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Unexpected dimerization during hydrogenation of 2-(2-pyridylmethylene)-3(2*H*)-benzofuran-3-ones

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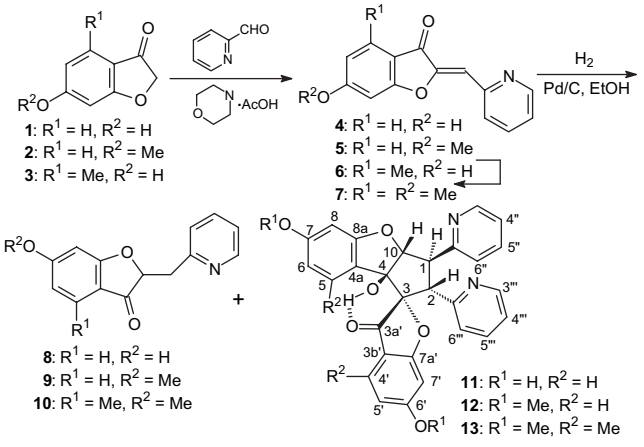
Abstract—Palladium catalyzed hydrogenation of 2-(2-pyridylmethylene)-3(2*H*)-benzofuran-3-ones (**1**–**3**) gave besides the expected 2,α-dihydro products **8**–**10** pentacyclic dimers formed by an attack of a semihydrogenated species on the substrate.

1. Introduction

For testing purposes a series of 2-(2-pyridylmethylene)-3(2*H*)-benzofuran-3-ones (**4**–**6**) were prepared by condensation of 3(2*H*)-benzofuran-3-ones (**1**–**3**) with pyridine-2-aldehyde in the presence of morpholine acetate (Scheme 1).[1]



Scheme 1.

Alkene **5** was subjected to catalytic hydrogenation over palladium-on-charcoal in ethanol. Owing to its poor solubility the substrate was added as a solid to the ethanolic suspension of the prehydrogenated catalyst. Unexpectedly hydrogen uptake completely stopped after the absorption of approximately 60% of the theoretically calculated volume. Chromatography of the product gave, apart from the expected 6-methoxy-2-(2-pyridylmethyl)-3(2*H*)-benzofuran-3-one (**9**), a substance with a mp 180 °C that even after several recrystallizations showed two complete sets of ^{1}H NMR signals in a 1:1 intensity ratio for the aromatic protons of the benzofuran and pyridine rings, as well as signals for a contiguous set of three aliphatic protons.

2. Results and discussion

2.1. Structural studies

Detailed spectroscopic studies summarized in Table 1 showed that the by-product of the hydrogenation of compound **5** was a dimer of structure **12** (see Scheme 1) in which one of the carbonyl groups was transformed into an alcohol. ^{1}H–^{1}H connectivities and the presence of five different spin systems were observed in the ^{1}H–^{1}H COSY spectrum, which also permitted complete ^{1}H signal assignment. The position of the H-5 signal (δ 6.57 ppm) indicated that, when compared to that of H-4′ (δ 7.50 ppm), H-5 was not *peri* to a carbonyl group. Furthermore, there was only one signal in the ^{13}C NMR spectrum, which could be assigned to a ketone. Long-range ^{1}H–^{13}C connectivities (HMBC spectrum) of the quaternary ^{13}C signals at 97.3 and 92.5 ppm (assigned to C-3 and C-4) gave further evidence for the postulated structure (**12**). The NOESY spectrum suggested that there was no steric proximity neither between H-1 and H-2 nor between H-1 and H-10. This indicated a trans–trans disposition, which was in agreement with the measured ^3J coupling constants.

