Low-Valent Titanium Reagent-Promoted Intramolecular Reductive Coupling Reactions of Ketomalononitriles: A Facile Synthesis of Benzo[4,5]indene, Acridine and Quinoline Derivatives

Daqing Shi,*[a–c] Liangce Rong,[a] Chunling Shi,[a] Qiya Zhuang,[a,b] Xiangshan Wang,[a,b] Shujiang Tu,[a,b] Hongwen Hu[c]

[a] Department of Chemistry, Xuzhou Normal University, Xuzhou 221116, P. R. China

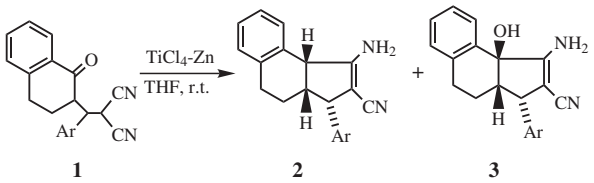
[b] The Key Laboratory of Biotechnology for Medical Plants of Jiangsu Province, Xuzhou 221116, P. R. China

[c] Department of Chemistry, Nanjing University, Nanjing 210093, P. R. China
Fax +86(516)3403164; E-mail: dqshi@263.net

Received 3 September 2004; revised 26 November 2004

Abstract: The intramolecular reductive coupling reactions of ketomalononitriles induced by a low-valent titanium reagent were studied. Benzo[4,5]indene, acridine and quinoline derivatives are prepared in good yields under neutral and mild conditions.

Key words: low-valent titanium, benzo[4,5]indene, acridine, quinoline



1 2 3

Scheme 1

Low-valent titanium reagents have an exceedingly high ability to promote reductive coupling of carbonyl compounds and are attracting increasing interest in organic synthesis.[1] Many other functional groups can also be coupled.[2] Recently, we have reported the cyclodimerization of α,β-unsaturated ketones and α,β-unsaturated nitriles promoted by this reagent yielding functional cyclopentanes[3] and cyclopentenes,[4] respectively. It is well known that the carbonyl group can easily be reduced by low-valent titanium. However, the cyano group is more stable to low-valent titanium reagent than the carbonyl group and could not be reduced unless the reaction mixture was refluxed for a long time and even then only with low reaction yield.[5] In our previous work, we have reported a novel cyclodimerzation of arylidenemalononitriles[4] and arylidenecyanoacetates[6] promoted by low-valent titanium reagents. Herein, we wish to describe our preliminary results on a novel intramolecular reductive cyclization of ketonemalononitrile promoted by low-valent titanium reagent in THF.

When racemate γ-ketomalononitriles **1** were treated with the low-valent titanium prepared from titanium tetrachloride and zinc powder in anhydrous THF at room temperature under a nitrogen atmosphere, the reductive cyclization products 1-aryl-2-cyano-3-amino-3a,3b,6,7-tetrahydrobenzo[4,5]indenes **2** and and 1-aryl-2-cyano-3-amino-3a-hydroxy-3a,3b,6,7-tetrahydrobenzo[4,5]indenes **3** were obtained (Scheme 1).

Table 1 summarizes our results on the intramolecular cyclization of γ-ketomalononitriles. All substrates were cyclized in good yields to afford two products **2** and **3**. The pinacol coupling products of ketones were not detected.

The chloro, bromo and fluoro groups of the substrates could not be reduced under the reaction conditions, but the methoxy group was cleaved partly into hydroxyl group to give **3i** accompanied by **3h**. A relevant ketone-nitrile coupling by a Ti(III) reagent has already been reported by Itoh et al.[7] and Chen et al.,[8] but this was different from what were reported by Itoh[7] and Chen et al.,[8] where the δ-ketonenitriles could be converted into substituted cyclopentanones under the same reaction conditions.

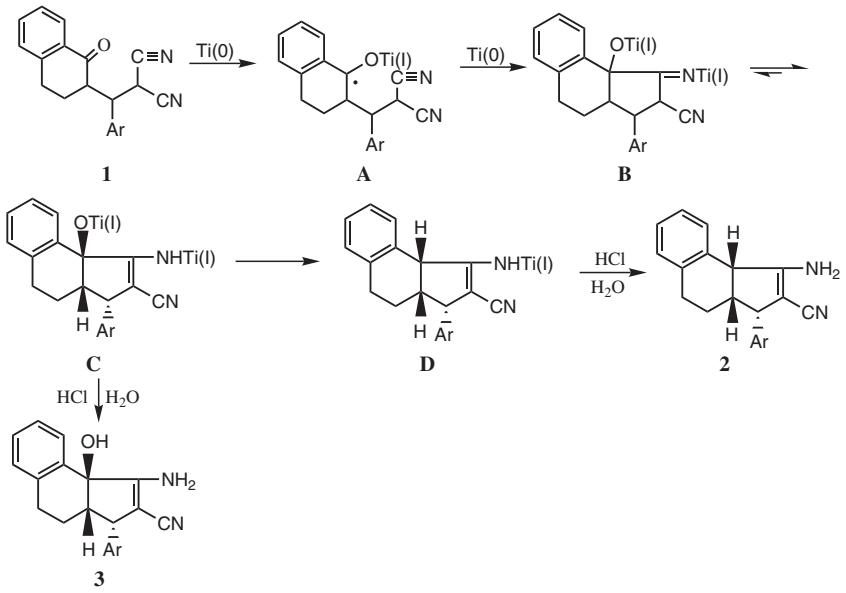
Although the detailed mechanism of the above reductive coupling reaction has not been clarified yet, the formation of tetrahydrobenzo[4,5]indenes may be explained by the possible mechanism presented in Scheme 2.

$TiCl_4$ is reduced by zinc dust to give low-valent titanium species Ti(0).[2h] In the initial step, an electron is transferred

Table 1 The Intramolecular Reductive Coupling of γ-Ketomalononitriles

Entry	Ar	Isolated yield (%)	
		2	**3**
a	C_6H_5	31	40
b	4-$CH_3C_6H_4$	32	49
c	4-ClC_6H_4	33	38
d	4-BrC_6H_4	30	36
e	4-FC_6H_4	32	41
f	2,4-$Cl_2C_6H_3$	21	61
g	2-ClC_6H_4	43	39
h	4-$CH_3OC_6H_4$	–	36
i	4-HOC_6H_4	–	43

SYNTHESIS 2005, No. 5, pp 0717–0724
Advanced online publication: 09.02.2005
DOI: 10.1055/s-2005-861820; Art ID: F12204SS



Scheme 2

from the low-valent titanium to γ-ketomalononitriles **1** to give a radical intermediate **A**, which was followed by the attack of the radical on the nitrile group to form the carbon-carbon bond and generate intermediate **B**. Then the carbon-nitrogen double bond is transformed to form a carbon-carbon double bond leading to intermediate **C** due to stabilization by the cyano group. The deoxygenation of the intermediate **C** gives a radical, which captures one hydrogen from the molecule of THF to form the intermediate **D**. Hydrolysis of the intermediates **C** and **D** give the products **2** and **3**, respectively.

The chemical structures of **2** and **3** have been established using spectroscopic data. The protons of **2** and **3** could be easily identified by 2D NMR spectra. The configurations of the products **2** and **3** have been confirmed by X-ray analysis. The X-ray diffraction studies on single crystal of **2a** and **3h** indicate that C^1-H, C^{3b}-H and C^{3a}-H, C^{3b}-OH are in *cis*-form. The molecular structures of the products **2a**, **3h,** and **3i** are shown in Figure 1, Figure 2, and Figure 3, respectively.

