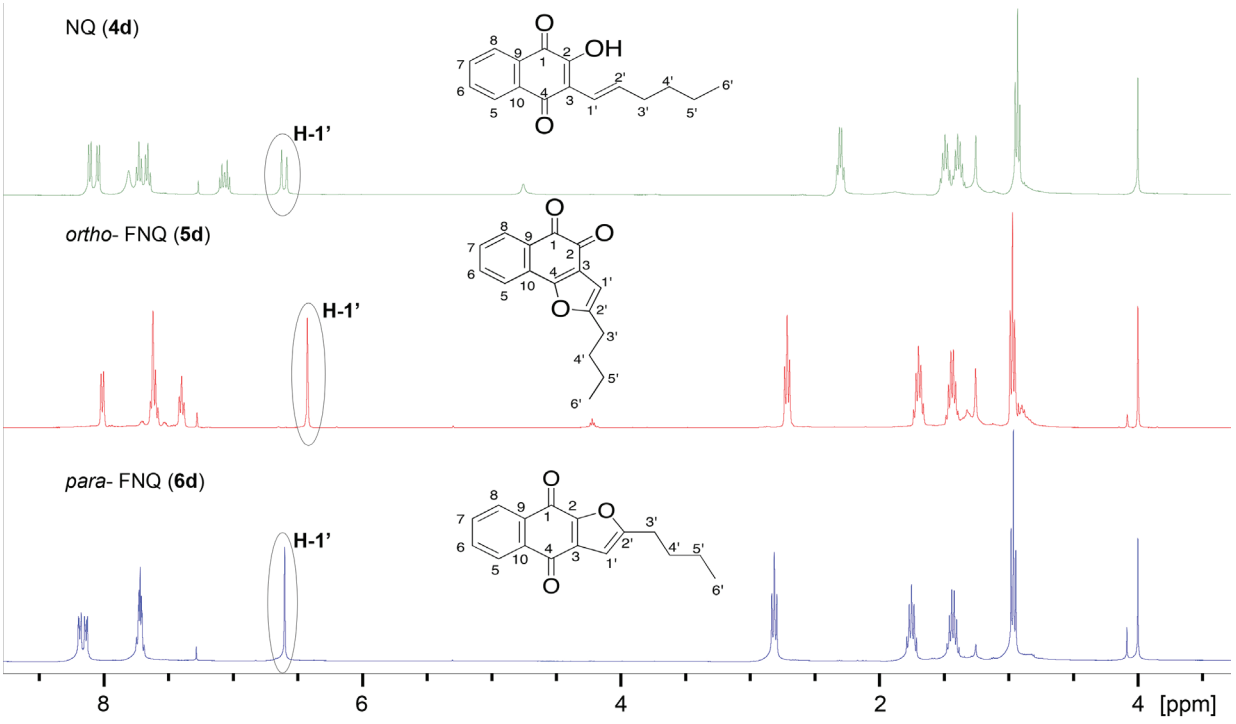

Figure 7. Difference between ^{1}H NMR spectra of compounds **4d**, **5d** and **6d**.