Keywords: 2-Pyridylmethylene-3(2*H*)-benzofuran-3-ones; Hydrogenation; Dimerization.
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Table 1. NMR data for compound **12**

Position	δ_H, Multiplicities, intensities, and coupling constants	^1H–^1H COSY cross-peaks	δ_C	Significant HMBC correlations of the ^{13}C signal
1	4.63, dd, (1H), 12.8, 6.5 Hz	2-H, 10-H	54.2	2-H, 6″-H
2	4.88, d, (1H), 12.8 Hz	1-H	58.0	1-H, 6‴-H
3			97.3	2-H, 10-H
4			92.5	5-H, 10-H
4a			117.9	6-H, 8-H
5	6.56, d, (1H), 8.3 Hz	6-H	124.1	
6	6.26, dd, (1H), 8.3, 2.0 Hz	5-H, 8-H	107.6	8-H
7			162.2	5-H, 6-H, 8-H
8	6.42, d, (1H), 2 Hz	6-H	96.4	5-H, 6-H
8a			162.5	5-H, 6-H, 8-H, 10-H
10	5.35, d, (1H), 6.5 Hz	1-H	99.2	1-H, 2-H
3a′			198.0	2-H, 5′-H
3b′			114.8	4′-H, 5′-H, 7′-H
4′	7.49, d, (1H), 8.8 Hz	5′-H	125.1	
5′	6.52, dd, (1H), 8.8, 2.0 Hz	4′-H, 7′-H	112.4	4′-H, 7′-H
6′			168.8	4′-H, 7′-H, OCH_3
7′	6.10, d, (1H), 2.0 Hz	5′-H	95.5	4′-H
7a′			174.1	4′-H, 7′-H
1″			158.7	1-H, 2-H, 10-H, 4″-H
3″	8.59, dd, (1H), 4.9, 1.9 Hz	7.10	149.8	4″-H, 5″-H
4″	7.10, dd, (1H), 7.5, 4.9 Hz	8.59, 7.55	122.1	
5″	7.55, ddd, (1H), 7.5, 7.5, 1.9 Hz	7.10, 7.39	136.4	3″-H
6″	7.39, d, (1H), 7.5 Hz	7.55	124.3	
1‴			153.4	1-H, 2-H, 4‴-H
3‴	8.33, dd, (1H), 5.2, 1.5 Hz	6.91	148.8	4‴-H, 5‴-H
4‴	6.91, dd, (1H), 7.5, 5.2 Hz	8.33, 7.32	122.3	
5‴	7.32, ddd, (1H), 7.5, 7.5, 1.5 Hz	6.91, 7.06	136.0	3‴-H
6‴	7.06, d, (1H), 7.5 Hz	7.32	123.8	
OH	5.15, br s, (1H)			
OCH_3	3.74, s, (3H)		55.7	
OCH_3'	3.71, s, (3H)		56.1	

A total of 32 ^{13}C signals was observed, that confirmed the dimeric structure of **12**. Total signal assignment was possible on the basis of HMBC connectivities.

Chelation between the carbonyl and hydroxyl groups was indicated by a slowly developing color reaction with iron(III) chloride[2] and a bathochromic shift (ν_{CO} 1704→1672 cm^{-1}) of the carbonyl absorption[3] relative to that in the parent compound (**2**) enabling the assignment of the disposition of the spiro system.

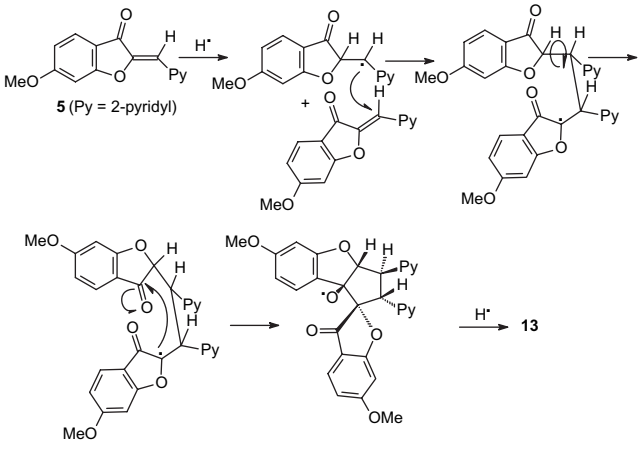
Finally mass spectrometry indicated for **12** a molecular mass of 508 corresponding to 2×**5**+2×H.

