An Efficient and Facile Microwave-assisted Synthesis of Benzo[*b*][4,7]phenanthroline Derivatives in Water

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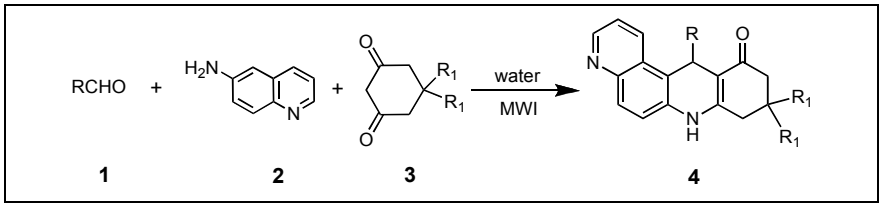

A series of benzo[*b*][4,7]phenanthroline derivatives were synthesized *via* a three-component reaction of aromatic aldehydes, 6-aminoquinoline and either 1,3-cyclohexanedione or dimedone in water under microwave irradiation without use of any catalyst. This method has the advantages of short reaction time, high yields, low cost and environmental friendliness as well as easy operation.

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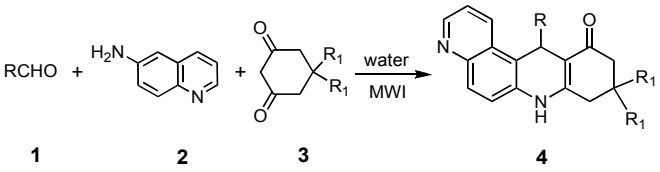
INTRODUCTION

Organic reactions in water have become an important research area. Many reactions have been accomplished in aqueous medium, such as Michael reaction [1], Claisen rearrangement [2], Mannich reaction [3], Reformatsky reaction [4], Tsuj-Trost reaction [5], Barbier-type reaction [6], Aldol-Type reaction [7], Fries rearrangement reaction [8] and Kröhnke reaction [9]. Water has therefore become an attractive medium for many organic reactions, not only for the advantages concerning the avoidance of expensive drying reactants, catalysts and solvents, but also for some unique reactivity and selectivity [10,11]. Similarly, microwave-enhanced procedures have proved highly useful in organic chemistry due to greater reaction control and high reaction rates [12]. Under microwave irradiation (MWI), water is rapidly heated to high temperatures, enabling it to act as a less polar pseudo-organic solvent. Moreover, precise control of the reaction temperature is easily achieved because of the very high heat capacity of water [13].

Compounds with the 4,7-phenanthroline motif which are analogs of ergot alkaloids, possess high and versatile pharmacological effects, such as serotonin antagonism, vasoconstriction, oxytocic and psychotropic activities [14]. And they are also used as inhibitors of the pituitary hormone prolactin [15] and fungicides [16]. Hence, the preparation of this heterocyclic unit has gained much attention.

Kozlov Gusak [17] and co-workers have reported the synthesis of 4,7-phenanthroline derivatives using 1-butanol as solvent by refluxing, the procedure was complicated and toxic reagents such as benzene were used. Therefore, the development of a simple and clean method for the preparation of this skeleton is still strongly desirable. Interested in the bioactivities of the 4,7-phenanthroline skeleton and clean reaction procedure, we would like to report a facile, rapid and green methodology for the synthesis of benzo[*b*][4,7]phen-anthroline derivatives by three-component condensations in water under microwave irradiation (Scheme 1).

Scheme 1



RESULTS AND DISCUSSION

To explore the scope and versatility of this method, various reaction conditions were investigated, including solvent and temperature variations. Highlighted in Table 1 for compound **4a** for example, is the influence of solvent and temperature on the reaction yield. The MW-assisted reaction of 4-fluorobenzaldehyde (**1a**, 1.0 mmol), 6-aminoquinoline (**2**, 1.0 mmol) and 1,3-cyclohexanedione (**3**, 1.0 mmol) was examined using glycol, glacial acetic acid, ethanol and *N*,*N*-dimethylformamide as solvent (2.0 mL) at 100 °C, respectively. All reactions were carried out at the maximum power of 250 W. The results were summarized in Table 1.

It is shown in Table 1 that the reaction using glycol or water as the solvent resulted in higher yields and shorter reaction time than those using AcOH, DMF or EtOH as solvents (Entries 1–5, Table 1). Considering environmental friendliness and the avoidance of using toxic organic reagents, water was chosen as the solvent for all further microwave-assisted reactions.

To further optimize reaction conditions, the same reaction was carried out in water at temperatures ranging from 90 to 140 °C, with an increment of 10 °C each time. The yield of product **4a** was increased and the reaction time was shortened as the temperature was increased from 90 °C to 120 °C (Table 1, entries 6-8). However, further increase of the temperature to 130-140 °C failed to improve the yield of product **4a** (Table 1, entries 9-10). Therefore, 120 °C was chosen as the reaction temperature for all further microwave-assisted reactions.

Table 1

Optimization of reaction conditions of compound **4a**

Entry	Solvent	T / °C	Time / min	Yield / %
1	Glycol	100	10	89
2	HOAc	100	12	80
3	EtOH	100	14	79
4	water	100	10	88
5	DMF	100	13	75
6	water	90	12	84
7	water	110	9	90
8	water	120	8	91
9	water	130	8	90
10	water	140	8	89

The maximum power of microwave irradiation was optimized by carrying out the same reaction at powers of 100, 150, 200, 250 and 300 W respectively, using water as solvent at 120 °C (Table 2). When the power was at 100–200 W, the time taken for the temperature to reach 120 °C was too long. Microwave irradiation at 250 W gave the highest yield and the maximum temperature reached during the reaction was 122 °C. Therefore, microwave power of 250 W was chosen as the optimum power.

