A Convenient One-Pot Synthesis of 4′-Aryl-2,2′:6′,2″-terpyridines and 2,4,6-Triarylpyridines under Microwave Irradiation

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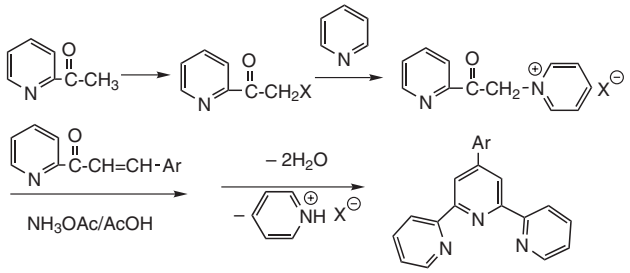
Abstract: A series of 4′-aryl-2,2′:6′,2″-terpyridines have been prepared by the one-pot reaction of 2-acetylpyridine with aromatic aldehydes in the presence of ammonium acetate under microwave irradiation. This method has the advantages of shorter route, easier workup, shorter reaction time, higher yield and more environmentally friendly conditions, compared to the conventional ones.

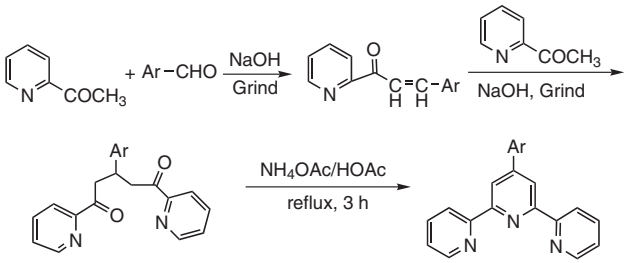
Key words: 2-acetylpyridine, aromatic aldehyde, terpyridine, microwave

4′-Substituted 2,2′:6′,2″-terpyridines(tpy),[1] as outstanding ligands, have attracted widespread attention due to their ability to form complexes with a variety of transition-metal ions. Potential applications of these complexes have been found in various fields such as supramolecular chemistry,[2] asymmetric catalysis,[3] photosensitization,[4] and molecular biology[5] and potential pharmaceutical application.[6] Therefore, much attention has been paid to the synthesis of tpy.[7–9] The methodology of preparation for such compounds has been described in several reviews. Among the traditional methods for the preparation of the tpy, Kröhnke approach has been regarded as a useful way to synthesize aryl-substituted tpy ligands, which consists in the reaction of chalcones with pyridinium salt[8] (Scheme 1).



Scheme 1

It is well-known that the pyridinium salt was obtained by the reaction of 2-halo-1-pyridin-2-ylethanone (halogenation of acetylpyridine) with pyridine, and the chalcone was obtained by the reaction of aromatic aldehyde with acetylpyridine using base as catalyst. This protocol was a time consuming procedure and the by-product pyridine is toxic. Besides, the final condensation step usually yields tar-like crude products, which requires special efforts to isolate and purify the desired terpyridine compounds. Recently, Cave and Raston[10] reported a modified Kröhnke method by solventless reactions (Scheme 2).



Scheme 2

This method overcame the drawback of the classical Kröhnke's reaction to some extent. However, it could not avoid the drawback of its multiple steps; moreover, sodium hydroxide and acetic acid are harmful to the environment. Since tpy was first synthesized in 1932,[1] the development of simple, efficient and general synthetic methods for the widely used organic compounds from available reagent has been one of the major challenges in organic synthesis.

Microwave-assisted organic synthesis has attracted considerable attention in the past decade.[11] Microwave irradiation often leads to remarkably decreased reaction time, increased yield, and easier workup. They provide protocols consistent with green chemistry principles and may enhance the regio- and stereoselectivity of reactions.[12] The relative low cost of modern domestic microwave ovens makes them readily available to academic and industrial chemists.[13] Recently a synthesis of tpy has been described.[14] However, the method still used a strong base as catalyst which could do harm to the environment. Our group is interested in the application of microwave heating to organic synthesis.[15] In order to develop a simple and efficient synthesis towards tpy from available starting material, we investigated the one-pot reaction of 2-acetylpyridine, aromatic aldehydes and ammonium acetate in glycol under MWI without catalyst (Scheme 3).