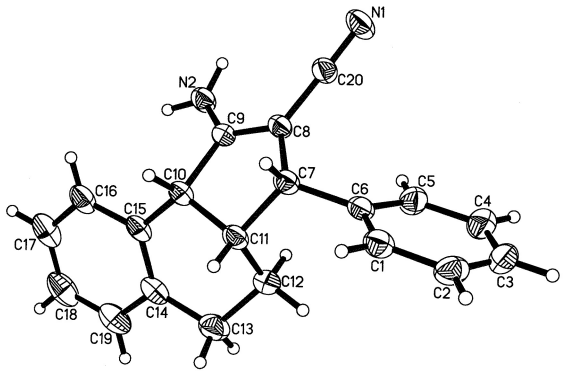


Figure 1 Molecular structure of **2a** showing the atom numbering scheme

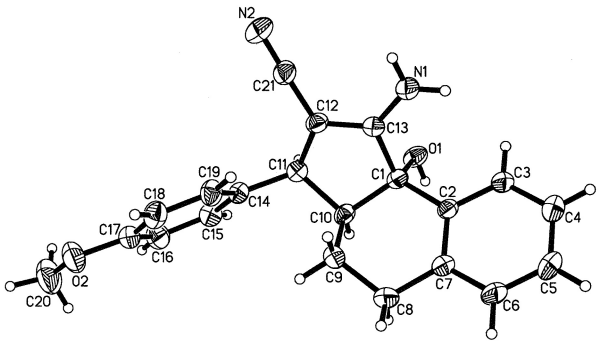


Figure 2 Molecular structure of **3h s**howing the atom numbering scheme

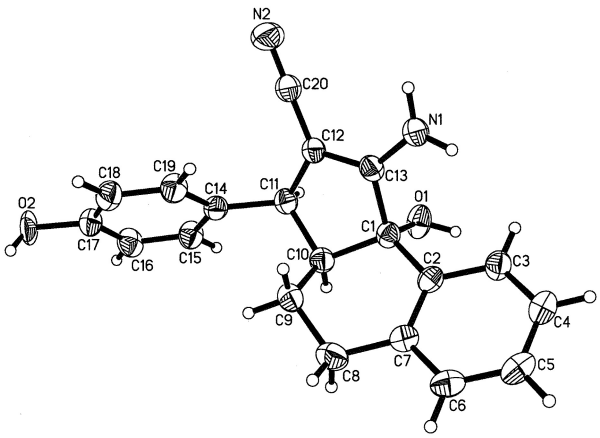
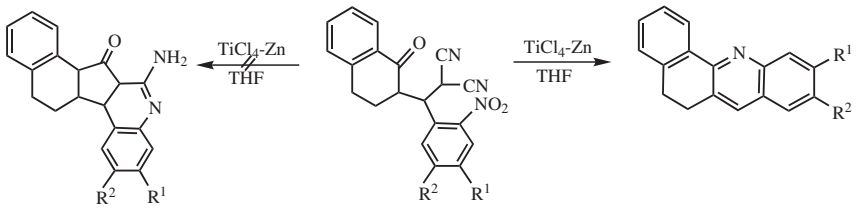


Figure 3 Molecular structure of **3i** showing the atom numbering scheme

To our surprise, the reduction racemate of α-(2-nitrophenyl)-γ-ketomalononitriles **4** with $TiCl_4$-Zn in the THF under the same reaction condition did not give us the expected product **5,** but we could isolate 5,6-dihydroben-



5 4 6

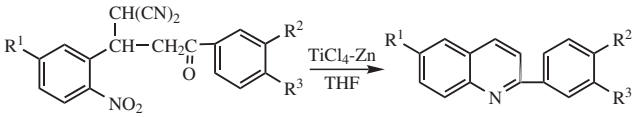
Scheme 3

zo[*c*]a-cridines **6** (Scheme 3). The results are summarized in Table 2. These acridine derivatives are most probably formed by the reductive coupling reaction of the nitro group with carbonyl group followed by the elimination of malononitrile. The driving force for this last step is the possibility for aromatization of the acridine system.

Table 2 The Synthesis of 5,6-Dihydrobenzo[*c*]acridines Promoted by Low-Valent Titanium

Entry	R^1	R^2	Isolated yield (%)
6a	H	H	79
6b	H	Cl	75
6c	OCH_2O		78
6d	CH_3O	CH_3O	80

Moreover, treatment of non-cyclic α-(2-nitrophenyl)-γ-ketomalononitriles **7** with low-valent titanium reagent under the same reaction conditions gave the similar product, 2-arylquinolines **8** (Scheme 4). The results are summarized in Table 3.



7 8

Scheme 4

Table 3 The Synthesis of 2-Arylquinolines Promoted by Low-Valent Titanium

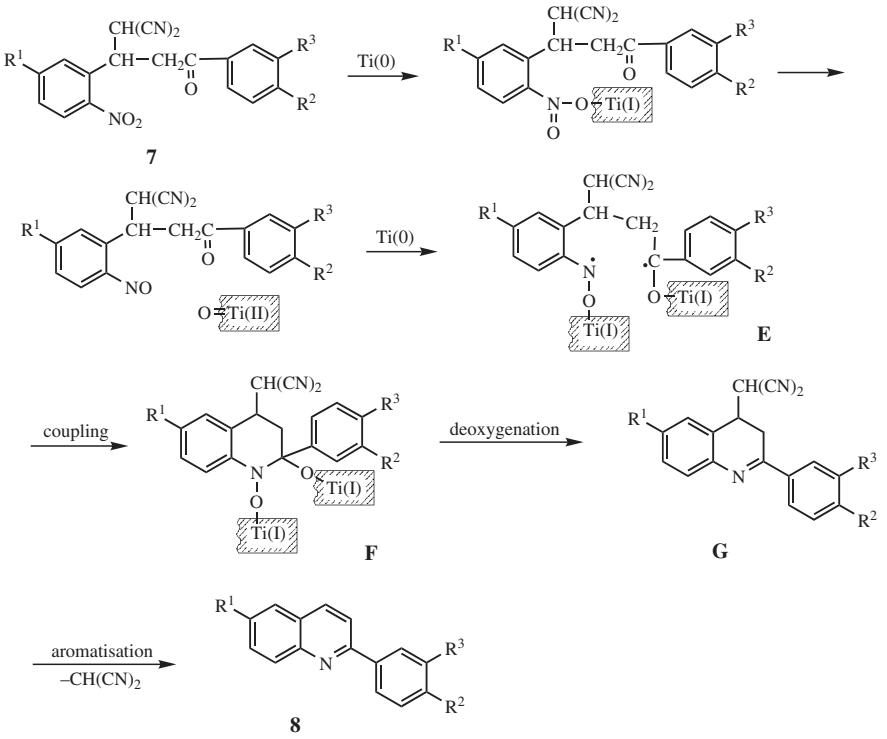
Entry	R^1	R^2	R^3	Isolated yield (%)
8a	H	H	H	78
8b	H	Cl	H	85
8c	H	Br	H	88
8d	Cl	H	H	79
8e	Cl	H	Cl	91
8f	Cl	Cl	H	90
8g	Cl	Br	H	78

Quinoline analogues have anti-inflammatory, analgesic, antihypertensive, chloroquine, and antidepressive properties.[9] It has been reported that quinine, primaquine, chloroquine, piperaquine, hydroxypiperquine, chloroquine-phosphate, primaquine phosphate and mefloquine have antimalarial properties.[10] Quinolines have attracted interest due to their biological properties. There have been a number of syntheses published,[11] but most of these procedures have some common disadvantageous features, such as harsh reaction condition, laborious manipulation or low yield. These observations promoted chemists to develop novel and convenient synthetic methods for the preparation of these quinoline compounds. In this paper, we have provided the novel and convenient synthesis of quinolines.