2.2. Investigations on other systems

Hydrogenation of compounds **4** and **7** proceeded similarly and provided along with the normal products (i.e., **8** and **10**) the dimers **11** and **13** both showing in their ^1H NMR spectra the duplication of the aromatic and pyridine signals, as well as signals for H-1, H-2, and H-10.

Although reactions other than π-bond saturation, such as hydrogen exchange, double bond migration, and cis–trans isomerization have been reported,[4] to our knowledge no intermolecular reactions accompanying catalytic hydrogenation have been observed.

A tentative mechanism shown in Scheme 2 is proposed for the formation of the dimers as exemplified by the transformation of **5**→**11**.



Scheme 2. Tentative mechanism for the formation of dimer **8**.

This mechanism is in conflict with the still widely accepted classical concept proposed more than 70 years ago by Horiuti and Polányi.[4,5] This postulates that the olefin adsorbed with its π-bond to the catalyst surface assumes, after the addition of one hydrogen atom a half-hydrogenated state, followed by the uptake of the second hydrogen atom. Even if the nature of the interaction of the olefin and the catalyst surface is disputed (dissociative or associative adsorption) it is supposed that the half-hydrogenated species remains on the catalyst until complete saturation.

Our results suggest that there exists a usually latent pathway along with the classical mechanism through which

a half-hydrogenated radical species can attack the olefin precursor. The question whether this occurs in solution or on the surface of the catalyst and how is the second hydrogen atom transferred to the dimeric radical remains open.

The scope of the above dimerization seems to be very narrow. Hydrogenation of 6-hydroxy-2-(3-pyridylmethylene)-3(2*H*)-benzofuran-3-one (**14**), 6-methoxy-2-(4-pyridylmethylene)-3(2*H*)-benzofuran-3-one (**15**), 6-hydroxy-2-(4-hydroxybenzylidene)-3(2*H*)-benzofuran-3-one[6] (**16**), and even of 2-(2-pyridylmethylene)-1-tetralone (**17**) (Fig. 1) only gave the regular dihydro products.

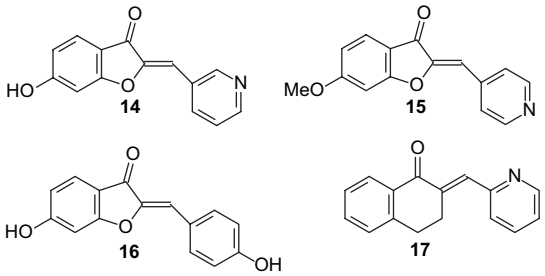


Figure 1.

3. Experimental

3.1. General

Infrared spectra were recorded on a Zeiss Specord IR 74 spectrometer as KBr pellets, ^{1}H (500 MHz) and ^{13}C (125 MHz) spectra were recorded on a Bruker DRX/Avance spectrometer. Fast atom bombardment (FAB/LSIMS) and daughter ion spectra were performed on a Finnigan MAT 95SQ hybrid tandem mass spectrometer. The Cs^+ gun was used at 20 kV and the matrix applied was 3-nitrobenzyl alcohol (NBA). For chromatography silica gel 60 (Merck) was used.

3.1.1. 6-Hydroxy-4-methyl-3(2*H*)-benzofuran-3-one (3). To a solution of orcinol (7.44 g, 60 mmol) and chloroacetonitrile (3.7 mL, 58 mmol) in dry diethyl ether (40 mL) was added powdered anhydrous zinc chloride (5 g). The mixture was cooled to 0 °C and saturated with hydrogen chloride gas. The next day the ether was decanted from the precipitated gummy imine hydrochloride. The rest of the solvent was removed in vacuo and the salt treated boiling water (300 mL). After cooling the precipitate was collected by filtration and dried to give the chloroketone (8.5 g). Without purification the latter was boiled for 15 min with potassium acetate (10 g) in methanol (75 mL). On cooling the product crystallized as needles (5.4 g, 77%), mp 245 °C. ν_{max} 3064, 1664, 1616, 1468, 1388, 1328, 1280, 1264, 1252, 1152, 1116, 1060, 1020, 856, 820, 768, 616, 528, 488 cm^{-1}; δ_H (DMSO-d_6) 2.41 (s, 3H, Me), (4.63, s, 2H, 2-H), 6.30 and 6.32 (2×s, 2H, 4,6-H), 10.77 (br s, 1H, OH). Anal. Calcd for $C_9H_8O_3$: C, 65.85; H, 4.91. Found: C, 65.72; H, 4.96.