Table 2

Power optimization of reaction conditions of compound **4a** under microwave irradiation.

Entry	Power / W	Time / min	Yield / %
1	100	8	79
2	150	8	83
3	200	8	86
4	250	8	91
5	300	8	90

The use of these optimal microwave experimental conditions [water, 120 °C, 250 W (Maximum power)] for the reactions of different aromatic aldehydes afforded good yields of benzo[*b*][4,7]phenanthroline derivatives. The results (Table 3, entries 1-11) show that aromatic aldehydes bearing either electron-donating (such as alkoxyl groups) or electron-withdrawing (such as nitro or halide groups) functional groups were able to affect the synthesis of compounds **4**. Moreover, a heterocyclic aldehyde, thiophene-2-carbaldehyde (Table 3, entries 12), still showed high reactivity and clean reaction under these standard conditions.

Although the detailed mechanism of the above reaction remains to be fully clarified, the formation of benzo-[*b*][4,7]phenanthrolin **4** could be explained by a possible reaction sequence presented in Scheme 2. The product **4** may be synthesized *via* sequential condensation, addition, cyclization and elimination. The condensation between aldehydes **1** and 1,3-cyclohexanedione or dimedone **3** lead to intermediate **5**, Michael addition between **5** and **2** would give **6**, which upon intermolecular cyclization and dehydration, would generate the product **4**.

In this study, all the products were characterized by mp, IR and ^{1}H NMR spectral data as well as elemental analyses. Furthermore, the structure of **4d** [18] was established by X-ray crystallographic analysis. The molecular structure of **4d** was shown in Figure 1.

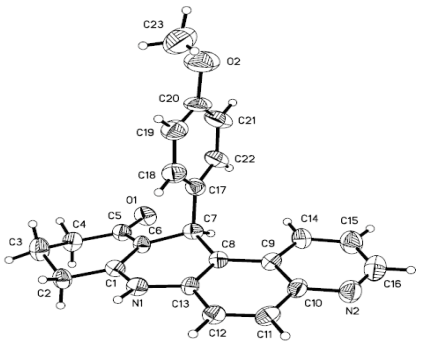


Figure 1. ORTEP diagram of **4d**.

In summary, we have developed a three-component reaction of an aldehyde, 6-aminoquinoline and either 1,3-cyclohexanedione or dimedone in high-temperature water, and have shown its application to the synthesis of a number of benzo[*b*][4,7]phenanthroline derivatives. This green procedure offers several advantages including operational simplicity, clean reactions, increased safety for small-scale high-speed synthesis, and minimal environmental impact that make it a useful and attractive process for the synthesis of these compounds.

EXPERIMENTAL

Microwave irradiation was carried out with a microwave oven Emrys™ Creator from Personal Chemistry, Uppsala, Sweden. Melting points were determined in the open capillaries and were uncorrected. IR spectra were taken on a FT-IR-Tensor 27 spectrometer in KBr pellets and reported in cm^{-1}. ^{1}H NMR spectra were measured on a Bruker DPX 400 MHz spectrometer using TMS as an internal standard and DMSO-d_6 as solvent. Elemental analysis was determined by using a Perkin-Elmer 240c elemental analysis instrument.

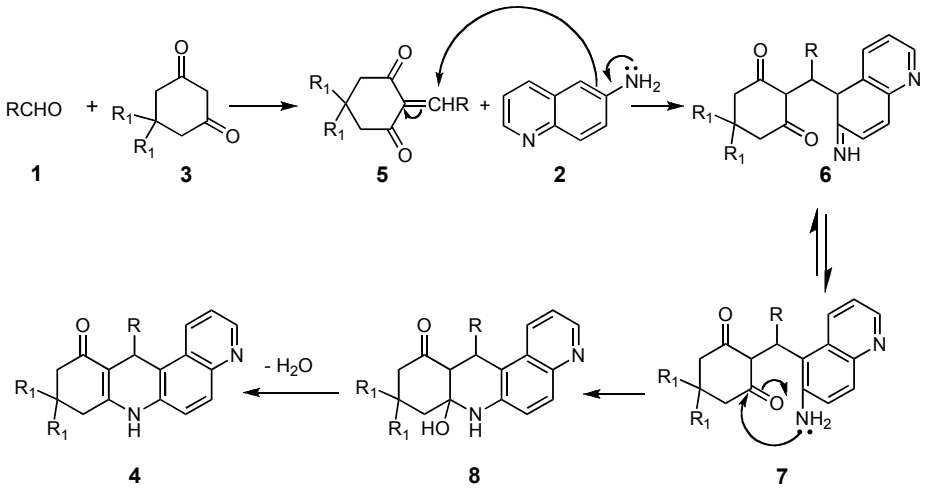
General procedure for the one-pot synthesis of benzo[*b*]-[4,7]phenanthroline derivatives 4 in water under microwave irradiation conditions. Typically, in a 10-mL Emrys™ reaction vial, aldehyde **1** (1 mmol), 6-aminoquinoline **2** (1 mmol), 1,3-cyclohexanedione or dimedone **3** (1 mmol) and water (2 mL)