In literature,[12] a plausible mechanistic pathway to quinolines is illustrated as depicted in Scheme 5, though the details are unclear as yet. $TiCl_4$ is reduced by Zn dust to give low-valent titanium. It is well known that nitro and carbonyl groups can be more easily reduced by low-valent titanium reagent than the cyano group. So in the initial steps, electrons are transferred from low-valent titanium reagent to nitro group and carbonyl group to give radical anion **E**; the latter couples to form the carbon-nitrogen bond and generates intermediate **F**. The intermediate (**F**) then undergoes deoxygenation to form **G**, which loses malononitrile to give the product **8**.

In conclusion, a series of 1-aryl-2-cyano-3-amino-3a,3b,6,7-tetrahydrobenzo[4,5]indenes, 1-aryl-2-cyano-3-amino-3a-hydroxy-3a,3b,6,7-tetrahydrobenzo[4,5]indenes, 5,6-dihydrobenzo[*c*]acridines and 2-arylquinolines were synthesized via reductive cyclization of γ-ketomalononitriles induced by the $TiCl_4$-Zn system. The advantages of our method are the easily accessible starting materials, convenient manipulation and moderate to high yields.

THF was distilled from sodium–benzophene immediately prior to use. All reactions were conducted under N_2 atmosphere. Melting points are uncorrected. IR spectra were recorded on FTIR-8101 spectrometer in KBr with absorptions in cm^{-1}. ^1H NMR and ^{13}C NMR spectra were determined on Inova-400 MHz spectrometer in $CDCl_3$ or DMSO-d_6 solution. *J* values are in Hz. Chemical shifts are expressed in ppm downfield from internal standard, TMS. MS spectra were carried out on HP 5973 GC-MS or VG-ZAB-HS instruments. Microanalyses were carried out on Perkin-Elmer 2400 II instruments. X-ray diffraction was recorded on a Siemens P4 diffractometer. Zinc dust (100 mesh) was activated by being soaked in



Scheme 5

5% HCl, then washed with water, acetone, and Et_2O successively and dried in vacuo. $TiCl_4$ was distilled before use. γ-Ketomalononitriles were prepared according to the published literature.[13] Other chemicals were used as purchased.

Preparation of Tetrahydrobenzo[4,5]indenes; General Procedure

$TiCl_4$ (1.1 mL, 10 mmol) was added dropwise using a syringe to a stirred suspension of zinc dust (1.3 g, 20 mmol) in freshly distilled anhyd THF (15 mL) at r.t. under a dry N_2 atmosphere. After completion of the addition, the mixture was refluxed for 3 h. The suspension of the low-valent titanium reagent formed was cooled to r.t. and a solution of γ-ketomalononitriles (3 mmol) in THF (5 mL) was added dropwise. The reaction mixture was then stirred at r.t. for about 5 h. After this period, the TLC analysis of the mixture showed the reaction to be complete. The reaction mixture was quenched with 5% HCl (20 mL) and extracted with CH_2Cl_2 (3 × 30 mL). The combined extracts were washed with water (3 × 50 mL) and dried over anhyd Na_2SO_4. After evaporation of the solvent under reduced pressure, the crude product was purified by column chromatography on silica gel (200–300 mesh) using petroleum ether (bp 60–90 °C)–acetone (4:1) as eluent to give **2** and **3**, respectively.

1-Phenyl-3-amino-2-cyano-3a,3b,6,7-tetrahydrobenzo[4,5]indene (2a)

Solid; mp 196–198 °C.

IR (KBr): 3469, 3321, 2187, 1649, 1593, 1489, 1451, 783, 756, 708 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.40–7.13 (m, 9 H, ArH), 4.71 (s, 2 H, NH_2), 4.40 (d, *J* = 10.0 Hz, 1 H, C_1-H), 3.97 (d, *J* = 9.0 Hz, 1 H, C_{3a}-H), 2.75–2.64 (m, 2 H, C_6-H, C_{3b}-H), 2.58–2.47 (m, 1 H, C_6-H), 1.48–1.34 (m, 1 H, C_7-H), 1.06–0.98 (m, 1 H, C_7-H).

^{13}C NMR (400 MHz, $CDCl_3$): δ = 164.6, 138.5, 138.3, 131.9, 129.8, 128.6, 128.4, 128.3, 127.4, 126.9, 126.4, 119.1, 51.3, 48.8, 42.7, 28.4, 21.4.

Anal. Calcd for $C_{20}H_{18}N_2$: C, 83.88; H, 6.34; N, 9.78. Found: C, 83.92; H, 6.19; N, 9.51.

Crystal Data and Structure Refinement for 2a

Crystal suitable for X-ray analysis was obtained by slow evaporation of an EtOH solution of **2a**. $C_{20}H_{18}N_2$, M = 286.36, triclinic, space group *P*-1, *a* = 9.169 (2), *b* = 9.520 (2), *c* = 10.276 (2) Å, α = 91.09 (2)°, β = 107.95 (1)°, γ = 111.05 (2)°, *V* = 787.8 (3) $Å^3$, *Z* = 2, ρ_{calcd} = 1.207 $g \cdot cm^{-3}$, *F* (000) = 304, μ (MoKα) = 0.071 mm^{-1}, colorless block crystals, crystal size 0.52 mm × 0.50 mm × 0.40 mm. Intensity data were collected at 296 K on a Siemens P4 diffractometer with graphite-monochromated MoKa radiation (l = 0.71073 Å): 2922 independent reflections were collected using w scan mode in the range of 2.11° to 25.50°, of which 2137 intensity data with [I > 2s (I)] were observed. The corrections for Lp factors were applied. The structure was solved by direct methods and expanded using Fourier techniques. Some non-hydrogen atoms were refined anisotropically, while the rest were refined isotropically. Hydrogen atoms were induced in *F* value calculation but fixed during the structure refinement. A full matrix least-squares refinement gave final *R*1 = 0.0399 and *wR*2 = 0.1008, with w = 1/[s^2Fo^2 + (0.0595P)^2] where P = (Fo^2 +2 Fc^2)/3, S = 1.047. The maximum peak in the final difference Fourier map was 0.184 e/$Å^3$ and the minimum peak was –0.145 e/$Å^3$. In the final circle refinement the largest parameter shift $(D/s)_{max}$ is 0.000. All calculations were performed using TEXSAN program package.

1-Phenyl-3-amino-2-cyano-3a-hydroxy-3a,3b,6,7-tetrahydrobenzo[4,5]indene (3a)

Solid; mp 200–201 °C.

IR (KBr): 3466, 3367, 2903, 2186, 1633, 1588, 1492, 1453, 1412, 1317, 1289, 1250, 1163, 1067, 1033, 1005, 917, 786, 763, 734, 707, 650 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 7.77–6.92 (m, 9 H, ArH), 6.37 (s, 2 H, NH_2), 5.74 (s, 1 H, OH), 4.32 (d, *J* = 10.0 Hz, 1 H, C_1-H),

2.68–2.60 (m, 1 H, C_{3b}-H), 2.47–2.40 (m, 1 H, C_6-H), 2.39–2.01 (m, 1 H, C_6-H), 1.39–1.33 (m, 1 H, C_7-H), 1.25–1.19 (m, 1 H, C_7-H).

^{13}C NMR (400 MHz, DMSO-d_6): δ = 165.8, 140.3, 137.9, 137.1, 128.5, 127.9, 127.4, 127.1, 126.5, 125.9, 119.5, 79.9, 72.6, 49.1, 26.7, 22.2.

