Synthesis and ^{13}C, ^{15}N NMR Study of a New Functionalized Pyrido[2,3-*b*]indole Derivative

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Dedicated to the memory of Professor Nicholas Alexandrou

New functionalized α-carbolinones especially the 4-hydroxy-3-nitro-1*H*,9*H*-pyrido[2,3-*b*]indol-2-one were synthesized in a good yield, three-step reaction. A complete ^{13}C, ^{15}N nmr study of this carbolinone and precursors is presented.

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The first α-carboline synthesis was achieved in 1924 by Lawson, Perkin and Robinson, by means of a Graebe-Ullmann type reaction [1]. Several later approaches to diversely substituted α-carbolines were carried out and reviewed until 1980 [2]. Since then, pyrido[2,3-*b*]indoles received much attention owing to the fact that this heterocyclic system is the basic structure of biologically active compounds displaying cytostatic and antitumor activities [3-6] and new synthetic pathways series appeared [7-14].

More recently, Grossularines, a naturally occurring family of imidazo[4',5':4,3]pyrido[2,3-*b*]indole derivatives, were isolated from *Dendrodoa Grossularia*, their structures established, and proved to be efficient cytostatic compounds [15-17]. The total syntheses of Grossularines and some analogues, were published last year [18-20].

We describe herein the synthesis, some derivatives and a complete nmr study of a new functionalized α-carbolinone namely the 4-hydroxy-3-nitro-1*H*,9*H*-pyrido[2,3-*b*]indol-2-one (**1**), a convenient synthon for the preparation of various derivatives including new polyheterocyclic compounds.

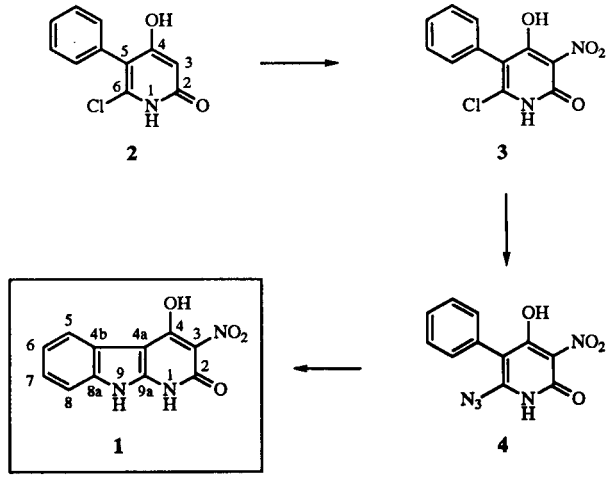
Chemistry.

Starting from the already known 6-chloro-4-hydroxy-5-phenyl-2(1*H*)-pyridinone (**2**) [21], the reaction process involved three steps, affording the end product **1** in 66% overall yield (Scheme 1).

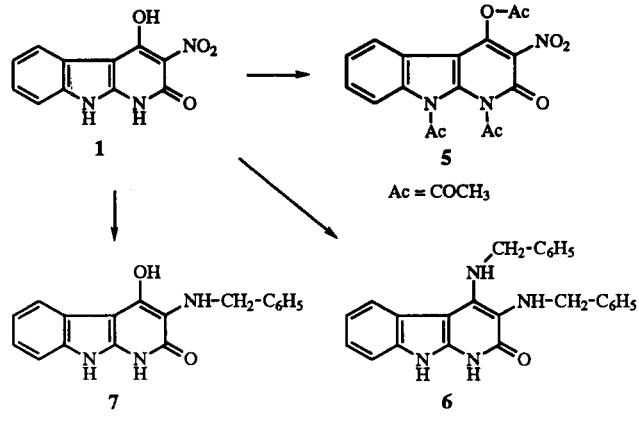
As the C-Cl bond of **2** is unreactive towards sodium azide, the 6-position was activated by setting an electron-withdrawing group at position 3, leading to the nitro-derivative **3**. This compound **3** was almost quantitatively transformed in the required azide **4** with sodium azide in dimethylformamide. Finally, the azide **4** was cyclized by heating with anhydrous hydrochloric acid in acetic acid, affording the title compound **1**.