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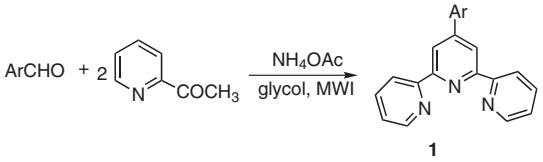


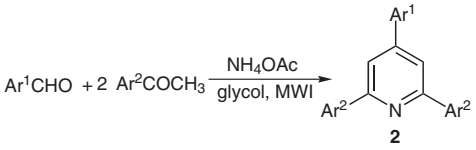
Scheme 3

The initial results are summarized in Table 1. The scope of the reaction regarding the aldehydes was examined and found to be excellent. The substituted groups of aromatic aldehydes, such as halogens and nitro, can tolerate the reaction condition with excellent yields. A series of tpy have been facilely synthesized in high yield. All the products were conformed on the basis of their IR and ^{1}H NMR spectra. In contrast to the methods described above, the one-pot reactions promoted by MWI (Scheme 3) are over within nine minutes with higher yield and easier work-up.

Table 1 Synthesis of **1**

Entry	Ar	Mp (°C) (Lit.)	Yield (%)
1a	4-ClC_6H_4	173–175 (171–172)[7]	91
1b	2-ClC_6H_4	156–157	88
1c	2,4-$Cl_2C_6H_3$	158.4–159.3	84
1d	3,4-$Cl_2C_6H_3$	153–155	91
1e	Ph	210–211 (206–207)[7]	80
1f	4-FC_6H_4	161–162	89
1g	4-$MeOC_6H_4$	167–168 (171–172)[7]	81
1h	4-BrC_6H_5	154–156 (158–160)[7]	89
1i	4-$NO_2C_6H_4$	195–197 (210–211)[7]	89
1j	3,4-$(MeO)_2C_6H_3$	146–147	90
1k	4-MeC_6H_4	166–167 (166–167)[7]	80
1l	3-$NO_2C_6H_4$	199–200	83

In order to examine the scope of this reaction, we employed aromatic ketones instead of 2-acetylpyridine to react with aromatic aldehydes (Scheme 4). The results (Table 2) show that a wide range of aromatic aldehydes and ketones can take part in this reaction, leading to the preparation of a series of 2,4,6-triarylpyridines **2**.[16] Recently, a modified method[17] for synthesis of 2,4,6-triarylpyridines was reported. But it suffered from using chalcone as starting material with low yield.



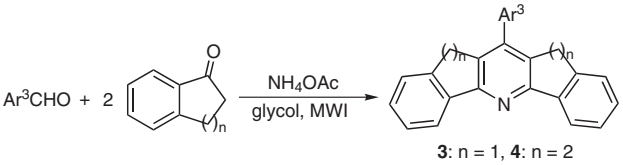
Scheme 4

Table 2 Synthesis of **2**

Entry	Ar^1	Ar^2	Mp (°C)	Yield (%)
2a	4-ClC_6H_4	3-$NO_2C_6H_4$	285.6–286.6	92
2b	4-ClC_6H_4	4-MeC_6H_4	200.6–202	90
2c	4-ClC_6H_4	2-ClC_6H_4	155.8–156	91
2d	4-ClC_6H_4	4-FC_6H_4	209.4–210.1	92
2e	4-ClC_6H_4	4-$OMeC_6H_4$	113.8–115.0	91
2f	4-ClC_6H_4	2,4-Cl2C_6H_3	176.4–177.0	95
2g	4-$NO_2C_6H_4$	4-$OMeC_6H_4$	143.1–144.7	90
2h	3-$NO_2C_6H_4$	3-$NO_2C_6H_4$	>300	91
2i	4-$OMeC_6H_4$	2,4-$Cl_2C_6H_3$	161.0–161.8	89
2j	4-$OMeC_6H_4$	4-$OMeC_6H_4$	136–137[a]	92
2k	2-ClC_6H_4	2-ClC_6H_4	146.5–147.3	89
2l	2-ClC_6H_4	2,4-$Cl_2C_6H_3$	201.2–201.6	89
2m	4-BrC_6H_4	2,4-$Cl_2C_6H_3$	177.9–178.2	92
2n	4-BrC_6H_4	4-$OMeC_6H_4$	163.9–165	92
2o	Ph	2,4-$Cl_2C_6H_3$	160.1–161	88
2p	2,4-$Cl_2C_6H_3$	2,4-$Cl_2C_6H_3$	203.9–204.8	91
2q	3,4-$Cl_2C_6H_3$	2,4-$Cl_2C_6H_3$	152.9–154.8	90
2r	3-indolyl	4-$OMeC_6H_4$	232.0–233.0	89

[a] Lit.[18] mp 135 °C.