Table 3

Synthesis of **4** under microwave irradiation at 120 °C

Entry	Product	R	R_1	Time / min	Yield / %	Mp / °C
1	**4a**	4-FC_6H_4	H	8	91	>300
2	**4b**	4-ClC_6H_4	H	7	93	>300
3	**4c**	4-BrC_6H_4	H	6	94	>300
4	**4d**	4-$CH_3OC_6H_4$	H	6	95	>300
5	**4e**	2,4-$Cl_2C_6H_3$	H	7	94	>300
6	**4f**	3,4-$(CH_3O)_2C_6H_3$	H	8	92	>300
7	**4g**	3-$NO_2C_6H_4$	H	9	90	>300
8	**4h**	3,4-$OCH_2OC_6H_3$	H	6	95	>300
9	**4i**	2-ClC_6H_4	H	5	96	>300
10	**4j**	C_6H_5	H	5	97	>300
11	**4k**	4-OH-3-$NO_2C_6H_3$	H	9	90	>300
12	**4l**	thiophen-2-yl	H	8	91	>300
13	**4m**	4-FC_6H_4	CH_3	9	93	>300
14	**4n**	4-ClC_6H_4	CH_3	8	92	>300
15	**4o**	4-BrC_6H_4	CH_3	7	94	>300
16	**4p**	4-$CH_3OC_6H_4$	CH_3	5	95	>300
17	**4q**	2,4-$Cl_2C_6H_3$	CH_3	9	91	>300
18	**4r**	3,4-$(CH_3O)_2C_6H_3$	CH_3	8	92	>300
19	**4s**	3-$NO_2C_6H_4$	CH_3	5	95	>300
20	**4t**	3,4-$OCH_2OC_6H_3$	CH_3	7	93	>300
21	**4u**	2-ClC_6H_4	CH_3	7	93	>300
22	**4v**	C_6H_5	CH_3	9	92	>300
23	**4w**	4-OH-3-$NO_2C_6H_3$	CH_3	8	93	>300
24	**4x**	thiophen-2-yl	CH_3	6	94	>300

Scheme 2



were mixed and then capped. The mixture was irradiated for a given time at 120 °C under microwave irradiation (initial power 200 W and maximum power 250 W). Upon completion, monitored by TLC, the reaction mixture was filtered to give the crude product, which was further purified by recrystallization from EtOH (95%) to give pure benzo[*b*][4,7]-phenanthroline derivatives **4**.

12-(4-Fluorophenyl)-9,10-dihydrobenzo[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4a). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3257, 3066, 3022, 1603, 1514, 1426, 1386, 1280, 1187, 1093, 961cm^{-1}; ^{1}H nmr: δ 9.95 (s, 1H, NH), 8.67 (s, 1H, ArH), 8.34 (d, 1H, J = 8.4 Hz, ArH), 7.89 (d, 1H, J = 8.8 Hz, ArH), 7.56 (d, 1H, J = 9.2 Hz, ArH), 7.38-7.41 (m, 1H, ArH), 7.23-7.26 (m, 2H, ArH), 6.96 (t, 2H, J = 8.8 Hz, ArH), 5.85 (s, 1H, CH), 2.62 (s, 2H, CH_2), 2.25-2.28 (m, 2H, CH_2), 1.76-1.95 (m, 2H, CH_2). *Anal*. calcd for $C_{22}H_{17}FN_2O$: C, 76.73; H, 4.98; N, 8.13. Found: C, 76.70; H, 4.99; N, 8.10.

12-(4-Chlorophenyl)-9,10-dihydrobenzo[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4b). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3251, 3069, 3023, 1603, 1515, 1489, 1387, 1281, 1189, 1091, 961cm^{-1}; ^{1}H nmr: δ 9.95 (s, 1H, NH), 8.67-8.68 (m, 1H, ArH), 8.32 (d, 1H, J = 8.8 Hz, ArH), 7.90 (d, 1H, J = 8.8

Hz, ArH), 7.56 (d, 1H, J = 9.2 Hz, ArH), 7.39-7.42 (m, 1H, ArH), 7.19-7.25 (m, 4H, ArH), 5.84 (s, 1H, CH), 2.61-2.62 (m, 2H, CH_2), 2.22-2.34 (m, 2H, CH_2), 1.77-1.94 (m, 2H, CH_2). *Anal.* calcd for $C_{22}H_{17}ClN_2O$: C, 73.23; H, 4.75; N, 7.76. Found C, 73.25; H, 4.74; N, 7.75.

12-(4-Bromophenyl)-9,10-dihydrobenzo[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4c). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3250, 3190, 3096, 1602, 1514, 1464, 1336, 1236, 1141, 1099, 961, 802 cm^{-1}; ^1H nmr: δ 9.96 (s, 1H, NH), 8.67-8.68 (m, 1H, ArH), 8.31 (d, 1H, J = 8.8 Hz, ArH), 7.90 (d, 1H, J = 8.8 Hz, ArH), 7.56 (d, 1H, J = 8.8 Hz, ArH), 7.38-7.41(m, 1H, ArH), 7.33 (d, 2H, J = 8.0 Hz, ArH), 7.18 (d, 2H, J = 8.4 Hz , ArH), 5.83 (s, 1H, CH), 2.61-2.62 (m, 2H, CH_2), 2.25-2.26 (m, 2H, CH_2), 1.77-1.95 (m, 2H, CH_2). *Anal.* calcd for $C_{22}H_{17}BrN_2O$: C, 65.20; H, 4.23; N, 6.91. Found C, 65.22; H, 4.25; N, 6.90.