Anal. Calcd for $C_{20}H_{18}N_2O$: C, 79.44; H, 6.00; N, 9.26. Found: C, 79.71; H, 5.84; N, 9.43.

1-(4-Methylphenyl)-3-amino-2-cyano-3a,3b,6,7-tetrahydrobenzo[4,5]indene (2b)
Solid; mp 202–203 °C.

IR (KBr): 3435, 3331, 2180, 1649, 1593, 1512, 1488, 1425, 851, 781, 754 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 7.38–7.05 (m, 8 H, ArH), 6.16 (s, 2 H, NH_2), 4.25 (d, J = 6.4 Hz, 1 H, C_1-H), 3.91 (d, J = 7.2 Hz, 1 H, C_{3a}-H), 2.73–2.67 (m, 1 H, C_{3b}-H), 2.55–2.38 (m, 2 H, C_6-H), 2.28 (s, 3 H, CH_3), 1.24–1.11 (m, 1 H, C_7-H), 1.01–0.97 (m, 1 H, C_7-H).

Anal. Calcd for $C_{21}H_{20}N_2$: C, 83.93; H, 6.71; N, 9.33. Found: C, 83.43; H, 6.55; N, 9.57.

1-(4-Methylphenyl)-3-amino-2-cyano-3a-hydroxy-3a,3b,6,7-tetrahydrobenzo[4,5]indene (3b)
Solid; mp 189–190 °C.

IR (KBr): 3443, 3326, 3261, 3215, 3048, 2922, 2859, 2197, 1654, 1599, 1514, 1488, 1452, 1363, 1353, 1232, 1196, 1159, 1038, 1007, 807, 768 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.01 (d, J = 7.2 Hz, 1 H, ArH), 7.49 (dd, J_1 = 7.2 Hz, J_2 = 7.2 Hz, 1 H, ArH), 7.42 (dd, J_1 = 7.2 Hz, J_2 = 7.2 Hz, 1 H, ArH), 7.27 (d, J = 7.2 Hz, 2 H, ArH), 7.22 (d, J = 7.2 Hz, 1 H, ArH), 7.12 (d, J = 7.2 Hz, 2 H, ArH), 6.56 (s, 2 H, NH_2), 5.96 (s, 1 H, OH), 4.54 (d, J = 7.2 Hz, 1 H, C_1-H), 2.91–2.86 (m, 1 H, C_{3b}-H), 2.73–2.68 (m, 1 H, C_6-H), 2.48 (s, 3 H, CH_3), 2.40–2.35 (m, 1 H, C_6-H), 1.66–1.60 (m, 1 H, C_7-H), 1.49–1.40 (m, 1 H, C_7-H).

Anal. Calcd for $C_{21}H_{20}N_2O$: C, 79.72; H, 6.37; N, 8.85. Found: C, 79.89; H, 6.13; N, 8.65.

1-(4-Chlorophenyl)-3-amino-2-cyano-3a,3b,6,7-tetrahydrobenzo[4,5]indene (2c)
Solid; mp 158–160 °C.

IR (KBr): 3467, 3326, 2962, 2941, 2193, 1671, 1599, 1491, 1456, 1297, 1229, 1213, 1096, 1014, 942, 795, 758, 733 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 7.85–7.19 (m, 8 H, ArH), 6.29 (s, 2 H, NH_2), 5.80 (d, J = 7.2 Hz, 1 H, C_1-H), 4.06–4.02 (m, 1 H, C_{3a}-H), 3.30–3.28 (m, 1 H, C_{3b}-H), 3.14–3.08 (m, 1 H, C_6-H), 2.99–2.94 (m, 1 H, C_6-H), 2.24–2.21 (m, 1 H, C_7-H), 1.74–1.65 (m, 1 H, C_7-H).

Anal. Calcd for $C_{20}H_{17}ClN_2$: C, 74.88; H, 5.34; N, 8.73. Found: C, 75.02; H, 5.08; N, 8.81.

1-(4-Chlorophenyl)-3-amino-2-cyano-3a-hydroxy-3a,3b,6,7-tetrahydrobenzo[4,5]indene (3c)
Solid; mp 195–196 °C.

IR (KBr): 3443, 3327, 3258, 3214, 2927, 2863, 2195, 1652, 1595, 1490, 1451, 1410, 1361, 1229, 1071, 1039, 1012, 831, 768 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 7.77–6.95 (m, 8 H, ArH), 6.42 (s, 2 H, NH_2), 5.76 (s, 1 H, OH), 4.33 (d, J = 7.2 Hz, 1 H, C_1-H), 2.69–2.64 (m, 1 H, C_{3b}-H), 2.47–2.44 (m, 1 H, C_6-H), 2.09–2.05 (m, 1 H, C_6-H), 1.43–1.38 (m, 1 H, C_7-H), 1.25–1.18 (m, 1 H, C_7-H).

Anal. Calcd for $C_{20}H_{17}ClN_2O$: C, 71.32; H, 5.09; N, 8.32. Found: C, 71.48; H, 4.80; N, 8.51.

1-(4-Bromophenyl)-3-amino-2-cyano-3a,3b,6,7-tetrahydrobenzo[4,5]indene (2d)
Solid; mp 220–222 °C.

IR (KBr): 3466, 3320, 2939, 2922, 2192, 1649, 1594, 1486, 1451, 1433, 1407, 1217, 1007, 833, 784, 749 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 7.56–7.07 (m, 8 H, ArH), 6.29 (s, 2 H, NH_2), 4.29 (d, J = 7.2 Hz, 1 H, C_1-H), 3.93 (d, J = 7.6 Hz, 1 H, C_{3a}-H), 2.76–2.69 (m, 1 H, C_{3b}-H), 2.48–2.39 (m, 2 H, C_6-H), 1.20–1.10 (m, 1 H, C_7-H), 1.00–0.96 (m, 1 H, C_7-H).

Anal. Calcd for $C_{20}H_{17}BrN_2$: C, 65.76; H, 4.69; N, 7.67. Found: C, 65.93; H, 4.48; N, 7.56.

1-(4-Bromophenyl)-3-amino-2-cyano-3a-hydroxy-3a,3b,6,7-tetrahydrobenzo[4,5]indene (3d)
Solid; mp 125–126 °C.

IR (KBr): 3440, 3325, 3258, 3213, 2950, 2924, 2196, 1653, 1596, 1488, 1451, 1362, 1310, 1230, 1196, 1158, 1072, 1039, 1010, 829, 799, 768 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 7.89–7.13 (m, 8 H, ArH), 6.79 (s, 2 H, NH_2), 5.87 (s, 1 H, OH), 4.31 (d, J = 6.8 Hz, 1 H, C_1-H), 3.10–3.04 (m, 1 H, C_{3b}-H), 2.69–2.65 (m, 1 H, C_6-H), 2.28–2.26 (m, 1 H, C_6-H), 1.83–1.76 (m, 1 H, C_7-H), 1.60–1.57 (m, 1 H, C_7-H).

Anal. Calcd for $C_{20}H_{17}BrN_2O$: C, 63.10; H, 4.49; N, 7.35. Found: C, 63.27; H, 4.36; N, 7.47.

1-(4-Fluorophenyl)-3-amino-2-cyano-3a,3b,6,7-tetrahydrobenzo[4,5]indene (2e)
Solid; mp 199–200 °C.

IR (KBr): 3467, 3330, 3066, 2955, 2192, 1675, 1600, 1510, 1480, 1454, 1228, 1158, 964, 790, 774, 737 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 7.39–7.07 (m, 8 H, ArH), 6.26 (s, 2 H, NH_2), 4.31 (d, J = 6.0 Hz, 1 H, C_1-H), 3.92 (d, J = 7.6 Hz, 1 H, C_{3a}-H), 2.74–2.67 (m, 1 H, C_{3b}-H), 2.47–2.39 (m, 2 H, C_6-H), 1.21–1.11 (m, 1 H, C_7-H), 0.99–0.95 (m, 1 H, C_7-H).