3.1.2. 6-Hydroxy-2-(2-pyridylmethylene)-3(2*H*)-benzofuran-3-one (4). 6-Hydroxy-3(2*H*)-benzofuran-3-one[7] (**1**) (3.3 g, 22 mmol), pyridine-2-aldehyde (2.4 g 22 mmol), and morpholine acetate (0.6 g) was boiled with stirring in methanol (20 mL) for 2 h. The product was filtered off hot and washed with methanol to give pure **4** as yellow needles (3.5 g, 74%), mp 278–280 °C. ν_{max} 3440, 2352, 1704, 1600, 1564, 1456, 1424, 1400, 1344, 1304, 1252, 1224, 1216, 1152, 1104, 1008, 960, 944, 872, 832, 776, 680, 628, 496, 456 cm^{-1}; δ_H (DMSO-d_6) 6.68 (s, 1H, α-H), 6.74 (dd, *J* 8.2, 1.9 Hz, 1H, 5-H), 6.80 (d, *J* 1.9 Hz, 1H, 7-H), 7.39 (dd, *J* 7.5, 4.5 Hz, 1H, 4′-H), 7.65 (d, *J* 7.5 Hz, 1H, 6′-H), 7.92 (ddd, *J* 7.5, 7.5, 1.5 Hz, 1H, 5′-H), 8.15 (d, *J* 8.2 Hz, 1H, 4-H), 8.68 (dd, *J* 4.5, 1.5 Hz, 1H, 3′-H). Anal. Calcd for $C_{14}H_9NO_3$: C, 70.29; H, 3.79; N, 5.86. Found: C, 70.08; H, 3.86; N, 5.70.

3.1.3. 6-Methoxy-2-(2-pyridylmethylene)-3(2*H*)-benzofuran-3-one (5). Condensation of 6-methoxy-3(2*H*)-benzofuran-3-one[8] (**2**) with pyridine-2-aldehyde as described under **4** gave the title compound as yellow needles in 70% yield, mp 155–157 °C (from EtOH); ν_{max} 3432, 1704, 1616, 1504, 1440, 1328, 1280, 1196, 1152, 1128, 1104, 1016, 960, 888, 816, 776, 760, 544 cm^{-1}; δ_H ($CDCl_3$) 3.93 (s, 3H, OMe), 6.75 (dd, *J* 8.2, 1.5 Hz, 1H, 5-H), 6.78 (s, 1H, α-H), 6.95 (d, *J* 1.5 Hz, 1H, 7-H), 7.25 (m, 1H, 4′-H), 7.72 (d, *J* 7.5 Hz, 1H, 6′-H), 7.78 (ddd, *J* 7.5, 7.5, 1.5 Hz, 1H, 5′-H), 8.09 (d, *J* 8.2 Hz, 1H, 4-H), 8.73 (dd, *J* 4.5, 1.5 Hz, 1H, 3′-H); δ_{13} 56.3, 76.8, 77.2, 77.4, 77.6, 97.2, 111.5, 112.6, 114.7, 123.3, 126.2, 126.7, 136.7, 149.4, 150.4, 152.4, 167.9, 169.5, 183.1; FABMS (NBA): MH^+ 254, daughter ions: *m/z* 239, 226. Anal. Calcd for $C_{15}H_{11}NO_3$: C, 71.14; H, 4.38; N, 5.53. Found: C, 71.28; H, 4.42; N, 5.61.