9,10-Dihydro-12-(4-methoxyphenyl)benzo[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4d). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3261, 3191, 3025, 1603, 1513, 1422, 1386, 1279, 1189, 1030, 962 cm^{-1}; ^1H nmr: δ 9.86 (s, 1H, NH), 8.66-8.67 (m, 1H, ArH), 8.34 (d, 1H, J = 8.4 Hz, ArH), 7.87 (d, 1H, J = 8.8 Hz, ArH), 7.54 (d, 1H, J = 9.2 Hz, ArH), 7.38-7.41 (m, 1H, ArH), 7.12 (d, 2H, J = 8.0 Hz, ArH), 6.69 (d, 2H, J = 8.0 Hz, ArH), 5.77 (s, 1H, CH), 3.61 (s, 3H, OCH_3), 2.60-2.61 (m, 2H, CH_2), 2.23-2.24 (m, 2H, CH_2), 1.91-1.96 (m, 2H, CH_2). *Anal.* calcd for $C_{23}H_{20}N_2O_2$: C, 77.51; H, 5.66; N, 7.86. Found C, 77.55; H, 5.64; N, 7.85.

12-(2,4-Dichlorophenyl)-9,10-dihydrobenzo[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4e). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3260, 3190, 3095, 1615, 1602, 1517, 1466, 1342, 1236, 1163, 1006, 958, 818 cm^{-1}; ^1H nmr: δ 10.03 (s, 1H, NH), 8.67-8.68 (m, 1H, ArH), 8.41 (d, 1H, J = 8.4 Hz, ArH), 7.89 (d, 1H, J = 8.8 Hz, ArH), 7.53 (d, 1H, J = 8.8 Hz, ArH), 7.44-7.47 (m, 1H, ArH), 7.40 (s, 1H, ArH), 7.34 (d, 1H, J = 8.4 Hz, ArH), 7.23 (d, 1H, J = 8.8 Hz, ArH), 6.02 (s, 1H, CH), 2.63-2.64 (m, 2H, CH_2), 2.20-2.27 (m, 2H, CH_2), 1.77-1.94 (m, 2H, CH_2). *Anal.* calcd for $C_{22}H_{16}Cl_2N_2O$: C, 66.85; H, 4.08; N, 7.09. Found C, 66.88; H, 4.05; N, 7.10.

9,10-Dihydro-12-(3,4-dimethoxyphenyl)benzo[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4f). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3259, 3195, 3100, 2950, 1605, 1516, 1464, 1337, 1236, 1138, 1023, 964, 808 cm^{-1}; ^1H nmr: δ 9.87 (s, 1H, NH), 8.66-8.67 (m, 1H, ArH), 8.39 (d, 1H, J = 8.8 Hz, ArH), 7.87 (d, 1H, J = 8.8 Hz, ArH), 7.54 (d, 1H, J = 8.8 Hz, ArH), 7.39-7.42 (m, 1H, ArH), 7.00 (s, 1H, ArH), 6.67 (d, 1H, J = 8.0 Hz, ArH), 6.51 (d, 1H, J = 8.4 Hz, ArH), 5.78 (s, 1H, CH), 3.65 (s, 3H, OCH_3), 3.59 (s, 3H, OCH_3), 2.62 (s, 2H, CH_2), 2.26 (s, 2H, CH_2), 1.78-1.96 (m, 2H, CH_2). *Anal.* calcd for $C_{24}H_{22}N_2O_3$: C, 74.59; H, 5.74; N, 7.25. Found C, 74.56; H, 5.75; N, 7.24.

9,10-Dihydro-12-(3-nitrophenyl)benzo[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4g). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3273, 3193, 3098, 2941,1605, 1525, 1426, 1352, 1234, 1188, 1095, 963, 806 cm^{-1}; ^1H nmr: δ 10.07 (s, 1H, NH), 8.67-8.68 (m, 1H, ArH), 8.37 (d, 1H, J = 8.0 Hz, ArH), 8.09 (s, 1H, ArH), 7.90-7.95 (m, 2H, ArH), 7.59-7.66 (m, 2H, ArH), 7.39-7.48 (m, 2H, ArH), 6.02 (s, 1H, CH), 2.64 (s, 2H, CH_2), 2.26-2.30 (m, 2H, CH_2), 1.76-1.95 (m, 2H, CH_2). *Anal.* calcd for $C_{22}H_{17}N_3O_3$: C, 71.15; H, 4.61; N, 11.31. Found C, 71.16; H, 4.60; N, 11.30.

12-(Benzo[*d*][1,3]dioxol-5-yl)-9,10-dihydrobenzo[*b*][4,7]-phenanthrolin-11(7*H*,8*H*,12*H*)-one (4h). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3254, 3192, 3100, 1656, 1603, 1517, 1466, 1335, 1236, 1133, 1040, 963, 812 cm^{-1}; ^1H nmr: δ 9.88 (s, 1H, NH), 8.67-8.68 (m, 1H, ArH), 8.36 (d, 1H, J = 8.8 Hz, ArH), 7.88 (d, 1H, J = 9.2 Hz, ArH), 7.55 (d, 1H, J = 9.2 Hz, ArH), 7.40-7.43 (m, 1H, ArH), 6.79 (s, 1H, ArH), 6.60-6.67 (m, 2H, ArH), 5.86-5.88 (m, 2H, CH_2), 5.76 (s, 1H, CH), 2.62 (s, 2H, CH_2), 2.25-2.26 (m, 2H, CH_2), 1.78-1.96 (m, 2H, CH_2). *Anal.* calcd for $C_{23}H_{18}N_2O_3$: C, 74.58; H, 4.90; N, 7.56. Found C, 74.60; H, 4.88; N, 7.60.