When boiled in acetic anhydride the nitrohydroxy α-carbolinone **1**, was transformed into the triacetate **5**.

Scheme 1



Scheme 2



This nitro hydroxy derivative **1** can also undergo two distinct nucleophilic substitutions with benzylamine, thus using freshly distilled anhydrous benzylamine, both the

hydroxy and nitro groups were replaced, leading to the dibenzylamino derivative **6** (Scheme 2).

If hydrated benzylamine (water 1% v/v) was used, only the nitro group of **1** was replaced by a benzylamine moiety, furnishing the 3-benzylamino-4-hydroxy-1*H*,9*H*-pyrido[2,3-*b*]indol-2-one (**7**).

The structures of the compounds described were established by ^{1}H, ^{13}C, ^{15}N nmr and mass spectrometry.

NMR Analysis.

1) Results.

The ^{13}C and ^{15}N chemical shifts of compounds **1**, **2**, **3** and **5** are reported in Table 1, and all the ^{1}H chemical shifts are given in the Experimental.

The assignments of the ^{1}H spectra are straightforward. In the carbolinone **1** the signals are assigned by comparison with indole [22], the most deshielded doublet corresponding to H-5. Contrarily, in the peracetylated derivative **5** the most deshielded doublet corresponds to H-8 due to the through space effect of the amide carbonyl at position 9. The protons of the hydroxyl groups and those linked to nitrogen atoms give distinct signals in **1** and **2**, one of them being narrower in each case but a single broad signal is observed for compound **3**.

The ^{13}C spectra are by far more difficult to analyse due to the occurrence of a number of non-protonated carbons and to line broadening due to exchange modulated couplings and/or to a tautomeric equilibrium. Unfortunately, the 2D experiments HMQC or HMBC, inverse δ ^{13}C-δ ^{1}H correlations, were not efficient due to the lack of significant coupling interactions for many carbons while δ ^{13}C-δ ^{13}C correlation was impossible due to the low solubility of compound **1**. Undecoupled spectra, selective low power decoupling experiments and correlations with model compounds, the 4-hydroxy-2(1*H*)-pyridinone (**8**), and the precursors **2** and **3** of the carbolinone **1** were used for the assignments.

For 4-hydroxy-2(1*H*)-pyridinone (**8**), the observation of typical coupling constants allows a complete assignment of the resonances (see data in Experimental part). The ^{1}J coupling constant is increased in α-position with respect to the nitrogen atom (179 Hz for ^{1}J C-6, H-6). The ^{3}J coupling constant has a high value when the nitrogen atom is included in the pathway (11.6 Hz for ^{3}J C-2, H-6) [23].

For compound **2** an undecoupled spectrum allows easy assignments of the signal of C-3 and of the signals of the carbons in the phenyl group on the basis of typical multiplicity. A broad signal is observed at 116.9 ppm. It becomes well resolved at 350K, and looks like a quadruplet as a result of similar ^{3}J couplings to the *ortho* protons of the phenyl substituent and to H-3. It is thus assigned to C-5. The two more deshielded signals slightly broadened at ambient temperature exhibit small coupling to H-3 at 350K. The signal with the greater coupling constant (2 Hz) is tentatively assigned to C-4 and the signal with the smallest constant (1.3 Hz) to C-2. The last signal is then ascribed to C-6.

For compound **3** where the proton at C-3 has been replaced by a nitro group the narrow signal at 125.3 ppm is assigned to C-3 due to the negative inductive effect of the substituent. The broad signal at 116.1 becomes well resolved at 335K and exhibits coupling to the *ortho* protons of the phenyl substituent. It is assigned to C-5. Finally the resonance at 143.8 ppm is assigned to C-6. Among the two deshielded resonances, 159.2 and 155.1, the first one, a broad signal, is assigned to C-4 and the very narrow signal to C-2. Similar patterns where previously described for this two sites in pyridinones differing from the compounds under study by the substituents at C-3, C-5 and C-6 but bearing equally an hydroxyl at C-4. This carbon was shown to undergo modulated coupling to the exchangeable proton [24].