3.1.4. 6-Hydroxy-4-methyl-2-(2-pyridylmethylene)-3(2*H*)-benzofuran-3-one (6). Condensation of 6-hydroxy-4-methyl-3(2*H*)-benzofuran-3-one (**3**) with pyridine-2-aldehyde as described for **4** gave the title compound as small yellow needles in 43% yield, mp 294–296 °C. ν_{max} 3440, 1696, 1664, 1616, 1580, 1472, 1352, 1288, 1184, 1152, 1052, 1008, 840, 784, 688, 628, 544 cm^{-1}; δ_H (DMSO-d_6) 2.48 (s, 3H, Me), 6.47 and 6.53 (2×d, *J* 2.0 Hz, 2H, 5- and 7-H), 6.60 (s, 1H, α-H), 7.31 (dd, *J* 7.5, 4.5 Hz, 1H, 4′-H), 7.80 (ddd, *J* 7.5, 7.5, 1.0 Hz, 1H, 5′-H), 8.15 (d, *J* 7.5 Hz, 1H, 6′-H), 8.86 (dd, *J* 4.5, 1.0 Hz, 1H, 3′-H). Anal. Calcd for $C_{15}H_{11}NO_3$: C, 71.14; H, 4.38; N, 5.53. Found: C, 71.06; H, 4.42; N, 5.62.

3.1.5. 6-Methoxy-4-methyl-2-(2-pyridylmethylene)-3(2*H*)-benzofuran-3-one (7). 6-Hydroxy-4-methyl-2-(2-pyridylmethylene)-3(2*H*)-benzofuran-3-one (**6**) (0.97 g, 3.8 mmol) was stirred in dry acetone (50 mL) in the presence of dry sodium hydrogen carbonate (2.4 g, 28 mmol) and dimethyl sulfate (0.4 mL, 4.3 mmol) for 24 h. Filtration and evaporation of the filtrate, and recrystallization of the residue from EtOH (14 mL) gave **7** as pale yellow needles (0.51 g, 50%), mp 168–169 °C. ν_{max} 2328, 1704, 1616, 1484, 1460, 1352, 1304, 1264, 1216, 1208, 1196, 1148, 1076, 1060, 1008, 832, 788, 768, 608, 544, 408 cm^{-1}; δ_H ($CDCl_3$) 2.62 (s, 3H, Me), 3.86 (s, 3H, OMe), 6.48 and 6.60 (2×d, *J* 2.0 Hz, 1H, 5- and 7-H), 6.90 (s, 1H, α-H), 7.19 (dd, *J* 7.5, 4.5 Hz, 1H, 4′-H), 7.73 (ddd, *J* 7.5, 7.5, 1.0 Hz, 1H, 5′-H), 8.08 (d, *J* 7.5 Hz, 1H, 6′-H), 8.70 (dd, *J* 4.5, 1.0 Hz, 1H, 3′-H). Anal. Calcd for $C_{16}H_{13}NO_3$: C, 71.90; H, 4.90; N, 5.24. Found: C, 71.93; H, 4.82; N, 5.30.

3.1.6. 6-Hydroxy-2-(2-pyridylmethyl)-3(2*H*)-benzofuran-3-one (8) and *rel*-1*S*,2*S*,3*S*,4*S*,10*R*-spiro[4,7-dihydroxy-1,2-bis-2-pyridyl-1,2,3,4-tetrahydro-1*H*-9-oxacyclopenta[*a*]indene-2′-(6-hydroxy-3(2*H*)-benzofuran-3-one)] (11). Hydrogenation of **4** (1.08 g, 5 mmol) was performed as described below (compound **9**). Extraction of the crude product with hot acetone (20 mL) gave **8** as colorless plates (0.35 g, 33%), mp 205–208 °C. Evaporation of the mother liquor yielded the dimer **11** as an amorphous powder (0.23 g, 21%), mp 203–204 °C.