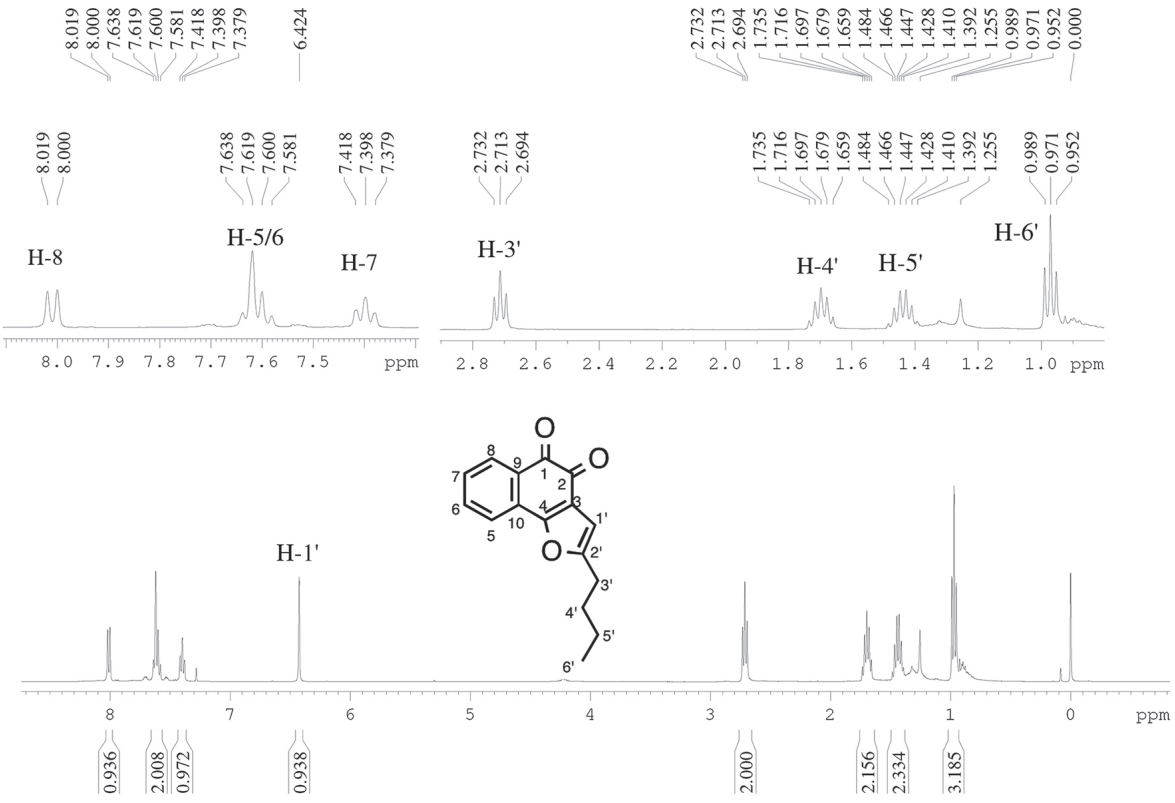

Figure 8. ^{1}H NMR spectrum of compound **5d**.

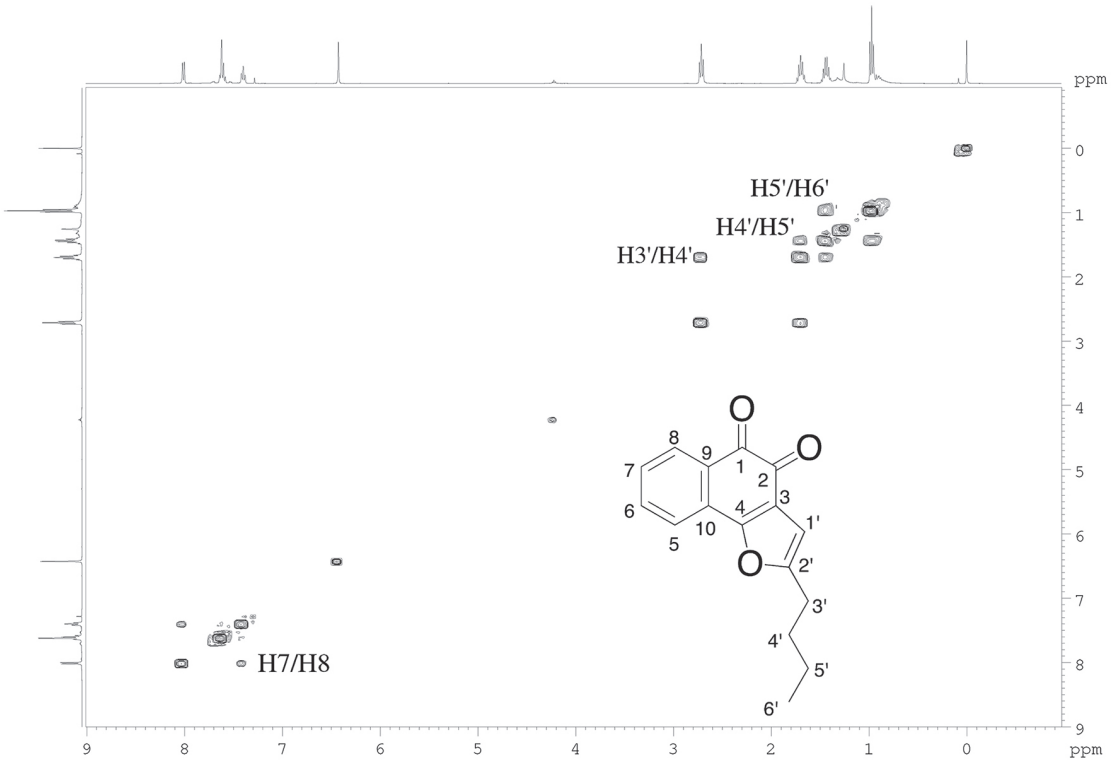

Figure 9. ^{1}H-^{1}H COSY contour map of compound **5d**.