As regards compound **1** the carbons in the phenyl ring are easily assigned on the basis of decoupling experiments and the results agree well with the known assignments in indole [22]. On increasing the temperature to 350K the very broad signal strongly shielded at 93.0 ppm becomes a resolved doublet with a small coupling interaction (2.5 Hz) suppressed upon irradiation of H-5. This signal thus assigned to C-4a is strongly shielded with respect to its chemical shift in **2** or **3** due to the mesomeric effect of N-9. The same effect, though attenuated, causes a shielding of C-3 with respect to its chemical shift in **3**. By comparison to **3** the narrow signal at 155.9 is ascribed to C-2 and the broad deshielded signal at 163.1 ppm to C-4.

For the peracetylated compound **5**, where all exchangeable hydrogen have been suppressed, narrow signals are observed, but a very complex spectrum occurs due to the existence, in the slow exchange limit, of all four possible conformers resulting from *cis* and *trans* orientations of the two acetamide groups. When the DMSO-d_6 was replaced by deuteriochloroform as the solvent a single set of resonances was observed as a result of a highly preferred conformation or of rapid interconversion. Since the observed chemical shifts do not significantly differ from those of the major conformer in DMSO-d_6 the first hypothesis is more likely. In the spectrum obtained with low power selective irradiation of H-5 a noticeable coupling interaction was suppressed for C-8a and a small one (2.5 Hz) for the most shielded signal which was thus ascribed to C-4a. The three resonances between 147 and 150 ppm correspond to C-2, C-4 and C-9a but are not univocaly assigned.

The ^{15}N resonances are easily detected by use of an INEPT sequence provided that the nitrogen-bound proton does not undergo significant exchange [25]. Since 4-hydroxy-2(1*H*)-pyridinone (**8**) and the precursory compounds **2** and **3** of the carbolinone **1** do not give any signal

through the INEPT sequence the proton at N-1 is most likely submitted to exchange process. In an undecoupled spectrum of **3** a narrow signal at -11.2 ppm is assigned to the nitro group on the basis of chemical shift [26] and a second signal (*circa* -167 ppm) is ascribed to N-1. This last signal is by far broader than the signals observed for the same nitrogen, N-1, in compounds **8** and **2** at -216.1 and -137.4 ppm, respectively. As regards compound **1** with the INEPT technique one nitrogen gives an antiphase doublet centred at -252.0 ppm with a coupling constant of 98.4 Hz. This signal was ascribed to N-9. Effectively in the same conditions, indole gives a doublet of triplet centred at -243.4 ppm with coupling constants of 97.6 Hz (^{1}J) and 5.5 Hz (^{2}J and ^{3}J to H-2 and H-3). These values differ slightly from those observed when deuteriochloroform was used as the solvent [27]. In a broad band decoupled spectrum the signal of the nitro group was observed nearly unshifted with respect to **3**. The signal at -252.0 ppm is intense and negative due to nuclear Overhauser effect (NOE). Finally the last signal, -232 ppm, which shows partial NOE, must correspond to N-1.

In the peracetylated compound **5** three ^{15}N narrow signals are observed. Except for the nitro group the signals are strongly deshielded with respect to compound **1**, the less deshielded being tentatively assigned to N-9 and the other to N-1.

Table 1

^{13}C and ^{15}N NMR Data for compounds **1**, **2**, **3** and **5**. δ ppm with Respect to Internal TMS for ^{13}C Spectra and to Neat Nitromethane (external reference) for ^{15}N Spectra

	Compounds			
Atoms	**1**	**2**	**3**	**5** [b]
N-1	-232	-137.4	-167	-143.8
C-2	155.9	165.8 [a]	155.1	149.6, 148.2 or 147.3 [c]
C-3	117.7	94.1	125.3	129.4
C-4	163.1	163.0 [a]	159.2	149.6, 148.2 or 147.3 [c]
C-4a	93.0			111.7
C-5 in **2** and **3**		116.9	116.1	
C-4b	121.7			119.8
C-5	119.9			121.8
C-6	122.2			125.2
C-7	124.1			129.9
C-8	112.3			117.8
C-8a	136.6			139.0
N-9	-252.0			-207.5
C-9a	145.7			149.6, 148.2 or 147.3 [c]
C-6 in **2** and **3**		146.2	143.8	
NO_2	-11.4		-11.2	-13.9
acetyl groups				
CO				170.4, 167.6 or 166.2 [c]
CH_3				28.0, 20.8 or 20.7 [c]
phenyl carbons		*i* 134.2	*i* 132.0	
		o 130.7	*o* 130.6	
		m 127.9	*m* 128.4	
		p 127.2	*p* 128.3	