Anal. Calcd for $C_{20}H_{17}FN_2$: C, 78.92; H, 5.63; N, 9.20. Found: C, 79.08; H, 5.44; N, 9.35.

1-(4-Fluorophenyl)-3-amino-2-cyano-3a-hydroxy-3a,3b,6,7-tetrahydrobenzo[4,5]indene (3e)
Solid; mp 204–205 °C.

IR (KBr): 3507, 3474, 3351, 2944, 2920, 2870, 2185, 1650, 1603, 1591, 1508, 1389, 1361, 1341, 1305, 1213, 1161, 1027, 1001, 838, 817, 769 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 7.77–6.94 (m, 8 H, ArH), 6.40 (s, 2 H, NH_2), 5.71 (s, 1 H, OH), 4.33 (d, J = 7.6 Hz, 1 H, C_1-H), 2.67–2.62 (m, 1 H, C_{3b}-H), 2.47–2.44 (m, 1 H, C_6-H), 2.09–2.03 (m, 1 H, C_6-H), 1.42–1.38 (m, 1 H, C_7-H), 1.24–1.21 (m, 1 H, C_7-H).

Anal. Calcd for $C_{20}H_{17}FN_2O$: C, 74.98; H, 5.35; N, 8.74. Found: C, 75.08; H, 5.47; N, 8.53.

1-(2,4-Dichlorophenyl)-3-amino-2-cyano-3a,3b,6,7-tetrahydrobenzo[4,5]indene (2f)
Solid; mp 189–190 °C.

IR (KBr): 3462, 3328, 2926, 2875, 2834, 2179, 1671, 1599, 1560, 1476, 1456, 1383, 1232, 1213, 1202, 1158, 1119, 1050, 1019, 826, 813, 735 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 7.84–7.06 (m, 7 H, ArH), 6.41 (s, 2 H, NH_2), 5.70 (d, J = 8.4 Hz, 1 H, C_1-H), 4.64 (d, J = 8.8 Hz, 1 H, C_{3a}-H), 3.38–3.31 (m, 1 H, C_{3b}-H), 3.15–2.95 (m, 2 H, C_6-H), 2.27–2.23 (m, 1 H, C_7-H), 1.90–1.82 (m, 1 H, C_7-H).

Anal. Calcd for $C_{20}H_{16}Cl_2N_2$: C, 67.62; H, 4.54; N, 7.89. Found: C, 67.83; H, 4.37; N, 7.96.

1-(2,4-Dichlorophenyl)-3-amino-2-cyano-3a-hydroxy-3a,3b,6,7-tetrahydrobenzo[4,5]indene (3f)
Solid; mp 210–211 °C.

IR (KBr): 3458, 3328, 3265, 3221, 2937, 2854, 2196, 1653, 1597, 1557, 1468, 1385, 1364, 1103, 1049, 1036, 1006, 814, 767, 760 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 7.77–6.94 (m, 7 H, ArH), 6.45 (s, 2 H, NH_2), 5.88 (s, 1 H, OH), 4.72 (d, *J* = 7.2 Hz, 1 H, C_1-H), 2.85–2.79 (m, 1 H, C_{3b}-H), 2.56–2.51 (m, 1 H, C_6-H), 2.22–2.18 (m, 1 H, C_6-H), 1.36–1.31 (m, 1 H, C_7-H), 1.21–1.12 (m, 1 H, C_7-H).

Anal. Calcd for $C_{20}H_{16}Cl_2N_2O$: C, 64.70; H, 4.34; N, 7.55. Found: C, 64.93; H, 4.15; N, 7.60.

1-(2-Chlorophenyl)-3-amino-2-cyano-3a,3b,6,7-tetrahydrobenzo[4,5]indene (2g)
Solid; mp 193–195 °C.

IR (KBr): 3477, 3378, 2953, 2930, 2901, 2187, 1633, 1586, 1471, 1445, 1405, 1340, 1245, 1198, 1035, 1004, 763, 743 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 7.78–6.96 (m, 8 H, ArH), 6.38 (s, 2 H, NH_2), 4.77 (d, *J* = 7.2 Hz, 1 H, C_1-H), 3.44 (d, *J* = 7.2 Hz, 1 H, C_{3a}-H), 2.85–2.80 (m, 1 H, C_{3b}-H), 2.51–2.45 (m, 1 H, C_6-H), 2.20–2.16 (m, 1 H, C_6-H), 1.34–1.29 (m, 1 H, C_7-H), 1.23–1.17 (m, 1 H, C_7-H).

Anal. Calcd for $C_{20}H_{17}ClN_2$: C, 74.88; H, 5.34; N, 8.73. Found: C, 75.07; H, 5.16; N, 8.92.

1-(2-Chlorophenyl)-3-amino-2-cyano-3a-hydroxy-3a,3b,6,7-tetrahydrobenzo[4,5]indene (3g)
Solid; mp 158–159 °C.

IR (KBr): 3448, 3350, 3224, 2927, 2855, 2189, 1646, 1594, 1490, 1474, 1439, 1339, 1214, 1181, 1088, 1050, 1035, 755, 737 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 7.91–7.16 (m, 8 H, ArH), 6.83 (s, 2 H, NH_2), 5.91 (s, 1 H, OH), 4.19 (d, *J* = 8.8 Hz, 1 H, C_1-H), 3.12–3.05 (m, 1 H, C_{3b}-H), 2.75–2.72 (m, 1 H, C_6-H), 2.40–2.38 (m, 1 H, C_6-H), 1.87–1.81 (m, 1 H, C_7-H), 1.65–1.61 (m, 1 H, C_7-H).

Anal. Calcd for $C_{20}H_{17}ClN_2O$: C, 71.32; H, 5.09; N, 8.32. Found: C, 71.35; H, 4.84; N, 8.09.

1-(4-Methoxyphenyl)-3-amino-2-cyano-3a-hydroxy-3a,3b,6,7-tetrahydrobenzo[4,5]indene (3h)
Solid; mp 197–198 °C.

IR (KBr): 3460, 3369, 3257, 2948, 2833, 2177, 1642, 1632, 1577, 1510, 1489, 1235, 1175, 1028, 836, 781, 757 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 7.38–6.84 (m, 8 H, ArH), 6.23 (s, 2 H, NH_2), 5.99 (s, 1 H, OH), 4.24 (d, *J* = 6.8 Hz, 1 H, C_1-H), 3.91–3.87 (m, 1 H, C_{3b}-H), 3.74 (s, 3 H, CH_3O), 2.70–2.62 (m, 1 H, C_6-H), 2.46–2.38 (m, 1 H, C_6-H), 1.22–1.12 (m, 1 H, C_7-H), 1.01–0.97 (m, 1 H, C_7-H).

Anal. Calcd for $C_{21}H_{20}N_2O_2$: C, 75.88; H, 6.06; N, 8.43. Found: C, 76.02; H, 5.84; N, 8.35.