Compound **8**: ν_{max} 3424, 3248, 1700, 1612, 1484, 1416, 1328, 1320, 1312, 1264, 1152, 1104, 1072, 1012, 840, 808, 768, 648, 544 cm^{-1}; δ_H (DMSO-d_6) 3.03 (dd, *J* 14.5, 9.5 Hz, 1H, α-H_1), 3.22 (dd, *J* 14.5, 3.8 Hz, 1H, α-H_2), 5.16 (dd, *J* 9.5, 3.8 Hz, 1H, 2-H), 6.42 (d, *J* 1.9 Hz, 1H, 7-H), 6.56 (dd, *J* 8.8, 1.9 Hz, 1H, 4-H), 7.24 (dd, *J* 7.5, 5.5 Hz, 1H, 4′-H), 7.33 (d, *J* 7.5 Hz, 1H, 6′-H), 7.46 (d, *J* 8.8 Hz, 1H, 4-H), 7.72 (ddd, *J* 7.5, 7.5, 1.5 Hz, 1H, 5′-H), 8.48 (dd, *J* 5.5, 1.5 Hz, 1H, 3′-H). Anal. Calcd for $C_{14}H_{11}NO_3$: C, 69.70; H, 4.60; N, 5.81. Found: C, 69.67; H, 4.63; N, 5.86.

Compound **11**: δ_H (DMSO-d_6) 4.30 (dd, *J* 13.2, 6.9 Hz, 1H, 1-H), 4.65 (d, *J* 13.2 Hz, 1H, 2-H), 5.06 (d, *J* 6.9 Hz, 1H, 10-H), 5.71 (br s, 1H, 7′-H), 6.14 (dd, *J* 8.5, 1.9 Hz, 1H, 6-H), 6.24 (d, *J* 1.9 Hz, 1H, 8-H), 6.26 (dd, *J* 8.5, 1.9 Hz, 1H, 5′-H), 6.42 (d, *J* 8.5 Hz, 1H, 5-H), 6.97 (dd, *J* 7.5, 4.5 Hz, 1H, 4‴-H), 7.09 (dd, *J* 7.5 Hz, 1H, 6‴-H), 7.19 (dd, *J* 7.5, 4.5 Hz, 1H, 4″-H), 7.26 (d, *J* 7.5 Hz, 1H, 6″-H), 7.37 (d, *J* 8.5 Hz, 1H, 4′-H), 7.43 (dd, *J* 7.5, 7.5 Hz, 1H, 5‴-H), 7.65 (dd, *J* 7.5, 7.5 Hz, 1H, 5″-H), 8.33 (d, *J* 4.5 Hz, 1H, 3‴-H), 8.53 (d, *J* 4.5 Hz, 1H, 3″-H). Anal. Calcd for $C_{28}H_{20}N_2O_6$: C, 69.99; H, 4.20; N, 5.83. Found: C, 69.80; H, 4.18; N, 5.80.

3.1.7. Hydrogenation of 6-methoxy-2-(2-pyridylmethylene)-3(2*H*)-benzofuran-3-one (5): 6-methoxy-2-(2-pyridylmethyl)-3(2*H*)-benzofuran-3-one (9) and *rel*-1*S*,2*S*,3*S*,4*S*,10*R*-spiro[4-hydroxy-7-methoxy-1,2-bis-2-pyridyl-1,2,3,4-tetrahydro-1*H*-9-oxacyclopenta[*a*]indene-2′-(6-methoxy-3(2*H*)-benzofuran-3-one)] (12). Palladium-on-carbon, (10%, 0.5 g) was prehydrogenated in ethanol (100 mL). The apparatus was opened, **5** (3.0 g, 11.8 mmol) was added as a solid and flushed with hydrogen. After rapid initial absorption hydrogen uptake stopped at about 60% of the theoretical amount (283 mL). After filtration and evaporation of the filtrate the residue was chromatographed (eluant: benzene–ethyl acetate, 2:1) to give 6-methoxy-2-(2-pyridylmethyl)-3(2*H*)-benzofuran-3-one (**9**) as colorless plates (0.7 g, 23%), mp 103–105 °C (from Et_2O) and the dimer **12** as colorless plates (0.31 g, 10%), mp 180–182 °C.