Furthermore, this versatile method is also suitable for the indan-1-one and 3,4-dihydronaphthalen-1(2*H*)-one. 11-Aryldiindeno[1,2-*b*:2′,1′-*e*]pyridine **3** and 13-aryldinaphtho[1,2-*b*:2′,1′-*e*]pyridine **4** were obtained in good yields (Scheme 5). The results are listed in Table 3.



Scheme 5

In conclusion, we have found a convenient method for preparation of 4′-aryl-2,2′:6′,2″-terpyridines and 2,4,6-triarylpyridines from available starting materials under microwave irradiation. This methodology is superior to the reported methods from the view of yield, shorter route, easier workup and environmental friendly reaction conditions.

Table 3 Synthesis of **3** and **4**

Entry	Ar^3	Mp (°C)	Yield (%)
3a	4-OH-3-$MeOC_6H_3$	>300	92
3b	4-$OMeC_6H_4$	251.8–252.2	93
3c	3-indolyl	>300	90
4a	4-OH-3-$MeOC_6H_3$	292.0–292.8	91
4b	4-$OMeC_6H_4$	183.6–184.4	92
4c	3,4-$OCH_2OC_6H_3$	193.0–195.6	93

Microwave irradiation was carried out with a modified commercial microwave oven (2450 MHz, 650 W) under atmospheric pressure. Melting points were determined in open capillaries and are uncorrected. IR spectra were recorded on a Shimadzu spectrometer. ^{1}H NMR spectra were measured on a 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.

One-Pot Synthesis of Terpyridines 1, Triarylpyrdines 2 and Pyridines 3 and 4; General Procedure

A dry flask (25 mL) was charged with a mixture of the appropriate aldehyde (2 mmol), 2-acetylpyridine or aromatic ketone (4 mmol), NH_4OAc (225 mg, 3 mmol), glycol (1 mL) and kept in a microwave oven. The flask was then connected to a refluxing equipment. The mixture was irradiated for 5–9 min (the reaction was monitored by TLC). The mixture was cooled and the solid precipitated from the solution was filtered and washed with EtOH to afford the crude products. The crude products were purified by recrystallization from EtOH (Tables 1– 3).

1a

IR (KBr): 1585, 1567, 1546, 1469, 1441, 1411, 1383, 1091, 1012, 826, 789 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.83 (d, J = 5.2 Hz, 2 H, 6,6″-H), 8.72 (s, 2 H, 3′,5′-H), 8.64 (d, J = 8.0 Hz, 2 H, 3,3″-H), 8.07 (dd, J = 8.0, 6.8 Hz, 2 H, 4,4″-H), 7.99 (d, J = 8.8 Hz, 2 H, ArH), 7.66 (d, J = 8.8 Hz, 2 H, ArH), 7.55 (dd, J = 6.8, 5.2 Hz, 2 H, 5,5″-H).

Anal. Calcd for $C_{21}H_{14}ClN_3$: C, 73.36; H, 4.10; N, 12.22. Found: C, 73.31; H, 4.12; N, 12.19.

1b

IR (KBr): 1585, 1567, 1551, 1467, 1442, 1392, 1088, 1040, 991, 790, 779, 749 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.81 (d, J = 5.2 Hz, 2 H, 6,6″-H), 8.51 (s, 2 H, 3′,5′-H), 8.47 (d, J = 8.0 Hz, 2 H, 3,3″-H), 8.27 (dd, J = 8.4, 8.0 Hz, 2 H, 4,4″-H), 8.05 (dd, J = 8.4, 5.2 Hz, 2 H, 5,5″-H), 7.50–7.70 (m, 4 H, ArH).

Anal. Calcd for $C_{21}H_{14}ClN_3$: C, 73.36; H, 4.10; N, 12.22. Found: C, 73.29; H, 4.11; N, 12.24.