Crystal Data and Structure Refinement for 3h
Crystal suitable for X-ray analysis was obtained by slow evaporation of an EtOH solution of **3h**. $C_{21}H_{18}N_2O_2$, M = 332.39, orthorhombic, space group *P*2(1)2(1)2(1), *a* = 7.820 (2), *b* = 7.911(2), *c* = 28.766 (7) Å, α = 90°, β = 90°, γ = 90°, V = 1779.4 (7) $Å^3$, *Z* = 4, ρ_{calcd} = 1.241 g·cm^{-3}, *F* (000) = 704, μ (MoKα) = 0.081 mm^{-1}, colorless block crystals, crystal size 0.58 mm × 0.46 mm × 0.24 mm. Intensity data were collected at 291 K on a Siemens P4 diffractometer with graphite-monochromated MoKa radiation (l = 0.71073 Å): 2361 independent reflections were collected using w scan mode in the range of 1.42° to 27.30°, of which 1575 intensity data with [I > 2s (I)] were observed. The corrections for Lp factors were applied. The structure was solved by direct methods and expanded using Fourier techniques. Some non-hydrogen atoms were refined anisotropically, while the rest were refined isotropically. Hydrogen atoms were induced in *F* value calculation but fixed during the structure refinement. A full matrix least-squares refinement gave final *R*1 = 0.0379 and *wR*2 = 0.0789, with w = 1/[s^2Fo^2 +(0.0417P)^2] where P = (Fo^2 +2 Fc^2)/3, *S* = 0.879. The maximum peak in the final difference Fourier map was 0.151 e/$Å^3$ and the minimum peak was –0.154 e/$Å^3$. In the final circle refinement the largest parameter shift $(D/s)_{max}$ was 0.000. All calculations were performed using TEXSAN program package.

1-(4-Hydroxyphenyl)-3-amino-2-cyano-3a-hydroxy-3a,3b,6,7-tetrahydrobenzo[4,5]indene (3i)
Solid; mp 213–214 °C.

IR (KBr): 3466, 3373, 3344, 2938, 2908, 2832, 2192, 1644, 1596, 1511, 1432, 1250, 1236, 1177, 1073, 1008, 830, 809, 770 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 7.75 (d, *J* = 7.6 Hz, 1 H, ArH), 7.25–7.15 (m, 2 H, ArH), 6.96 (d, *J* = 7.2 Hz, 1 H, ArH), 6.89 (d, *J* = 8.8 Hz, 2 H, ArH), 6.77 (d, *J* = 8.8 Hz, 2 H, ArH), 6.30 (s, 2 H, NH_2), 5.94 (s, 1 H, OH), 5.70 (s, 1 H, OH), 4.28 (d, *J* = 7.2 Hz, 1 H, C_1-H), 2.63–2.58 (m, 1 H, C_{3b}-H), 2.47–2.44 (m, 1 H, C_6-H), 2.12–2.09 (m, 1 H, C_6-H), 1.41–1.36 (m, 1 H, C_7-H), 1.24–1.20 (m, 1 H, C_7-H).

Anal. Calcd for $C_{20}H_{18}N_2O_2$: C, 75.45; H, 5.70; N, 8.80. Found: C, 75.57; H, 5.59; N, 8.74.

Crystal Data and Structure Refinement for 3i
Crystal suitable for X-ray analysis was obtained by slow evaporation of an EtOH solution of **3i**. $C_{20}H_{18}N_2O_2$, M = 318.36, monoclinic, space group $P2_1/n$, *a* = 7.701 (1), *b* = 9.841 (1), *c* = 20.768 (3) Å, α = 90°, β = 92.40 (1)°, γ = 90°, *V* = 1572.4 (3) $Å^3$, *Z* = 4, ρ_{calcd} = 1.345 g·cm^{-3}, *F* (000) = 672, μ (MoKα) = 0.088 mm^{-1}, colorless block crystals, crystal size 0.58 mm × 0.50 mm × 0.26 mm. Intensity data were collected at 291 K on a Siemens P4 diffractometer with graphite-monochromated Mo*K*α radiation (λ = 0.71073 Å): 2767 independent reflections were collected using w scan mode in the range of 1.96° to 25.00°, of which 2008 intensity data with [I > 2σ (I)] were observed. The structure was solved by direct methods and expanded using Fourier techniques. All non-hydrogen atoms were refined anisotropically. The hydrogen atoms were included but not refined. The final cycle of full-matrix least-squares refinement give *R*1 = 0.0439 and *wR*2 = 0.0608, with w = 1/[σ^2Fo^2 + (0.0693P)^2 + 0.1228*P*], *S* = 1.069. The maximum and minimum peak on the final difference Fourier map corresponded to 0.306 and –0.348 e/$Å^3$, respectively. All calculations were performed using TEXSAN program package.

Synthesis of 5,6-Dihydrobenzo[*c*]acridines (6) and 2-Arylquinolines (8); General Procedure
$TiCl_4$ (2.2 mL, 20 mmol) was added dropwise using a syringe to a stirred suspension of zinc dust (2.6 g, 40 mmol) in freshly distilled anhyd THF (20 mL) at r.t. under a dry N_2 atmosphere. After completion of the addition, the mixture was refluxed for 3 h. The suspension of the low-valent titanium reagent formed was cooled to r.t. and a solution of α-(2-nitrophenyl)-γ-ketomalononitriles (**4** or **7**) (5 mmol) in anhyd THF (10 mL) was added carefully at r.t. The reaction mixture was then stirred at r.t. for 4 h. The reaction mixture was quenched with 5% HCl (50 mL) and extracted with $CHCl_3$ (3 × 50 mL). The combined organic layers were washed with water (3 × 50 mL), dried (Na_2SO_4), and the solvent was removed in vacuo to give the crude product that was recrystallized from EtOH to give the pure product **6** or **8**.

5,6-Dihydrobenzo[*c*]acridine (6a)
Solid; mp 61–63 °C.

IR (KBr): 3031, 2928, 1621, 1609, 1551, 1493, 1459, 1432, 1400, 1284, 1015, 946, 912, 860, 770, 737 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.58 (d, *J* = 6.8 Hz, 1 H, ArH), 8.14 (d, *J* = 8.4 Hz, 1 H, ArH), 7.93 (s, 1 H, ArH), 7.75 (d, *J* = 7.2 Hz, 1 H, ArH), 7.65 (t, *J* = 8.4 Hz, 1 H, ArH), 7.49–7.36 (m, 3 H, ArH), 7.29–7.25 (m, 1 H, ArH), 3.13 (t, *J* = 7.2 Hz, 2 H, CH_2), 3.01 (t, *J* = 7.2 Hz, 2 H, CH_2).

^{13}C NMR (400 MHz, DMSO-d_6): δ = 153.0, 147.3, 139.9, 134.5, 134.4, 130.9, 130.3, 129.4, 129.3, 128.7, 128.0, 127.7, 127.5, 126.7, 125.9, 28.4, 28.0.

MS (%): *m*/*z* = 232 (16.2) [M + 1], 231 (96) [M^+], 230 (100) [M – 1].

Anal. Calcd for $C_{17}H_{13}N$: C, 88.28; H, 5.66; N, 6.06. Found: C, 88.43; H, 5.48; N, 6.25.

3-Chloro-5,6-dihydrobenzo[*c*]acridine (6b)
Solid; mp 101–103 °C.

IR (KBr): 3028, 2943, 1632, 1598, 1484, 1395, 1342, 1289, 1251, 1178, 1074, 1013, 914, 835, 760, 742, 725, 695 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.56 (d, *J* = 4.4 Hz, 1 H, ArH), 8.09 (s, 1 H, ArH), 7.85 (s, 1 H, ArH), 7.73 (s, 1 H, ArH), 7.59 (d, *J* = 8.8 Hz, 1 H, ArH), 7.45–7.37 (m, 2 H, ArH), 7.29–7.26 (m, 1 H, ArH), 3.13(t, *J* = 6.8 Hz, 2 H, CH_2), 3.02 (t, *J* = 6.8 Hz, 2 H, CH_2).