12-(2-Chlorophenyl)-9,10-dihydrobenzo[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4i). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3251, 3069, 3023, 1603, 1515, 1489, 1387, 1281, 1189, 1091, 961 cm^{-1}; ^1H nmr: δ 10.00 (s, 1H, NH), 8.66-8.67 (m, 1H, ArH), 8.48 (d, 1H, J = 8.4 Hz, ArH), 7.87 (d, 1H, J = 9.2 Hz, ArH), 7.54 (d, 1H, J = 8.8 Hz, ArH), 7.43-7.46 (m, 1H, ArH), 7.33 (d, 1H, J = 7.6 Hz, ArH), 7.25 (d, 1H, J = 8.0 Hz, ArH), 7.13 (t, 1H, J = 7.6 Hz, ArH), 7.05 (d, 1H, J = 7.2 Hz, ArH), 6.04 (s, 1H, CH), 2.64-2.66 (m, 2H, CH_2), 2.20-2.27 (m, 2H, CH_2), 1.77-1.96 (m, 2H, CH_2). *Anal.* calcd for $C_{22}H_{17}ClN_2O$: C, 73.23; H, 4.75; N, 7.76. Found C, 73.22; H, 4.76; N, 7.75.

9,10-Dihydro-12-phenylbenzo[*b*][4,7]phenanthrolin-11-(7*H*,8*H*,12*H*)-one (4j). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3248, 3065, 3021, 1604, 1513, 1493, 1385, 1278, 1139, 1029, 961 cm^{-1}; ^1H nmr: δ 9.89 (s, 1H, NH), 8.66-8.67 (m, 1H, ArH), 8.35 (d, 1H, J = 8.8 Hz, ArH), 7.88 (d, 1H, J = 8.8 Hz, ArH), 7.56 (d, 1H, J = 8.8 Hz, ArH), 7.38-7.41 (m, 1H, ArH), 7.23 (d, 2H, J = 7.6Hz, ArH), 7.13 (t, 2H, J = 7.6 Hz, ArH), 7.00 (t, 1H, J = 7.2 Hz, ArH), 5.83 (s, 1H, CH), 2.61-2.64 (m, 2H, CH_2), 2.25-2.26 (m, 2H, CH_2), 1.77-1.96 (m, 2H, CH_2). *Anal.* calcd for $C_{22}H_{18}N_2O$: C, 80.96; H, 5.56; N, 8.58. Found C, 80.95; H, 5.55; N, 8.60.

9,10-Dihydro-12-(4-hydroxy-3-nitrophenyl)benzo[*b*][4,7]-phenanthrolin-11(7*H*,8*H*,12*H*)-one (4k). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3250, 3183, 3062, 1602, 1515, 1463, 1387, 1280, 1189, 1038, 957 cm^{-1}; ^1H nmr: δ 10.63-10.64 (m, 1H, OH), 9.93 (s, 1H, NH), 8.68-8.69 (m, 1H, ArH), 8.35 (d, 1H, J = 8.4 Hz, ArH), 7.91 (d, 1H, J = 9.6 Hz, ArH), 7.71-7.72 (m, 1H, ArH), 7.57 (d, 1H, J = 8.4 Hz, ArH), 7.40-7.43 (m, 1H, ArH), 7.36 (dd, 1H, J_1 = 8.0 Hz, J_2 = 1.6 Hz, ArH), 6.93 (d, 1H, J = 8.4 Hz, ArH), 5.85 (s, 1H, CH), 2.62-2.64 (m, 2H, CH_2), 2.27-2.34 (m, 2H, CH_2), 1.82-1.99 (m, 2H, CH_2). *Anal.* calcd for $C_{22}H_{17}N_3O_4$: C, 68.21; H, 4.42; N, 10.85. Found C, 68.22; H, 4.45; N, 10.84.

9,10-Dihydro-12-(thiophen-2yl)benzo[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4l). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3253, 3194, 3099, 2956, 1606, 1516, 1424, 1336, 1234, 1188, 1075, 961, 814 cm^{-1}; ^1H nmr: δ 10.01 (s, 1H, NH), 8.72-8.73 (m, 1H, ArH), 8.43 (d, 1H, J = 8.4 Hz, ArH), 7.91 (d, 1H, J = 8.8 Hz, ArH), 7.53 (d, 1H, J = 8.8 Hz, ArH), 7.46-7.49 (m, 1H, ArH), 7.13-7.14 (m, 1H, ArH), 6.72-6.74 (m, 1H, ArH), 6.59-6.60 (m, 1H, ArH), 6.14 (s, 1H, CH), 2.63-2.64 (m, 2H, CH_2), 2.31-2.34 (m, 2H, CH_2), 1.83-2.00 (m, 2H, CH_2). *Anal.* calcd for $C_{20}H_{16}N_2OS$: C, 72.26; H, 4.85; N, 8.43; S, 9.65. Found C, 72.25; H, 4.86; N, 8.44; S, 9.70.

12-(4-Fluorophenyl)-9,10-dihydro-9,9-dimethylbenzo[*b*]-[4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4m). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3272, 3103, 3071, 1697, 1517, 1467, 1385, 1290, 1182, 1094, 970 cm^{-1}; ^1H nmr: δ 9.86 (s, 1H, NH), 8.67-8.68 (m, 1H, ArH), 8.36 (d, 1H, J = 8.4 Hz, ArH), 7.89 (d, 1H, J = 8.8 Hz, ArH), 7.55 (d, 1H, J = 8.8 Hz, ArH), 7.39-7.42 (m, 1H, ArH), 7.24-7.28 (m, 2H, ArH), 6.96 (t, 2H, J = 8.8 Hz, ArH), 5.82 (s, 1H, CH), 2.57 (d, 1H, J = 16.8 Hz, CH), 2.40 (d, 1H, J = 16.4 Hz, CH), 2.24 (d, 1H, J = 16.4 Hz, CH), 2.04 (d, 1H, J = 16.0 Hz, CH), 1.04 (s, 3H, CH_3), 0.85 (s, 3H, CH_3). *Anal.* calcd for $C_{24}H_{21}FN_2O$: C, 77.40; H, 5.68; N, 7.52. Found C, 77.42; H, 5.66; N, 7.55.