[a] Tentative assignments. [b] Solvent: deuteriochloroform. [c] Unassigned.

2) Discussion.

Usually, 2-(and 4)-hydroxypyridines are formulated as 2-(and 4)-pyridinones and it has been shown that the hydroxypyridine-pyridone tautomerism affects the value of the ^{2}J(^{13}C-^{1}H) coupling involving the proton linked to the carbon in α-position of the nitrogen, a low value (*circa* 3 Hz) being observed in the second case as compared to the high typical values (*circa* 6 Hz) in pyridines [23]. In compound **8** the observation of a small value (2.9 Hz) for ^{2}J C-5, H-6 is in favour of the displacement of the tautomeric equilibrium towards the 4-hydroxy-2(1*H*)-pyridinone form. A similar conclusion was previously quoted on the basis of uv spectra analysis [28]. In regard to the compounds under study the lack of hydrogen atoms precludes such an analysis and the most significant result is the important variation of the ^{15}N chemical shifts. From literature data it might be shown that the chemical shift values corresponding to typical pyridinone nitrogens lie in the range -210 to -225 ppm *e.g.* -212 for 2(1*H*)-pyridinone, -216 for *N*-methyl-2(1*H*)-pyridinone, -222 for 4(1*H*)-pyridinone [29]. The resonance obtained at -216.1 ppm for the unsubstituted **8** confirms the 4-hydroxy-2(1*H*)-pyridinone as the predominant form. The values for the nitrogen of pyridines substituted at their 2-position by an electron donor substituent are greater than -120 ppm *e.g.* -116 for 2-aminopyridine [30], -119 for 2-methoxypyridine [29]. By comparison and from the values obtained for the resonances of N-1 it might be inferred that compound **2** exits mainly in the pyridine form while carbolinone **1** corresponds essentially to the pyridinone form. A tautomeric equilibrium between the 2,4-dihydroxypyridine and 4-hydroxy-2(1*H*)-pyridinone forms is most likely occurring for the nitro compound **3**. The most extended electron delocalization pathway seems to play a major role in the position of the tautomeric equilibrium. In **2** the presence of the phenyl group at C-5 determines a direction for extended electron delocalization which involves C-2. An increased electron density favours the pyridine form. In contrast the simultaneous presence of a donor electron group at C-6 and of a withdrawing electron group at C-3 determines an extended electron delocalization pathway *via* C-3, C-6. The decrease of electron density at C-2 favours the 2(1*H*)-pyridinone form. This situation was realised for 4-hydroxy-2(1*H*)-pyridinones substituted at position 6 by a methyl group and bearing COOEt or $CONH_2$ groups at position 3 as the values of -217 and -223 ppm were respectively reported for the ring nitrogen atom [24]. For the carbolinone **1** where the indolic nitrogen has a strong donor mesomeric effect and which bears a strongly attractor NO_2 group at C-3, the 2(1*H*)-pyridinone form is more highly predominant. In the case of compound **3** where the chlorine atom at C-6 is a poor donor and which bears a phenyl group at C-5 both pathways are

available for electron delocalization and an equilibrium results between the 2-hydroxypyridine and 2(1*H*)-pyridinone tautomeric forms.

In regard to the carbon resonances, in compound **2** the signals of C-2 and C-4 are slightly broadened at ambient temperature and the chemical shifts are very similar. Contrarily for compound **3** and moreover for compound **1** the signal of C-4 is significantly broadened due to exchange modulated coupling while the signal of C-2 devoid of any coupling interaction is particularly narrow. The strong donor mesomeric effect of the indolic nitrogen in **1** is well reflected in the shielding of C-4a and C-3 with respect to the positions of C-5 and C-3 respectively in compound **3**.