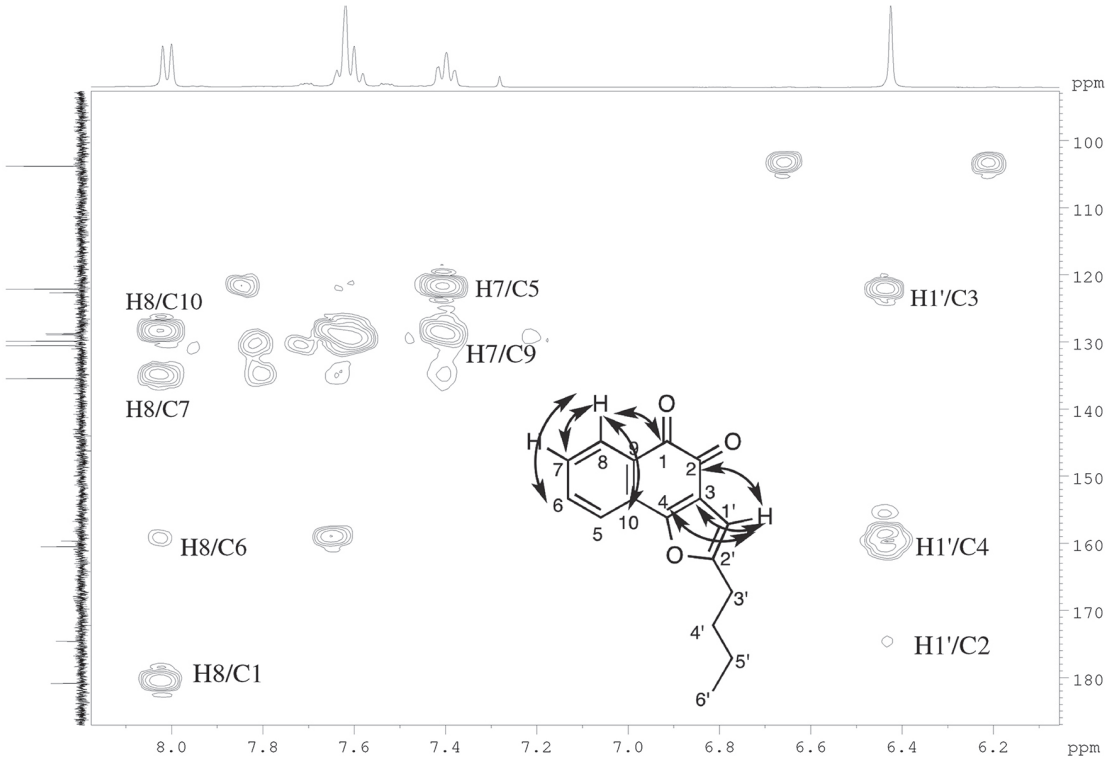

Figure 10. Expansion of ^{1}H-^{13}C HMBC contour map (δ 6.2-8.0 ppm) of compound **5d**.

In the ^{1}H-^{13}C HMBC contour map (Figure 10) the signal of H-8 (δ 8.00) shows a long-range correlation with the ones of C-1 at δ 180.89, C-10 at δ 128.78, C-6 at δ 135.46 ($^{3}J_{C,H}$) and C-7 at δ 130.55 ($^{2}J_{C,H}$). The H-7 signal (δ 7.40) is correlated with those of C-5 at 122.15 and C-9 at δ 128.92 ($^{3}J_{C,H}$). Assignments of the heteronuclear