1c

IR (KBr): 1583, 1568, 1544, 1468, 1402, 993, 816, 793 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.81 (d, J = 6.0 Hz, 2 H, 6,6″-H), 8.77 (d, J = 8.0 Hz, 2 H, 3,3″-H), 8.48 (s, 2 H, 3′,5′-H), 8.05 (dd, J = 8.4, 8.0 Hz, 2 H, 4,4″-H), 7.70 (dd, J = 8.4, 6.0 Hz, 2 H, 5,5″-H), 7.51–7.54 (m, 3 H, ArH).

Anal. Calcd for $C_{21}H_{13}Cl_2N_3$: C, 66.68; H, 3.46; N, 11.11. Found: C, 66.73; H, 3.51; N, 11.20.

1d

IR (KBr): 1584, 1567, 1540, 1469, 1440, 1405, 1370, 1137, 1030, 874, 823, 787, 732, 683 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.78 (d, J = 4.0 Hz, 2 H, 6,6″-H), 8.70 (s, 2 H, 3′,5′-H), 8.67 (d, J = 8.4 Hz, 2 H, 3,3″-H), 8.20 (d, J = 2.0 Hz, 1 H, ArH), 8.05 (dd, J = 8.4, 6.4 Hz, 2 H, 4,4″-H), 7.93 (dd, J = 8.0, 2.0 Hz, 1 H, ArH), 7.83 (d, J = 8.0 Hz, 1 H, ArH), 7.54 (dd, J = 6.4, 4.0 Hz, 2 H, 5,5″-H).

Anal. Calcd for $C_{21}H_{13}Cl_2N_3$: C, 66.68; H, 3.46; N, 11.11. Found: C, 66.73; H, 3.55; N, 11.21.

1e

IR (KBr): 1583, 1567, 1550, 1468, 1392, 993, 892, 796 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.82 (d, J = 4.8 Hz, 2 H, 6,6″-H), 8.72 (s, 2 H, 3′,5′-H), 8.68 (d, J = 8.0 Hz, 2 H, 3,3″-H), 8.04 (dd, J = 8.0, 6.4 Hz, 2 H, 4,4″-H), 7.93 (dd, J = 6.4, 4.8 Hz, 2 H, 5,5″-H), 7.52–7.63 (m, 5 H, ArH).

Anal. Calcd for $C_{21}H_{15}N_3$: C, 81.53; H, 4.89; N, 13.58. Found: C, 81.50; H, 4.87; N, 13.63.

1f

IR (KBr): 1585, 1567, 1552, 1512, 1466, 1416, 1386, 1225, 1161, 1039, 991, 832, 788, 733 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.77 (d, J = 5.2 Hz, 2 H, 6,6″-H), 8.70 (s, 2 H, 3′,5′-H), 8.67 (d, J = 8.4 Hz, 2 H, 3,3″-H), 8.05 (dd, J = 8.8, 8.4 Hz, 2 H, 4,4″-H), 7.99 (dd, J = 8.8, 5.2 Hz, 2 H, 5,5″-H), 7.53 (d, J = 8.8 Hz, 2 H, ArH), 7.40 (d, J = 8.8 Hz, 2 H, ArH).

Anal. Calcd for $C_{21}H_{14}FN_3$: C, 77.05; H, 4.31; N, 12.84. Found: C, 69.97; H, 4.34; N, 12.87.

1g

IR (KBr): 1583, 1566, 1546, 1467, 1402, 990, 888, 791 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.81 (d, J = 4.0 Hz, 2 H, 6,6″-H), 8.67 (s, 2 H, 3′,5′-H), 8.32 (d, J = 8.8 Hz, 2 H, 3,3″-H), 8.04 (dd, J = 8.8, 7.6 Hz, 2 H, 4,4″-H), 7.90 (d, J = 8.0 Hz, 2 H, ArH), 7.53 (dd, J = 7.6, 4.0 Hz, 2 H, 5,5″-H), 7.14 (d, J = 8.0 Hz, 2 H, ArH), 3.87 (s, 3 H, OCH_3).

Anal. Calcd for $C_{22}H_{17}N_3O$: C, 77.86; H, 5.05; N, 12.38. Found: C, 77.80; H, 5.11; N, 12.42.