EXPERIMENTAL

Melting points were measured on a Kofler or an Electrothermal apparatus and are uncorrected. The ^1H, ^{13}C and ^{15}N nmr spectra were recorded on a Bruker AM 500 or a Varian EM 390 spectrometer. The solvent was DMSO-d_6 unless otherwise specified. Chemical shifts are reported in ppm relative to tetramethylsilane for the ^1H and ^{13}C resonances and indirectly relative to neat nitromethane for the ^{15}N resonances, the secondary reference being the formamide in DMSO-d_6. For the INEPT sequence used for the ^{15}N spectra of indole and **1**: 90° ^1H and ^{15}N pulses were respectively 37.5 and 23 µs and delay adjusted to 1/4J. A broad band decoupled spectra was recorded for **1** while the other spectra were recorded without decoupling in order to avoid partial NOE effects leading to a possible vanishing of the resonances. The ir spectra were recorded on a Perkin-Elmer 1720 spectrometer, the uv spectra were measured with a Varian Cary 3E and the mass spectra were obtained with a Ribermag R10-10C apparatus. Commercially available reagents and solvents were used without further purification, except for benzylamine which needed to be freshly distilled. The yields indicated are the average of at least ten experiments.

6-Chloro-4-hydroxy-5-phenyl-2(1*H*)-pyridinone (**2**).

This compound was resynthesized according to a previously described technique [21] in a 52% yield. We report hereafter its ^1H nmr data (500 MHz, DMSO-d_6): δ 6.16 (s, H_3), 7.25 (m, $H_{2'}$ and $H_{6'}$), 7.34 (m, $H_{4'}$), 7.41 (m, $H_{3'}$ and $H_{5'}$), 10.91 (s, 1H), 11.15 (bs, 1H).

6-Chloro-4-hydroxy-3-nitro-5-phenyl-2(1*H*)-pyridinone (**3**).

To a stirred suspension of the phenylpyridinone **2** [21] (8.4 g, 38 mmoles) in acetic acid (85 ml), maintained at 15°, a solution of nitric acid (d = 1.52, 2.5 g, 1.7 ml, 39 mmoles) in acetic acid (85 ml) was slowly added (15 minutes). After stirring for 3 hours at room temperature, the reaction mixture was poured into water (1/l), the yellow precipitate was then collected and carefully washed with water. After drying, the pure nitro compound **3** weighed 9.4 g (98%), yellow crystals, mp 265-267° (acetic acid); ^1H nmr (500 MHz, DMSO-d_6): δ 7.32 (m, $H_{2'}$ and $H_{6'}$), 7.43 (m, $H_{4'}$), 7.47 (m, $H_{3'}$ and $H_{5'}$), 12.30 (bs, 2H); ir (potassium bromide): ν 1603 cm^{-1} (C=O); uv (ethanol): λ max (log ε) 203 (4.57), 240 (4.21), 353 (3.66); ms: (DCI^-, NH_3) m/z (%) 264-266 ($[M-H]^-$, 20-100).

Anal. Calcd. for $C_{11}H_7N_2O_4Cl$: C, 49.55; H, 2.65; N, 10.51; Cl, 13.13. Found: C, 49.49; H, 2.62; N, 10.30; Cl, 12.97.

6-Azido-4-hydroxy-3-nitro-5-phenyl-2(1*H*)-pyridinone (**4**).