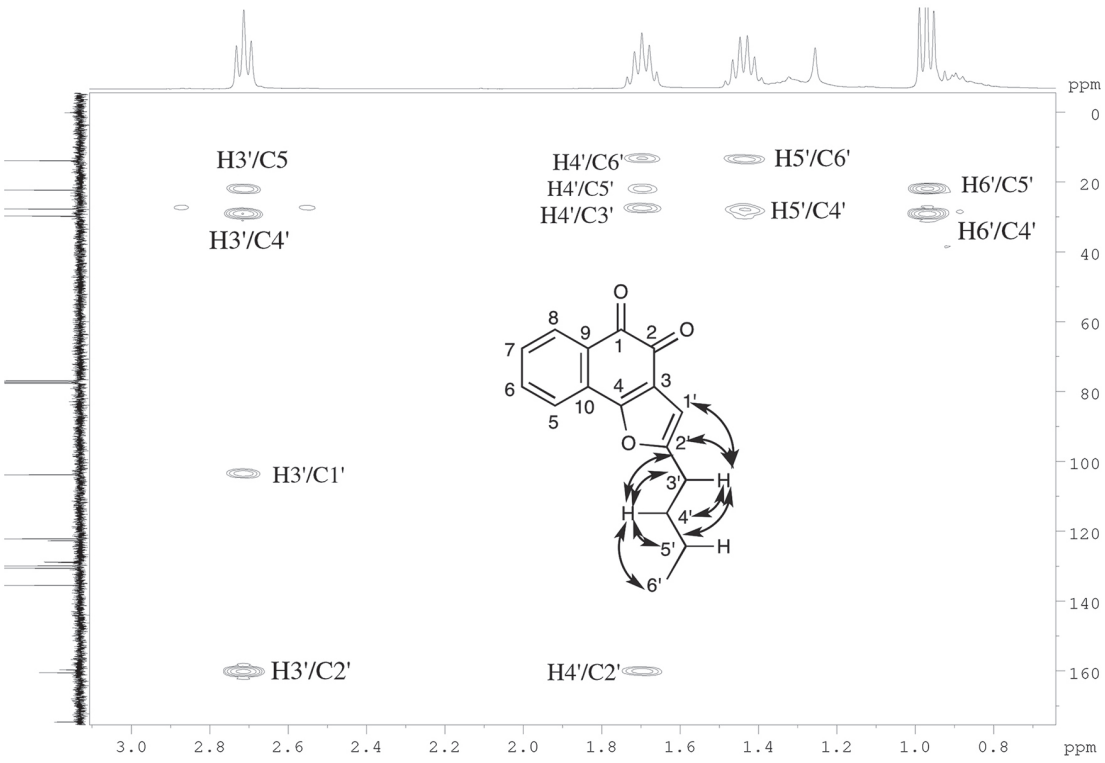

Figure 11. Expansion ^{1}H-^{13}C HMBC contour map (δ 0.8-3.0 ppm) of compound **5d**.

correlations observed in the ^{1}H-^{13}C HMBC contour map for compound **5d** are shown in Table 2.

Finally, in the ^{1}H NMR spectrum of *para*-FNQ **6d** (Figure 12) the singlet at δ 6.60 is related to H-1', the only hydrogen in the furan ring and it shows long-range correlation (^{1}H-^{13}C HMBC contour map) (Figures 13 and 14) to the carbonyl carbon C-4 (δ 181.06) ($^{3}J_{C,H}$). Thus the other carbonyl carbon at δ 173.23 corresponds to C-1. Therefore H-1' signal is correlated with those of C-2 at δ 151.72 ($^{3}J_{C,H}$), C-3 at δ 131.95 and C-2' at δ 164.99 ($^{2}J_{C,H}$). H-3' signal (δ 2.81, t, $^{3}J_{H,H}$ 7.60) shows long-range correlation with the carbon resonance of C-2' at δ 164.99, C-4' at δ 29.68 ($^{2}J_{C,H}$), C-1' at δ 104.30 and C-5' at δ 22.34 ($^{3}J_{C,H}$). H-4' signal (δ 1.75, quint, $^{3}J_{H,H}$ 7.60) is correlated with the carbon resonances to C-2' at δ 164.99, C-6' at δ 13.83 ($^{3}J_{C,H}$), C-3' at δ 28.20 and C-5' at δ 22.34 ($^{2}J_{C,H}$). H-5' (δ 1.43, st, $^{3}J_{H,H}$ 7.50) shows long-range couplings to C-3' at δ 29.20 ($^{3}J_{C,H}$) and C-6' at δ 13.83 ($^{2}J_{C,H}$). The H-6' signal (δ 0.96, t, $^{3}J_{H,H}$ 7.50) is correlated with the carbon resonances for C-4' at δ 29.68 ($^{3}J_{C,H}$) and C-5' at δ 22.34 ($^{2}J_{C,H}$).