12-(4-Chlorophenyl)-9,10-dihydro-9,9-dimethylbenzo[*b*]-[4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4n). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3262, 3106, 3024, 1601, 1516, 1464, 1384, 1258, 1159, 1093, 966 cm^{-1}; ^1H nmr: δ 9.89 (s, 1H, NH), 8.67-8.68 (m, 1H, ArH), 8.35 (d, 1H, J = 8.4 Hz, ArH), 7.90 (d, 1H, J = 9.2 Hz, ArH), 7.55 (d, 1H, J = 8.8 Hz, ArH), 7.39-7.42 (m, 1H, ArH), 7.20-7.27 (m, 4H, ArH), 5.81 (s, 1H, CH), 2.58 (d, 1H, J = 16.8 Hz, CH), 2.40 (d, 1H, J = 16.8 Hz, CH), 2.24 (d, 1H, J = 16.0 Hz, CH), 2.04 (d, 1H, J = 16.0 Hz, CH), 1.04 (s, 3H, CH_3), 0.85 (s, 3H, CH_3). *Anal.* calcd for $C_{24}H_{21}ClN_2O$: C, 74.12; H, 5.44; N, 7.20. Found C, 74.15; H, 5.45; N, 7.25.

12-(4-Bromophenyl)-9,10-dihydro-9,9-dimethylbenzo[*b*]-[4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4o). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3261, 3100, 3071, 1604, 1521, 1414, 1385, 1241, 1171, 1099, 966 cm^{-1}; ^1H nmr: δ 9.89 (s, 1H, NH), 8.67-8.68 (m, 1H, ArH), 8.34 (d, 1H, J = 8.8 Hz, ArH), 7.90 (d, 1H, J = 8.8 Hz, ArH), 7.55 (d, 1H, J = 8.8 Hz, ArH), 7.39-7.42 (m, 1H, ArH), 7.19-7.35 (m, 4H, ArH), 5.80 (s, 1H, CH), 2.57 (d, 1H, J = 16.8 Hz, CH), 2.40 (d, 1H, J = 16.4 Hz, CH), 2.24 (d, 1H, J = 16.0 Hz, CH), 2.03 (d, 1H, J = 16.0 Hz, CH), 1.04 (s, 3H, CH_3), 0.85 (s, 3H, CH_3). *Anal.* calcd for $C_{24}H_{21}BrN_2O$: C, 66.52; H, 4.88; N, 6.46. Found C, 66.55; H, 4.90; N, 6.45

9,10-dihydro-12-(4-methoxyphenyl)-9,9-dimethylbenzo[*b*]-[4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one(4p). This com-pound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3258, 3098, 3070, 1602, 1520, 1422, 1391, 1239, 1173, 1029, 981 cm^{-1}; ^1H nmr: δ 9.77 (s, 1H, NH), 8.66-8.67 (m, 1H, ArH), 8.36 (d, 1H, J = 8.4 Hz, ArH), 7.87 (d, 1H, J = 9.2 Hz, ArH), 7.53 (d, 1H, J = 9.2 Hz, ArH), 7.38-7.41 (m, 1H, ArH), 7.14 (d, 2H, J = 8.4 Hz, ArH), 6.69 (d, 2H, J = 8.4 Hz, ArH), 5.74 (s, 1H, CH), 3.61 (s, 3H, OCH_3), 2.56 (d, 1H, J = 16.8 Hz, CH), 2.40 (d, 1H, J = 16.8 Hz, CH), 2.23 (d, 1H, J = 16.4 Hz, CH), 2.03 (d, 1H, J = 16.0 Hz, CH), 1.04 (s, 3H, CH_3), 0.87 (s, 3H, CH_3). *Anal.* calcd for $C_{25}H_{24}N_2O_2$: C, 78.10; H, 6.29; N, 7.29. Found C, 78.11; H, 6.30; N, 7.30

12-(2,4-Dichlorophenyl)-9,10-dihydro-9,9-dimethylbenzo-[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4q). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3255, 3177, 3066, 2954, 1605, 1522, 1420, 1394, 1241, 1147, 1032, 983 cm^{-1}; ^1H nmr: δ 9.98 (s, 1H, NH), 8.67-8.68 (m, 1H, ArH), 8.41 (d, 1H, J = 8.4 Hz, ArH), 7.89 (d, 1H, J = 8.8 Hz, ArH), 7.52 (d, 1H, J = 8.8 Hz, ArH), 7.43-7.47 (m, 1H, ArH), 7.36-7.41 (m, 2H, ArH), 7.23-7.25 (m, 1H, ArH), 6.00 (s, 1H, CH), 2.61 (d, 1H, J = 16.8 Hz, CH), 2.41 (d, 1H, J = 16.8 Hz, CH), 2.23 (d, 1H, J = 16.0 Hz, CH), 2.00 (d, 1H, J = 16.0 Hz, CH), 1.05 (s, 3H, CH_3), 0.88 (s, 3H, CH_3). *Anal.* calcd for $C_{24}H_{20}Cl_2N_2O$: C, 68.09; H, 4.76; N, 6.62. Found C, 68.10; H, 4.75; N, 6.65.