A mixture of the nitrochloropyridinone **3** (5 g, 19 mmoles) and sodium azide (3.75 g, 57 mmoles) in DMF (20 ml) was heated under stirring during 2 hours in an oil bath at 80°. After cooling, the red reaction mixture was poured onto ice (100 g) and the resulting solution was acidified at 0° under a hood with 1*N* hydrochloric acid. The resulting yellow suspension was stirred one hour more, then allowed to separate (one night) and the supernatant was eliminated by careful decantation. The remaining precipitate was then washed by the same procedure with three portions of cold water (100 ml). The yellow solid was taken in 200 ml of water, collected and washed three times with 0.5 *N* hydrochloric acid (100 ml), then with water until neutral. After drying at room temperature under vacuum, the azide **4** (5 g, 98%), yellow crystals had mp 220-222° with deflagration (ethanol); ^1H nmr (90 MHz, DMSO-d_6): δ 7.18-7.76 (m, 5H), 13.00 (sh, 2H); ir (deuteriochloroform): ν 2137 (N_3), 1672 cm^{-1} (C=O); uv (ethanol): λ max (log ε) 200 (4.44), 293 (4.18), 425 (3.78); ms: (DCI, NH_3) m/z (%) 291 ($[M + NH_4]^+$, 100).

Anal. Calcd. for $C_{11}H_7N_5O_4$: C, 49.55; H, 2.65; N, 10.51. Found : C, 49.32; H, 2.44; N, 10.25.

4-Hydroxy-3-nitro-1*H*,9*H*-pyrido[2,3-*b*]indol-2-one (**1**).

A suspension of the azide **4** (5 g, 18 mmoles) in acetic acid containing 55 g of anhydrous hydrochloric acid per liter (150 ml) was heated with stirring in an oil bath at 100° for 8 hours. The solid azide dissolved when the temperature reached 80°; then, at 100°, the evolution of nitrogen started and the α-carbolinone **1** progressively precipitated. After cooling, the crystals were collected, washed three times with acetic acid (20 ml) then three times with anhydrous ether (30 ml). After drying, the compound **1** (3 g, 73%), yellow crystals, had mp >260° (pyridine 200 ml/g); ^1H nmr (500 MHz, DMSO-d_6): δ 7.23 (m, H_6), 7.27 (m, H_7), 7.45 (d, H_8, Jo = 7.5 Hz), 7.83 (d, H_5, Jo = 7.5 Hz), 12.08 (s, H_9), 12.9 and 13.7 (bs, OH and NH); ir (potassium bromide): ν 1671 cm^{-1} (C=O); uv (ethanol): λ max (log ε) 216 (4.68), 240 (4.27), 280 (4.41), 390 (4.13); ms: (DCI, NH_3) m/z (%) 263 ($[M + NH_4]^+$, 20), 246 $[M + H]^+$, 100).

Anal. Calcd. for $C_{11}H_7N_3O_4$: C, 53.87; H, 2.88; N, 17.14. Found: C, 54.07; H, 2.82; N, 16.90.

4-Acetoxy-1,9-diacetyl-3-nitro-1*H*,9*H*-pyrido[2,3-*b*]indol-2-one (**5**).

The acetylation of the α-carbolinone **1** (0.2 g, 0.7 mmole) was carried out in refluxing acetic anhydride (4 ml) for three hours. After cooling, the crystals were collected, washed with methanol, dried and the crude triacetate **5** was chromatographed (5 g of 230-400 mesh silica gel, elution with chloroform). The compound **5** (0.15 g, 50%), white crystals had mp 237-239° (acetic acid); ^1H nmr (90 MHz, deuteriochloroform): δ 2.40 (s, 3H, NAc), 2.55 (s, 3H, NAc), 3.00 (s, 3H, OAc), 7.26-7.86 (m, 3H arom), 8.60 (dd, 1H, H_5, J_o = 7.5 Hz, J_m = 1.5 Hz); ir (potassium bromide): ν 1801 and 1719 ($COCH_3$), 1626 cm^{-1} (C=O); uv (ethanol): λ max (log ε) 218 (4.52), 240 (4.29), 273 (4.27), 278 (4.27), 390 (3.75); ms: (DCI, NH_3) m/z (%) 389 ($[M + NH_4]^+$, 25), 372 $[M + H]^+$, 100).

Anal. Calcd. for $C_{17}H_{13}N_3O_7$: C, 54.98; H, 3.50; N, 11.32. Found: C, 55.12; H, 3.65; N, 11.44.

3,4-Dibenzylamino-1*H*,9*H*-pyrido[2,3-*b*]indol-2-one (**6**).