^{13}C NMR (400 MHz, $CDCl_3$): δ = 153.7, 145.9, 139.4, 134.3, 132.8, 131.7, 131.6, 130.9, 130.0, 129.6, 128.4, 128.0, 127.4, 126.1, 125.6, 28.8, 28.2.

MS (%): *m*/*z* = 267 (31.3) [M + 2], 266 (40) [M + 1], 265 (100) [M^+], 264 (80.1) [M – 1].

Anal. Calcd for $C_{17}H_{12}ClN$: C, 76.84; H, 4.55; N, 5.27. Found: C, 77.07; H, 4.38; N, 5.09.

2,3-Methylenedioxy-5,6-dihydrobenzo[*c*]acridine (6c)
Solid; mp 206–208 °C.

IR (KBr): 3050, 2990, 1652, 1618, 1547, 1471, 1377, 1314, 1267, 1200, 1030, 964, 925, 865, 845, 784, 757, 682 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.43 (d, *J* = 6.0 Hz, 1 H, ArH), 8.33 (s, 1 H, ArH), 7.66 (s, 1 H, ArH), 7.48–7.43 (m, 4 H, ArH), 6.29 (s, 2 H, OCH_2O), 3.08 (t, *J* = 7.2 Hz, 2 H, CH_2), 2.98 (t, *J* = 7.2 Hz, 2 H, CH_2).

^{13}C NMR (400 MHz, DMSO-d_6): δ = 153.2, 149.4, 147.6, 141.0, 139.7, 132.3, 132.1, 130.2, 129.1, 127.7, 127.2, 125.8, 103.8, 103.3, 27.6, 27.3.

MS (%): *m*/*z* = 275 (100) [M^+], 274 (92.9) [M – 1].

Anal. Calcd for $C_{18}H_{13}NO_2$: C, 78.53; H, 4.76; N, 5.09. Found: C, 78.73; H, 4.54; N, 5.21%

2,3-Dimethoxy-5,6-dihydrobenzo[*c*]acridine (6d)
Solid; mp 175–176 °C.

IR (KBr): 3050, 2990, 1621, 1585, 1503, 1453, 1426, 1386, 1320, 1291, 1239, 1145, 1009, 911, 843, 792, 760, 735 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.38 (d, *J* = 5.6 Hz, 1 H, ArH), 7.98 (s, 1 H, ArH), 7.40–7.31 (m, 4 H, ArH), 7.27 (s, 1 H, ArH), 3.94 (s, 3 H, CH_3O), 3.90 (s, 3 H, CH_3O), 3.04 (t, *J* = 7.2 Hz, 2 H, CH_2), 2.94 (t, *J* = 7.2 Hz, 2 H, CH_2).

^{13}C NMR (400 MHz, DMSO-d_6): δ = 152.2, 150.4, 149.9, 144.2, 139.3, 134.9, 132.9, 129.5, 128.6, 128.5, 127.3, 125.4, 123.5, 108.1, 105.6, 56.1, 56.0, 28.2.

MS (%): *m*/*z* = 291 (100) [M^+], 289 (29) [M – 2].

Anal. Calcd for $C_{19}H_{17}NO_2$: C, 78.33; H, 5.88; N, 4.81. Found: C, 78.47; H, 5.64; N, 4.75.

2-Phenylquinoline (8a)
Solid; mp 79–81 °C (lit.[14] 83 °C).

IR (KBr): 3055, 1622, 1596, 1546, 1496, 1442, 1321, 1204, 1128, 1026, 830, 792, 772, 691 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.24 (d, *J* = 8.4 Hz, 1 H, ArH), 8.20–8.16 (m, 3 H, ArH), 7.89 (d, *J* = 8.4 Hz, 1 H, ArH), 7.84 (d, *J* = 7.2 Hz, 1 H, ArH), 7.74 (t, *J* = 7.2 Hz, 1 H, ArH), 7.56–7.45 (m, 4 H, ArH).

^{13}C NMR (400 MHz, $CDCl_3$): δ = 157.3, 147.9, 139.3, 137.1, 129.9, 129.5, 128.9, 127.7, 127.5, 127.2, 126.5, 119.1.

MS (%): *m*/*z* = 205 (100) [M^+], 204 (96) [M – 1].

2-(4-Chlorophenyl)quinoline (8b)
Solid; mp 112–114 °C.

IR (KBr): 3043, 1623, 1588, 1552, 1486, 1430, 1127, 1090, 1008, 817, 787, 752, 714 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.24 (d, *J* = 8.4 Hz, 1 H, ArH), 8.18–8.12 (m, 3 H, ArH), 7.85 (dd, J_1 = 8.4 Hz, J_2 = 4.4 Hz, 2 H, ArH), 7.74 (t, *J* = 7.2 Hz, 1 H, ArH), 7.57–7.49 (m, 3 H, ArH).

^{13}C NMR (400 MHz, $CDCl_3$): δ = 156.0, 148.1, 137.9, 137.1, 135.6, 129.9, 129.6, 129.1, 128.9, 127.5, 127.2, 126.6, 118.6.

MS (%): *m*/*z* = 241 (31.4) [M + 2], 239 (100) [M^+], 238 (36) [M – 1].

Anal. Calcd for $C_{15}H_{10}ClN$: C, 75.16; H, 4.20; N, 5.84. Found: C, 75.23; H, 4.09; N, 5.62.

2-(4-Bromophenyl)quinoline (8c)
Solid; mp 114–116 °C.

IR (KBr): 3034, 1623, 1594, 1485, 1429, 1126, 1070, 1005, 815, 787, 751, 713 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.25 (d, *J* = 8.4 Hz, 1 H, ArH), 8.18 (d, *J* = 8.4 Hz, 1 H, ArH), 8.07 (d, *J* = 7.2 Hz, 2 H, ArH), 7.85 (dd, J_1 = 8.4 Hz, J_2 = 4.4 Hz, 2 H, ArH), 7.77 (t, *J* = 7.2 Hz, 1 H, ArH), 7.66 (d, *J* = 8.4 Hz, 2 H, ArH), 7.55 (t, *J* = 7.2 Hz, 1 H, ArH).

^{13}C NMR (400 MHz, $CDCl_3$): δ = 156.0, 148.5, 138.6, 137.1, 132.0, 130.0, 129.6, 129.1, 127.5, 127.3, 126.6, 124.0, 118.6.

MS: (%): *m*/*z* = 285 (96) [M + 2], 283 (100) [M^+], 204 (87) [M – Br].

Anal. Calcd for $C_{15}H_{10}BrN$: C, 63.40; H, 3.55; N, 4.93. Found: C, 63.69; H, 3.38; N, 4.77.

6-Chloro-2-phenylquinoline (8d)
Solid; mp 109–110 °C.

IR (KBr): 3050, 1618, 1595, 1546, 1483, 1318, 1191, 1129, 1073, 1022, 944, 876, 833, 782, 754, 715, 694 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.17–8.11 (m, 4 H, ArH), 7.91 (d, *J* = 8.4 Hz, 1 H, ArH), 7.82 (s, 1 H, ArH), 7.66 (d, *J* = 8.4 Hz, 1 H, ArH), 7.54 (t, *J* = 7.2 Hz, 2 H, ArH), 7.50–7.47 (m, 1 H, ArH).

^{13}C NMR (400 MHz, $CDCl_3$): δ = 157.6, 146.6, 139.1, 135.9, 132.0, 131.3, 130.6, 129.6, 128.9, 127.7, 127.6, 126.2, 119.8.

MS (%): *m*/*z* = 241 (32) [M + 2], 239 (100) [M^+], 238 (48) [M – 1], 204 (30.5) [M – Cl].