Compound **9**: ν_{max} 2928, 2384, 1620, 1508, 1444, 1376, 1252, 1156, 1028, 784, 616 cm^{-1}; δ_H ($CDCl_3$) 3.11 (dd, *J* 15.5, 9.5 Hz, 1H, α-H_1), 3.14 (dd, *J* 15.5, 3.5 Hz, 1H, α-H_2), 3.84 (s, 3H, OMe), 5.16 (dd, *J* 9.5, 3.5 Hz, 1H, 2-H), 6.59 (d, *J* 1.5 Hz, 1H, 7-H), 6.63 (dd, *J* 8.5, 1.5 Hz, 1H, 5-H), 7.17 (dd, *J* 7.5, 5 Hz, 1H, 4′-H), 7.24 (d, *J* 7.5 Hz, 1H, 6′-H), 7.57 (d, *J* 8.5 Hz, 1H, 4-H), 7.62 (ddd, *J* 7.5, 7.5, 1.5 Hz, 1H, 5′-H), 8.57 (dd, *J* 5, 1.5 Hz, 1H, 3′-H). Anal. Calcd for $C_{15}H_{13}NO_3$: C, 70.58; H, 5.13; N, 5.49. Found: C, 70.62; H, 5.02; N, 5.45.

Compound **12**: ν_{max} 3368, 3064, 3032, 3008, 1672, 1608, 1592, 1500, 1472, 1444, 1288, 1276, 1260, 1200, 1152, 1104, 1064, 1008, 760, 584 cm^{-1}; δ_H ($CDCl_3$) 3.71 and 3.74 (2×s, 2×3H, 2×OMe), 4.63 (dd, *J* 12.8, 6.5 Hz, 1H, 1-H), 4.88 (d, *J* 12.8 Hz, 1H, 2-H), 5.15 (br s, 1H, OH), 5.35 (d, *J* 6.5 Hz, 1H, 10-H), 6.10 (d, *J* 2.0 Hz, 1H, 7′-H), 6.26 (d, *J* 8.3, 2.0 Hz, 1H, 6-H), 6.42 (d, *J* 2.0 Hz, 1H, 8-H), 6.52 (dd, *J* 8.8, 2.0 Hz, 1H, 5′-H), 6.56 (d, *J* 8.3 Hz, 1H, 5-H), 6.91 (dd, *J* 7.5, 5.2 Hz, 1-H, 4‴-H), 7.06 (d, *J* 7.5, 1H, 6‴-H) 7.10 (dd, *J* 7.5, 4.9 Hz, 1H, 4″-H), 7.32 (ddd, *J* 7.5, 7.5, 1.5 Hz, 1H, 5‴-H), 7.39 (d, *J* 7.5, 1H, 6″-H), 7.49 (d, *J* 8.8 Hz, 1H, 4′-H), 7.55 (ddd, *J* 7.5, 7.5, 1.5 Hz, 1H, 5″-H), 8.33 (dd, *J* 5.2, 1.5 Hz, 1H, 3‴-H), 8.59 (dd, *J* 4.9, 1.9 Hz, 1H, 3″-H); δ_{13} ($CDCl_3$) 54.2 (C-1), 55.7 (OMe), 56.1 (OMe), 58.0 (C-2), 92.5 (C-4), 95.5 (C-7′), 96.4 (C-7), 97.3 (C-3), 99.2 (C-9), 107.6 (C-5), 112.4 (C-5′), 114.8 (C-3b′), 117.9 (C-3b), 122.1 (C-4″), 122.3 (C-4‴), 123.8 (C-6‴), 124.1 (C-4), 124.3 (C-6″), 125.1 (C-4′), 136.0 (C-5‴), 136.4 (C-5″), 148.77 (C-3‴), 148.83 (C-3″), 153.4 (C-1‴), 158.7 (C-1″), 162.2 and 162.5 (C-6 and C-7a), 168.8 (C-6′), 174.1 (C-7a′), 198.0 (C-3a′); FABMS (NBA): MH^+ 509, daughter ions: *m/z* 519, 268. Anal. Calcd for $C_{30}H_{24}N_2O_6$: C, 70.86; H, 4.76; N, 5.51. Found: C, 70.90; H, 4.80; N, 5.55.