The signals at δ 8.20-8.17, 8.15-8.13 and 7.75-7.69 refer to the benzenoid hydrogens of the naphthoquinone moiety H-5 (m), H-8 (m) and H-6/7 (m), respectively. In the HMBC contour map (Figure 13) H-5 shows long range coupling to C-4 (δ 181.06) ($^{3}J_{C,H}$) and the same for H-8 to C-1 (δ 173.23) ($^{3}J_{C,H}$), as expected. On the other hand, HMBC correlations for C9, C10, C6 and C7 are not clearly shown in the spectrum and their assignments were based on similarities with **4d** that is a NQ, structurally closer to **6d** because of the carbonyl carbons positions.

Table 2. ^{1}H NMR chemical shifts (δ), multiplicities, coupling constants (J) and heteronuclear correlations observed in the HMBC for compound **5d**

^{1}H (δ, multiplicity, $^{3}J_{H,H}$ / Hz)	^{3}J ^{13}C (δ / ppm)	^{2}J ^{13}C (δ / ppm)
H-7 (7.40, at, *J* 7.70)	C-5 (122.15); C-9 (128.92)	–
H-8 (8.00, ad, *J* 7.57)	C-1 (180.89); C-6 (135.46); C-10 (128.78)	C-7 (130.55)
H-1' (6.42, s)	C-2 (174.60); C-4 (159.65)	C-3 (122.68)
H-3' (2.71, t, *J* 7.60)	C-1'(103.84); C-5'(22.28)	C-2' (160.49); C-4'(29.71)
H-4' (1.70, quint, *J* 7.60)	C-2' (160.49); C-6'(13.85)	C-3'(27.70); C-5'(22.28)
H-5' (1.44, st, *J* 7.60)	–	C-4'(29.71); C-6'(13.85)
H-6' (0.97, t, *J* 7.60)	C-4'(29.71)	C-5'(22.28)

s: singlet; ad: apparent doublet; at: apparent triplet; t: triplet; quint: quintet; st: sextet.