9,10-Dihydro-12-(3,4-dimethoxyphenyl)-9,9-dimethylbenzo-[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one(4r). This com-pound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3259, 3190, 3098, 2955, 1607, 1515, 1417, 1383, 1235, 1138, 1025, 980 cm^{-1}; ^1H nmr: δ 9.81 (s, 1H, NH), 8.67-8.68 (m, 1H, ArH), 8.45 (d, 1H, J = 8.4 Hz, ArH), 7.87 (d, 1H, J = 9.2 Hz, ArH), 7.54 (d, 1H, J = 8.8 Hz, ArH), 7.40-7.43 (m, 1H, ArH), 6.98 (s, 1H, ArH), 6.68 (d, 1H, J = 8.4 Hz, ArH), 6.59 (d, 1H, J = 8.0 Hz, ArH), 5.74 (s, 1H, CH), 3.64 (s, 3H, OCH_3), 3.60 (s, 3H, OCH_3), 2.57 (d, 1H, J = 16.4 Hz, CH), 2.41 (d, 1H, J = 16.8 Hz, CH), 2.24 (d, 1H, J = 16.4 Hz, CH), 2.05 (d, 1H, J = 16.0 Hz, CH), 1.05 (s, 3H, CH_3), 0.89 (s, 3H, CH_3). *Anal.* calcd for $C_{26}H_{26}N_2O_3$: C, 75.34; H, 6.32; N, 6.76. Found C, 75.35; H, 6.33; N, 6.75.

9,10-Dihydro-9,9-dimethyl-12-(3-nitrophenyl)benzo[*b*]-[4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4s). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3268, 3194, 3086, 1601, 1522, 1468, 1392, 1299, 1153, 1030, 984 cm^{-1}; ^1H nmr: δ 10.01 (s, 1H, NH), 8.67-8.68 (m, 1H, ArH), 8.42 (d, 1H, J = 8.0 Hz, ArH), 8.12 (s, 1H, ArH), 7.92 (t, 2H, J = 9.6 Hz, ArH), 7.69 (d, 1H, J = 7.6 Hz, ArH), 7.59 (d, 1H, J = 8.8 Hz, ArH), 7.46 (t, 1H, J = 8.0 Hz, ArH), 7.39-7.42 (m, 1H, ArH), 5.99 (s, 1H, CH), 2.57 (d, 1H, J = 16.4 Hz, CH), 2.41 (d, 1H, J = 16.8 Hz, CH), 2.24 (d, 1H, J = 16.4 Hz, CH), 2.05 (d, 1H, J = 16.0 Hz, CH), 1.04 (s, 3H, CH_3), 0.82 (s, 3H, CH_3). *Anal.* calcd for $C_{24}H_{21}N_3O_3$: C, 72.16; H, 5.30; N, 10.52. Found C, 72.18; H, 5.32; N, 10.55.

12-(Benzo[*d*][1,3]dioxo-5-yl)-9,10-dihydro-9,9-dimethyl-benzo[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4t). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3256, 3172, 3071, 1591, 1520, 1414, 1385, 1240, 1180, 1092, 965 cm^{-1}; ^1H nmr: δ 9.80 (s, 1H, NH), 8.67-8.68 (m, 1H, ArH), 8.39 (d, 1H, J = 8.4 Hz, ArH), 7.88 (d, 1H, J = 8.8 Hz, ArH), 7.54 (d, 1H, J = 8.8 Hz, ArH), 7.40-7.43 (m, 1H, ArH), 6.82 (s, 1H, ArH), 6.63-6.67 (m, 2H, ArH), 5.85-5.88 (m, 2H, CH_2), 5.74 (s, 1H, CH), 2.55 (d, 1H, J = 16.8 Hz, CH), 2.42 (d, 1H, J = 16.4 Hz, CH), 2.23 (d, 1H, J = 16.0 Hz, CH), 2.06 (d, 1H, J = 16.0 Hz, CH), 1.04 (s, 3H, CH_3), 0.89 (s, 3H, CH_3). *Anal.* calcd for $C_{25}H_{22}N_2O_3$: C, 75.36; H, 5.57; N, 7.03. Found C, 75.35; H, 5.58; N, 7.00.

12-(2-Chlorophenyl)-9,10-dihydro-9,9-dimethylbenzo[*b*]-[4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4u). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3249, 3170, 3066, 1605, 1521, 1465, 1312, 1241, 1173, 1033, 979 cm^{-1}; ^1H nmr: δ 9.91 (s, 1H, NH), 8.66-8.67 (m, 1H, ArH), 8.50 (d, 1H, J = 8.4 Hz, ArH), 7.88 (d, 1H, J = 8.8 Hz, ArH), 7.53 (d, 1H, J = 8.8 Hz, ArH), 7.43-7.46 (m, 1H, ArH), 7.36 (d, 1H, J = 7.6 Hz, ArH), 7.25 (d, 1H, J = 8.0 Hz, ArH), 7.13 (t, 1H, J = 7.6 Hz, ArH), 7.02-7.05 (m, 1H, ArH), 6.02 (s, 1H, CH), 2.61 (d, 1H, J = 16.4 Hz, CH), 2.42 (d, 1H, J = 16.4 Hz, CH), 2.23 (d, 1H, J = 16.0 Hz, CH), 2.00 (d, 1H, J = 16.0 Hz, CH), 1.05 (s, 3H, CH_3), 0.88 (s, 3H, CH_3). *Anal.* calcd for $C_{24}H_{21}ClN_2O$: C, 74.12; H, 5.44; N, 7.20. Found C, 74.13; H, 5.43; N, 7.25.