3.1.8. 6-Methoxy-4-methyl-2-(2-pyridylmethyl)-3(2*H*)-benzofuran-3-one (10) and *rel*-1*S*,2*S*,3*S*,4*S*,10*R*-spiro[4-hydroxy-7-methoxy-5-methyl-1,2-bis-2-pyridyl-1,2,3,3a-tetrahydro-1*H*-8-oxacyclopenta[*a*]indene-2′-(6-methoxy-4-methyl-3(2*H*)-benzofuran-3-one)] (13). Hydrogenation of **7** (396 mg, 1.48 mmol) was performed as described for **5**. Chromatography of the crude product (eluant: PhMe–EtOAc, 2:1) gave **10** as colorless needles (119 mg, 30%), mp 76–78 °C and (**13**) as an amorphous powder (83 mg, 21%), mp 247–248 °C.

Compound **10**: ν_{max} 3384, 3024, 1656, 1616, 1456, 1440, 1352, 1344, 1332, 1316, 1272, 1200, 1148, 1052, 1040, 944, 808, 752, 696, 544, 496 cm^{-1}; δ_H ($CDCl_3$) 2.52 (s, 3H, CH_3), 3.08 (dd, *J* 15.5, 9.5 Hz, 1H, α-H_1), 3.53 (dd, *J* 15.5, 3.5 Hz, 1H, α-H_2), 3.81 (s, 3H, OCH_3), 5.09 (dd, *J* 9.5, 3.5 Hz, 1H, 2-H), 6.34 (d, *J* 2.0 Hz, 1H, 6-H), 6.37 (m, 1H, 4-H), 7.16 (dd, *J* 7.5, 5.5 Hz, 1H, 4′-H), 7.25 (d, *J* 7.5 Hz, 1H, 6′-H), 7.63 (ddd, *J* 7.5, 7.5, 1.5 Hz, 1H, 5′-H), 8.57 (dd, *J* 5.5, 1.5 Hz, 1H, 3′-H). Anal. Calcd for $C_{16}H_{15}NO_3$: C, 71.36; H, 5.61; N, 5.20. Found: C, 71.24; H, 5.42; N, 5.41.

Compound **13**: ν_{max} 3424, 3240, 2592, 1960, 1700, 1648, 1616, 1516, 1484, 1428, 1416, 1356, 1312, 1288, 1168, 1152, 1124, 1104, 1084, 1072, 1028, 1012, 976, 904, 860, 840, 820, 808, 792, 768, 760, 752, 660, 648, 636, 624, 612, 596, 584, 576, 520, 504, 464, 440, 428 cm^{-1}; δ_H ($CDCl_3$) 2.15, 2.50 (2×s, 2×Me, 6H), 3.71, 3.73 (2×s, 2×OMe, 6H), 4.63 (dd, *J* 13.0, 6.5 Hz, 1H, 1-H), 4.81 (d, *J* 13.0 Hz, 1H, 2-H), 5.31 (d, *J* 6.5 Hz, 1H, 10-H), 5.64 (br s, 1H, OH), 5.98 (d, *J* 2.0 Hz, 1H, 7′-H), 6.09 (m, 1H, 6-H), 6.21 (m, 1H, 5′-H), 6.24 (d, *J* 2.0 Hz, 1H, 8-H), 6.90 (ddd, *J* 7.5, 5.0, 1.5 Hz, 1H, 4‴-H), 7.05–7.10 (m, 2H, 4″- and 6‴-H), 7.31 (ddd, *J* 7.5, 7.5, 1.5 Hz, 1H, 5‴-H), 7.36 (d, *J* 7.5 Hz, 1H, 6″-H), 7.63 (ddd, *J* 7.5, 7.5, 2.0 Hz, 1H, 5″-H), 8.32 (dd, *J* 5.0, 1.5 Hz, 1H, 3″-H), 8.58 (dd, *J* 5.0, 1.5 Hz, 1H, 3″-H); FABMS (NBA): MH^+ 537, daughter ions: *m/z* 519, 268. Anal. Calcd for

$C_{32}H_{28}N_2O_6$: C, 71.63; H, 5.26; N, 5.22. Found: C, 71.70; H, 5.32; N, 5.18.

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