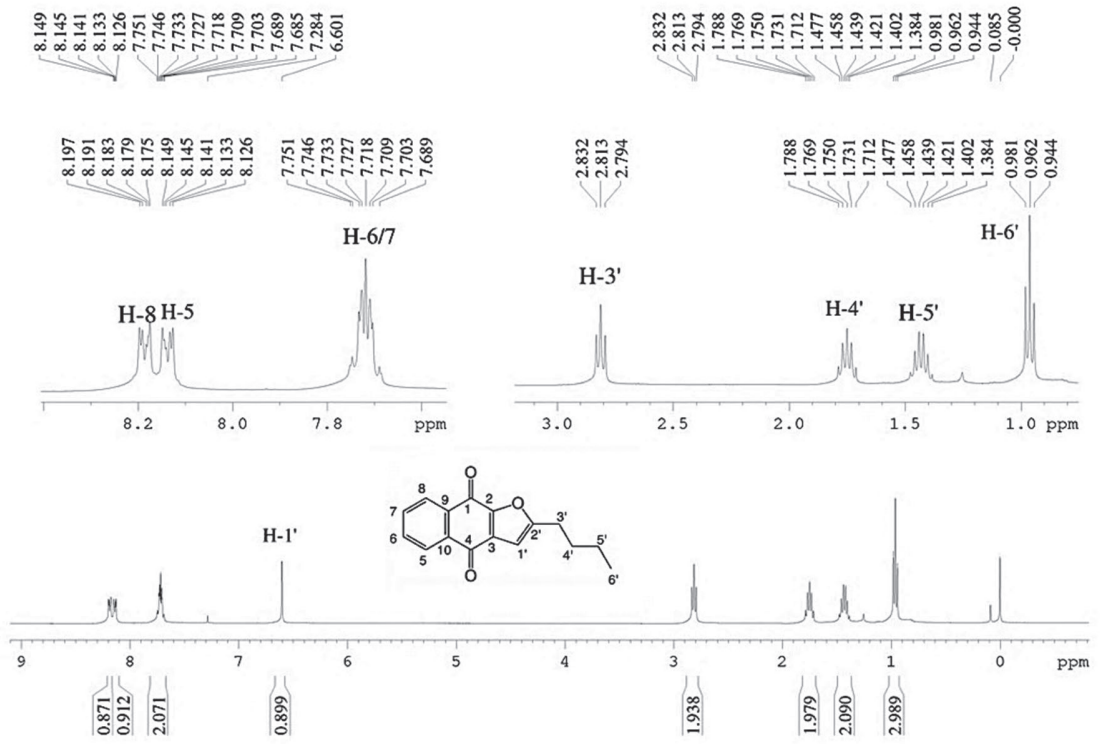

Figure 12. ^{1}H NMR spectrum of compound **6d**.

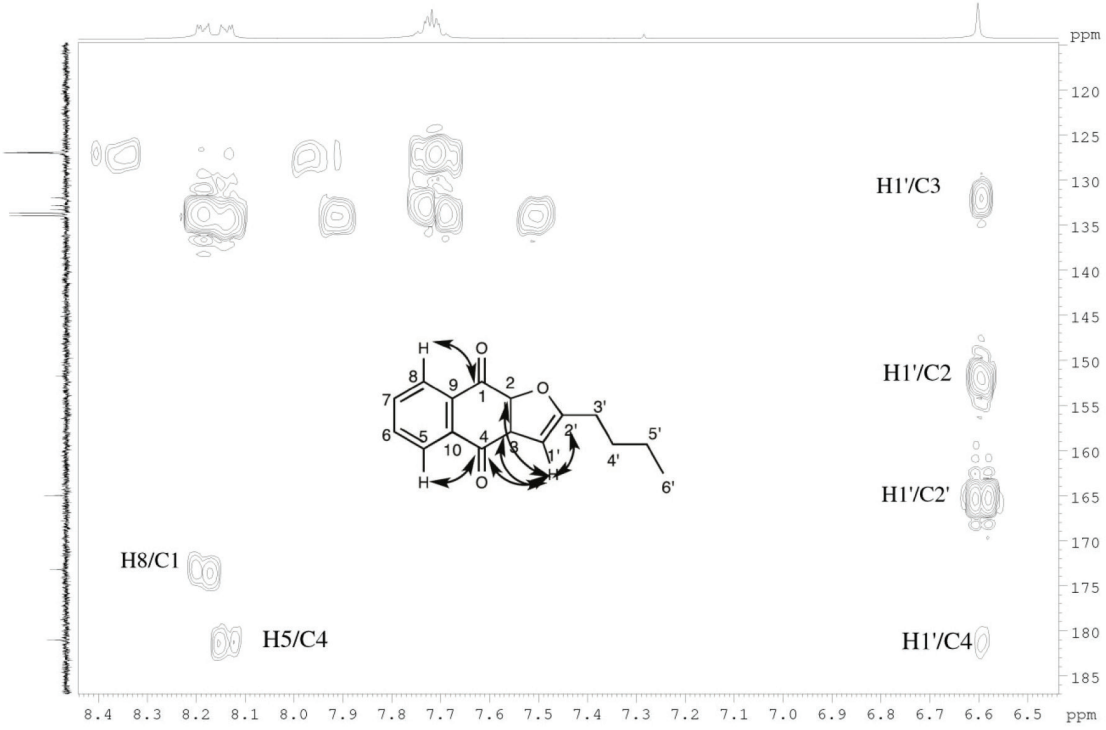

Figure 13. Expansion ^{1}H-^{13}C HMBC contour map (δ 6.5-8.4 ppm) of compound **6d**.

All the hydrogens and heteronuclear correlations observed in the HMBC for compound **6d** are shown in Table 3.