The α-carbolinone **1** (0.5 g, 2 mmoles) was refluxed for one hour in anhydrous freshly redistilled benzylamine (20 ml) under argon atmosphere. After evaporation of the excess of benzylamine under reduced pressure (0.1 Torr, 80°), the residue was taken in dichloromethane (20 ml) and left overnight at 0°. The precipitated crystals were collected and washed with cyclohexane, furnishing 0.24 g (30%) of the dibenzylamino derivative **6** as yellow-green crystals, mp 263-265°; ^{1}H nmr (90 MHz, DMSO-d_6): δ 2.90 (d, 1H, J = 12 Hz), 3.05 (d, 1H, J = 12 Hz), 4.45 (d, 1H, J = 15 Hz), 4.65 (d, 1H, J = 15 Hz), 6.75-7.30 (m, 13H), 7.65 (dd, 1H, H_5, J_o = 7.5 Hz, J_m = 1.5 Hz), 11.30 (bs, 4H); ir (potassium bromide): ν 3360 and 3337 (NH), 1621 cm^{-1} (C=O); uv (ethanol): λ max (log ε) 200 (4.53), 270 (4.67), 286 (4.52), 380 (3.93); ms: (DCI, NH_3) m/z (%) 395 ([M + H]$^+$, 100).

Anal. Calcd. for $C_{25}H_{22}N_4O$: C, 76.11; H, 5.62; N, 14.21. Found: C, 76.02; H, 5.68; N, 14.07.

3-Benzylamino-4-hydroxy-1*H*,9*H*-pyrido[2,3-*b*]indol-2-one (**7**).

The α-carbolinone **1** (0.5 g, 2 mmoles), benzylamine (12 ml) and water (0.2 ml) were stirred at room temperature for one hour, then refluxed with stirring for another one hour. After evaporation of benzylamine in excess under reduced pressure (0.1 Torr, 80°), the residue was taken in dichloromethane (15 ml). After two days at 0°, the precipitated crystals were collected and washed first with cold dichloromethane (-30°, 5 ml), then with pentane, furnishing 0.5 g (83%) of the monobenzylamino derivative **7** as yellow-green crystals, mp 158-160° dec; ^{1}H nmr (90 MHz, DMSO-d_6): δ 4.20 (s, 2H, CH_2), 6.90-7.55 (m, 8H), 7.80 (dd, 1H, H_5, J_o = 7.5 Hz, J_m = 1.5 Hz); ir (potassium bromide): ν 3200 (NH), 1625 cm^{-1} (C=O); uv (ethanol): λ max (log ε) 205 (4.51), 250 (4.39), 270 (4.06), 320 (3.91); ms: (70 eV) m/z (%) 305 ([M]$^+$, 10), 214 (20), 186 (25), 158 (20), 131 (15).

Anal. Calcd. for $C_{18}H_{15}N_3O_2$: C, 70.79; H, 4.95; N, 13.77. Found: C, 70.52; H, 5.12; N, 13.51.

4-Hydroxy-2(1*H*)-pyridinone (**8**).

This compound was from commercial origin (Aldrich). The nmr data (^{1}H, ^{13}C and ^{15}N) recorded under the same conditions as for the other compounds are listed hereafter: ^{1}H nmr (500 MHz, DMSO-d_6): δ 5.53 (d, H_3, J = 2.3 Hz), 5.83 (dd, H_5, J = 7.2 Hz and 2.3 Hz), 7.23 (d, H_6, J = 7.2 Hz), 10.7 and 11.1 (bs, OH and NH); ^{13}C nmr: δ 98.7 (C_3, ^{3}J C_3, H_5: 4.4 Hz), 100.3 (C_5, ^{2}J C_5, H_6: 2.9 Hz, ^{3}J C_5, H_3: 4.4 Hz), 136.1 (C_6, ^{1}J C_6, H_6: 179 Hz, ^{2}J C_6, H_5: 2.9 Hz), 165.0 (C_4, ^{3}J C_4, H_6: 8.8 Hz); 168.3 (C_2, ^{3}J C_2, H_6: 11.6 Hz, ^{2}J C_2, H_3: 2.9 Hz); ^{15}N nmr: δ -216.1 (N_1).

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