Anal. Calcd for $C_{15}H_{10}ClN$: C, 75.16; H, 4.20; N, 5.84. Found: C, 75.32; H, 4.09; N, 5.92.

6-Chloro-2-(3-chlorophenyl)quinoline (8e)
Solid; mp 96–98 °C.

IR (KBr): 3043, 1625, 1596, 1548, 1474, 1328, 1190, 1131, 1099, 1079, 947, 898, 870, 831, 811, 785, 757, 697 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 8.19–8.13 (m, 3 H, ArH), 8.03 (d, *J* = 5.6 Hz, 1 H, ArH), 7.88 (d, *J* = 8.8 Hz, 1 H, ArH), 7.83 (s, 1 H, ArH), 7.69 (d, *J* = 10.0 Hz, 1 H, ArH), 7.49–7.46 (m, 2 H, ArH).

^{13}C NMR (400 MHz, $CDCl_3$): δ = 155.9, 146.5, 140.8, 136.2, 135.1, 132.4, 131.3, 130.9, 130.1, 129.6, 127.9, 127.7, 126.2, 125.6, 119.6.

MS (%): *m*/*z* = 277 (11) [M + 4], 275 (61) [M + 2], 273 (100) [M$^+$], 238 (57) [M – Cl].

Anal. Calcd for $C_{15}H_9Cl_2N$: C, 65.72; H, 3.31; N, 5.11. Found: C, 65.83; H, 3.06; N, 4.92.

6-Chloro-2-(4-chlorophenyl)quinoline (8f)
Solid; mp 162–164 °C.

IR (KBr): 3040, 1623, 1596, 1484, 1407, 1180, 1092, 1073, 1012, 886, 847, 823, 804, 665 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.16–8.09 (m, 4 H, ArH), 7.87 (d, *J* = 10.0 Hz, 1 H, ArH), 7.82 (s, 1 H, ArH), 7.67 (d, *J* = 8.4 Hz, 1 H, ArH), 7.50 (d, *J* = 8.8 Hz, 2 H, ArH).

^{13}C NMR (400 MHz, DMSO-d_6): δ = 155.8, 146.4, 137.5, 137.3, 135.3, 131.7, 131.4, 131.1, 129.5, 129.4, 128.3, 127.1, 120.1.

MS (%): *m*/*z* = 277 (7.3) [M + 4], 275 (51.3) [M + 2], 273 (100) [M$^+$], 238 (54.4) [M – Cl].

Anal. Calcd for $C_{15}H_9Cl_2N$: C, 65.72; H, 3.31; N, 5.11. Found: C, 65.81; H, 2.94; N, 5.25.

6-Chloro-2-(4-bromophenyl)quinoline (8g)
Solid; mp 174–175 °C.

IR (KBr): 3040, 1617, 1596, 1546, 1482, 1403, 1314, 1179, 1072, 886, 844, 823, 803, 657 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.19 (d, *J* = 8.4 Hz, 2 H, ArH), 8.06 (d, *J* = 8.4 Hz, 2 H, ArH), 7.88 (d, *J* = 8.8 Hz, 1 H, ArH), 7.83 (s, 1 H, ArH), 7.70–7.66 (m, 3 H, ArH).

^{13}C NMR (400 MHz, $CDCl_3$): δ = 156.2, 146.7, 138.0, 136.2, 132.3, 132.1, 131.2, 130.9, 129.1, 127.8, 126.2, 124.4, 119.4.

MS (%): *m*/*z* = 321 (9.4) [M + 4], 319 (100) [M + 2], 317 (95.2) [M$^+$], 238 (43) [M – Br], 203 (22.1) [M – Br – Cl].

Anal. Calcd for $C_{15}H_9BrClN$: C, 56.55; H, 2.85; N, 4.40. Found: C, 56.71; H, 2.62; N, 4.28.

Acknowledgment

We are grateful to the Natural Science Foundation of Jiangsu Education Department (No. 03KJB150136) and Foundation of the Key Laboratory of Biotechnology for Medical Plants of Jiangsu Province (No. 02AXL13) for financial support.

References

(1) McMurry, J. E. *Chem. Rev.* **1989**, *89*, 1513.
(2) (a) McMurry, J. E.; Fleming, M. P. *J. Org. Chem.* **1976**, *41*, 896. (b) McMurry, J. E. *Acc. Chem. Res.* **1983**, *16*, 405. (c) Lenoir, D. *Synthesis* **1989**, 883. (d) Fürstner, A.; Bogdanovi, B. *Angew. Chem., Int. Ed. Engl.* **1996**, *35*, 2443. (e) Shi, D. Q.; Chen, J. X.; Chai, W. Y.; Chen, W. X.; Kao, T. Y. *Tetrahedron Lett.* **1993**, *34*, 2963. (f) Shi, D. Q.; Rong, L. C.; Wang, J. X.; Zhuang, Q. Y.; Wang, X. S.; Hu, H. W. *Tetrahedron Lett.* **2003**, *44*, 3199. (g) Shi, D. Q.; Wang, J. X.; Shi, C. L.; Rong, L. C.; Zhuang, Q. Y.; Hu, H. W. *Synlett* **2004**, 1098. (h) Li, J.; Shi, D. Q.; Chen, W. X. *Heterocycles* **1997**, *45*, 2381. (i) Shi, D. Q.; Shi, C. L.; Wang, X. S.; Zhuang, Q. Y.; Tu, S. J.; Hu, H. W. *Synlett* **2004**, 2239.
(3) Zhou, L. H.; Shi, D. Q.; Gao, Y.; Shen, W. B.; Dai, G. Y.; Chen, W. X. *Tetrahedron Lett.* **1997**, *38*, 2729.
(4) Zhou, L. H.; Tu, S. J.; Shi, D. Q.; Dai, G. Y.; Chen, W. X. *Synthesis* **1998**, 851.
(5) (a) Chen, W. X.; Zhang, J. H.; Hu, M. Y.; Wang, X. C. *Synthesis* **1990**, 701. (b) Chen, J. X.; Jiang, J. P.; Chen, W. X.; Kao, T. Y. *Chin. Chem. Lett.* **1991**, *2*, 351. (c) Chen, J. X.; Jiang, J. P.; Chen, W. X.; Kao, T. Y. *Heterocycles* **1990**, 701.
(6) Shi, D. Q.; Zhao, H.; Wang, X. S.; Yao, C. S.; Zhou, L. H. *J. Chem. Res., Synop.* **2002**, 452.
(7) Yamamoto, Y.; Matsumi, D.; Itoh, K. *Chem. Commun.* **1998**, 875.
(8) Chen, J. X.; Chen, W. X.; Zhang, J. H. *Chin. J. Org. Chem.* **1992**, *12*, 26.
(9) Huang, L. S. *Acta Pharm. Simica* **1983**, *18*, 553.
(10) (a) Huang, L. S. *Acta Pharm. Simica* **1983**, *18*, 633. (b) Akira, Y.; Kazuo, K. *Radioisotopes* **1979**, *28*, 687.
(11) Claret, P. A. In *Comprehensive Organic Chemistry*, Vol. 4; Barton, D. H. R.; Ollis, W. D., Eds.; Pergamon Press: Oxford, **1979**, 155.
(12) Jiang, J. P.; Gao, J.; Shen, W. B.; Chen, W. X. *Acta Chimica Sinica* **1992**, *50*, 1134.
(13) Shi, D. Q.; Lu, Z. S.; Wang, S. H.; Tu, S. J.; Dai, G. Y. *Synth. Commun.* **1998**, *28*, 4003.
(14) Kundu, N. G.; Mahanty, J. S.; Das, B. *Tetrahedron Lett.* **1993**, *34*, 1625.