9,10-Dihydro-9,9-dimethyl-12-phenylbenzo[*b*][4,7]phen-anthrolin-11(7*H*,8*H*,12H)-one (4v). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3253, 3170, 3070, 1602, 1592, 1423, 1333, 1236, 1161, 1068, 980 cm^{-1}; ^1H nmr: δ 9.84 (s, 1H, NH), 8.66-8.67 (m, 1H, ArH), 8.39 (d, 1H, J = 8.8 Hz, ArH), 7.88 (d,

1H, J = 8.8 Hz, ArH), 7.55 (d, 1H, J = 8.8 Hz, ArH), 7.39-7.42 (m, 1H, ArH), 7.25 (d, 2H, J = 7.6 Hz, ArH), 7.13 (t, 2H, J = 7.6 Hz, ArH), 7.00 (t, 1H, J = 7.6 Hz, ArH), 5.79 (s, 1H, CH), 2.57 (d, 1H, J = 16.8 Hz, CH), 2.41 (d, 1H, J = 16.8 Hz, CH), 2.23 (d, 1H, J = 16.0 Hz, CH), 2.03 (d, 1H, J = 16.0 Hz, CH), 1.04 (s, 3H, CH_3), 0.85 (s, 3H, CH_3). *Anal.* calcd for $C_{24}H_{22}N_2O$: C, 81.33; H, 6.26; N,7.90. Found C, 81.35; H, 6.25; N, 7.92.

9,10-Dihydro-12-(4-hydroxy-3-nitrophenyl)-9,9-dimethylbenzo[*b*][4,7]phenanthrolin-11(7*H*,8*H*,12*H*)-one (4w). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3398, 3256, 3096, 2925, 1602, 1518, 1427, 1313, 1264, 1164, 1080, 982 cm^{-1}; ^1H nmr: δ 10.69 (s, 1H, OH), 9.91 (s, 1H, NH), 8.69 (s, 1H, ArH), 8.39 (d, 1H, J = 8.8 Hz, ArH), 7.91 (d, 1H, J = 8.8 Hz, ArH), 7.75 (s, 1H, ArH), 7.55 (d, 1H, J = 9.2 Hz, ArH), 7.38-7.43 (m, 2H, ArH), 6.93 (d, 1H, J = 8.8 Hz, ArH), 5.82 (s, 1H, CH), 2.57 (d, 1H, J = 16.8 Hz, CH), 2.42 (d, 1H, J = 16.4 Hz, CH), 2.25 (d, 1H, J = 16.0 Hz, CH), 2.05 (d, 1H, J = 16.0 Hz, CH), 1.04 (s, 3H, CH_3), 0.86 (s, 3H, CH_3). *Anal.* calcd for $C_{24}H_{21}N_3O_4$: C, 69.39; H, 5.10; N, 10.11. Found C, 69.40; H, 5.13; N, 10.10.

9,10-Dihydro-9,9-dimethyl-12-(thiophen-2-yl)benzo[*b*][4,7]-phenanthrolin11(7*H*,8*H*,12*H*)-one (4x). This compound was obtained as yellow solid (95% ethanol), mp>300 °C; ir (potassium bromide): 3273, 3199, 3109, 1615, 1592, 1463, 1304, 1237, 1163, 1032, 981 cm^{-1}; ^1H nmr: δ 9.96 (s, 1H, NH), 8.71-8.72(m, 1H, ArH), 8.44 (d, 1H, J = 8.4 Hz, ArH), 7.91 (d, 1H, J = 8.8 Hz, ArH), 7.53 (d, 1H, J = 9.2 Hz, ArH), 7.46-7.49 (m, 1H, ArH), 7.13-7.14 (m, 1H, ArH), 6.72-6.74 (m, 1H, ArH), 6.63-6.64 (m, 1H, ArH), 6.13 (s, 1H, CH), 2.58 (d, 1H, J = 16.4 Hz, CH), 2.42 (d, 1H, J = 17.2 Hz, CH), 2.28 (d, 1H, J = 16.0 Hz, CH), 2.12 (d, 1H, J = 16.0 Hz, CH), 1.06 (s, 3H, CH_3), 0.85 (s, 3H, CH_3). *Anal.* calcd for $C_{22}H_{20}N_2OS$: C, 73.30; H, 5.59; N, 7.77; S, 8.90. Found C, 73.33; H, 5.60; N, 7.75; S, 8.83.

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[18] The single-crystal growth was carried out in ethanol at room temperature. X-ray crystallographic analysis was performed with a Siemens SMART CCD and a Semens P4 diffractometer (graphite monochromator, MoKa radiation λ = 0.71073 Å). Crystal data for: Empirical formula $C_{23}H_{20}N_2O_2$, yellow, crystal dimension 0.25×0.22×0.17 mm, monoclinic, space group C2/c, a = 25.072(3) Å, b = 7.3183(16) Å, c = 23.335(2) Å, α = 90°, β = 107.922(2)°, γ = 90°, V = 4073.9(11) $Å^3$, Mr = 356.41, Z = 8, Dc = 1.162 Mg/m^3, λ = 0.71073 Å, μ (MoKα) = 0.075 mm^{-1}, $F(000)$ = 1504, S = 1.016, R_1 = 0.074, wR_2 = 0.114