The isomers *ortho*- and *para*-FNQ can be distinguished by ^{1}H-^{13}C HMBC data. In *para*-FNQ (**6d**) signals of the two carbonyl carbons C-1 and C-4 exhibit long-range correlation to the hydrogen resonances for H-8 and H-5 (Figure 13), respectively, whereas in *ortho*-FNQ (**5d**) only

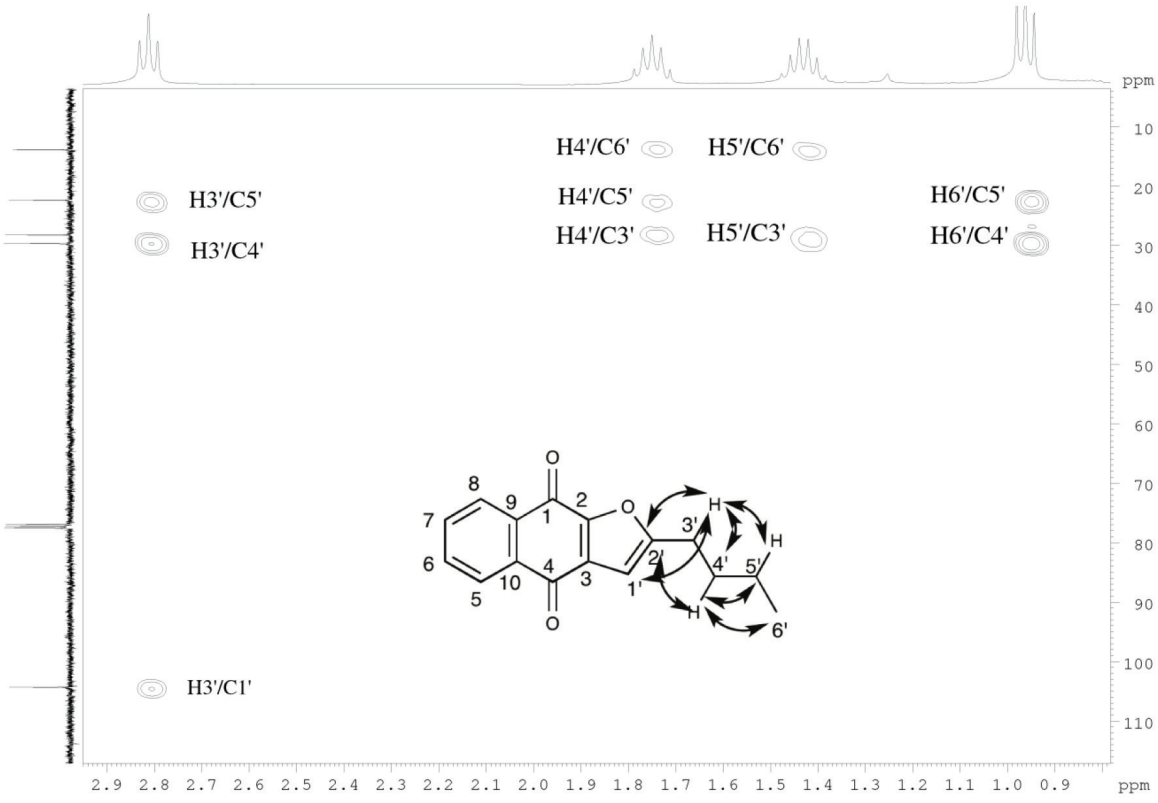

Figure 14. Expansion ^{1}H-^{13}C HMBC contour map (δ 0.9-2.9 ppm) of compound **6d**.

Table 3. ^{1}H NMR chemical shifts (δ), multiplicities, coupling constants (J) and heteronuclear correlations observed in the HMBC for compound **6d**

^{1}H (δ, multiplicity, $^{3}J_{H,H}$ / Hz)	^{3}J ^{13}C (δ / ppm)	^{2}J ^{13}C (δ / ppm)
H-5 (8.20-8.17, m)	C-4 (181.06)	–
H-8 (8.15-8.13, m)	C-1 (173.23)	–
H-1' (6.60, s)	C-2 (151.72); C-4 (181.06)	C-2' (164.99); C-3 (131.95)
H-3' (2.81, t, *J* 7.60)	C-1'(104.30); C-5'(22.34)	C-4'(29.68); C-2' (164.99)
H-4' (1.75, quint, *J* 7.60)	C-2' (164.99); C-6'(13.83)	C-3'(28.20); C-5'(22.34)
H-5' (1.43, st, *J* 7.50)	C-3' (29.20)	C-6'(13.83)
H-6' (0.96, t, *J* 7.50)	C-4'(29.68)	C-5'(22.34)

s: singlet; t: triplet; quint: quintet; s: sextet; m: multiplet.

H-8 shows long-range correlation of carbon resonance for carbonyl carbon C-1 (Figure 10). Therefore in NQs the chemical shifts of carbonyl carbon C-4 ranged from δ 184.31 to 184.53 and were higher than those of C-1 (δ 181.17-181.61) while in the *para*-FNQs the differences in chemical shifts of C-4 (180.88-181.10) and C-1 (δ 171.64-173.30) are still higher. These data might be related to the resonance effect between the oxygen bonded to C-2 and the C-4 carbonyl (Figure 15). However in the *ortho*-FNQs the chemical shift of the carbonyl carbon C-1 (δ 180.76-183.91) was higher than that of C-2 (δ 174.44-180.92) probably because the resonance effect is more effective between the C-1 carbonyl and the oxygen bonded to C-4 (Figure 15). From the chemical shifts of *para*- and *ortho*-FNQs it is clear that the substituents at C-2' in the furan ring have practically no influence in the shielding of the hydrogens and carbons of the naphthoquinone moiety.

Conclusions

In this work we have shown the complete and unambiguous assignments of ^{1}H and ^{13}C chemical shifts of 2-hydroxy-3-(1'-alkenyl)-1,4-naphthoquinones (NQs), naphtho[1,2-*b*]furan-4,5-diones (*ortho*-FNQs) and naphtho[2,3-*b*]furan-4,9-diones (*para*-FNQs), as discussed

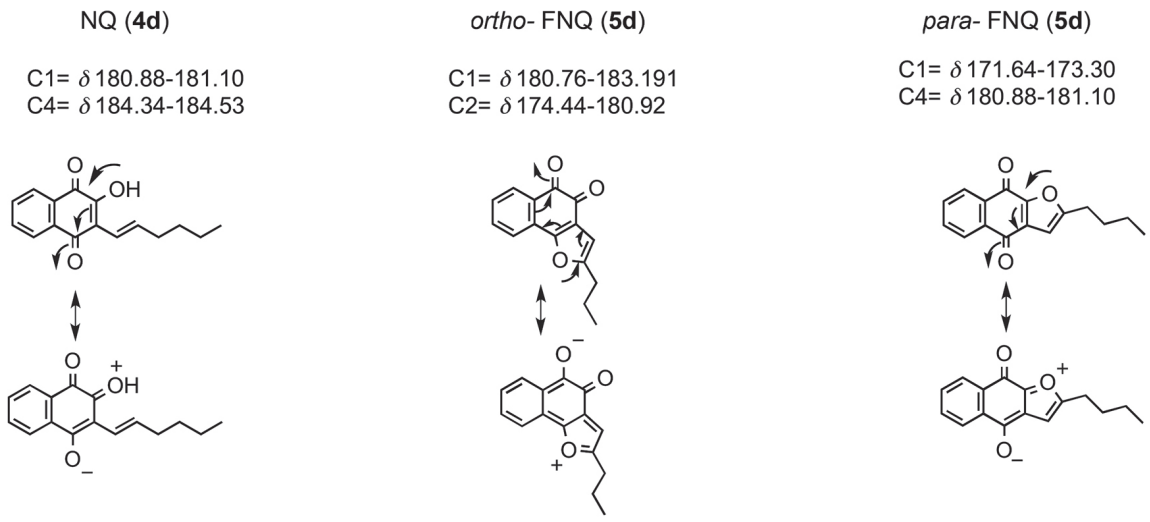

Figure 15. Resonance structures for compounds **4d**, **5d** and **6d**.

for **4d**, **5d** and **6d**, respectively. It was observed that the nature of the substituents at C-3 in the NQs and at C-2' in the furan ring in the FNQs do not affect significantly the ^{1}H and ^{13}C chemical shifts of the naphthoquinone system. As far as we are concerned, this is the first report on the distinction between NQs and FNQs by NMR data. The results described for *ortho*- and *para*-FNQs isomers can be used as a model for ^{1}H and ^{13}C assignments of compounds possessing the naphthoquinones and furanonaphthoquinones system.

Supplementary Information

Supplementary information (assignment tables of all hydrogen and carbon signals shifts, and copies of the ^{1}H and ^{13}C NMR spectra of compounds **1**, **4a-h**, **5a-h** and **6a-h**) is available free of charge at http://jbcs.sbq.org.br as a PDF file.

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