1h

IR (KBr): 1584, 1567, 1550, 1490, 1408, 889, 823, 789 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.82 (d, J = 5.2 Hz, 2 H, 6,6″-H), 8.71 (s, 2 H, 3′,5′-H), 8.67 (d, J = 8.0 Hz, 2 H, 3,3″-H), 8.04 (dd, J = 8.0, 6.8 Hz, 2 H, 4,4″-H), 7.91 (d, J = 8.0 Hz, 2 H, ArH), 7.78 (d, J = 8.0 Hz, 2 H, ArH), 7.53 (dd, J = 6.8, 5.2 Hz, 2 H, 5,5″-H).

Anal. Calcd for $C_{21}H_{14}BrN_3$: C, 64.96; H, 3.63; N, 10.82. Found: C, 65.01; H, 3.68; N, 10.78.

1i

IR (KBr): 1584, 1567, 1550, 1415, 1386, 1350, 1107, 991, 854, 789, 754, 694 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.85 (d, J = 6.4 Hz, 2 H, 6,6″-H), 8.74 (s, 2 H,3′,5′-H), 8.66 (d, J = 8.4 Hz, 2 H, 3,3″-H), 8.63 (d, J = 9.2 Hz, 2 H, Ar-H), 8.20 (d, J = 9.2 Hz, 2 H, Ar-H). 8.04 (dd, J_1 = 8.4, J_2 = 7.25 Hz, 2 H, 4,4″-H), 7.53 (dd, J_1 = 7.2, J_2 = 6.4 Hz, 2 H, 5,5″-H).

Anal. Calcd for $C_{21}H_{14}N_4O_2$: C, 71.18; H, 3.98; N, 15.81. Found: C, 71.08; H, 4.08; N, 15.80.

1j
IR (KBr): 1585, 1566, 1543, 1469, 1437, 1391, 1324, 1262, 1208, 1169, 1145, 1025, 850, 789, 731 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.77 (d, *J* = 5.2 Hz, 2 H, 6,6″-H), 8.68 (s, 2 H, 3′,5′-H), 8.65 (d, *J* = 8.0 Hz, 2 H, 3,3″-H), 8.04 (dd, *J* = 8.4, 8.0 Hz, 2 H, 4,4″-H), 7.54 (dd, *J* = 8.4, 5.2 Hz, 2 H, 5,5″-H), 7.49 (d, *J* = 8.8 Hz, 1 H, ArH), 7.45 (s, 1 H, ArH), 7.18 (d, *J* = 8.8 Hz, 1 H, ArH), 3.39 (s, 3 H, OCH_3), 3.86 (s, 3 H, OCH_3).

Anal. Calcd for $C_{23}H_{19}N_3O_2$: C, 74.78; H, 5.18; N, 11.37. Found: C, 74.68; H, 5.26; N, 11.43.

1k
IR (KBr): 1584, 1566, 1544, 1467, 1387, 989, 888, 790 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.77 (d, *J* = 5.6 Hz, 2 H, 6,6″-H), 8.72 (s, 2 H, 3′,5′-H), 8.68 (d, *J* = 8.0 Hz, 2 H, 3,3″-H), 8.02–8.07 (m, 2 H, 4,4″-H), 7.85 (d, *J* = 8.0 Hz, 2 H, ArH), 7.51–7.55 (m, 2 H, 5,5″-H), 7.42 (d, *J* = 8.0 Hz, 2 H, ArH), 2.42 (s, 3 H, CH_3).

Anal. Calcd for $C_{22}H_{17}N_3$: C, 81.71; H, 5.30; N, 12.99. Found: C, 81.61; H, 5.35; N, 13.04.

1l
IR (KBr): 1585, 1567, 1527, 1470, 1390, 1348, 1075, 993, 885, 781, 733 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.83 (d, *J* = 5.6 Hz, 2 H, 6,6″-H), 8.77 (2 H, s, 3′,5′-H), 8.68 (d, *J* = 8.0 Hz, 2 H, 3,3″-H), 8.64 (1 H, s, ArH), 8.63 (d, *J* = 8.0 Hz, 1 H, Ar-H), 8.42 (d, *J* = 8.4 Hz, 1 H, ArH), 8.04 (dd, *J* = 8.0, 7.2 Hz, 2 H, 4,4″-H), 7.88 (dd, *J* = 8.4, 8.0 Hz, 1 H, ArH), 7.55 (dd, *J* = 7.2, 5.6 Hz, 2 H, 5,5″-H).

Anal. Calcd for $C_{21}H_{14}N_4O_2$: C, 71.18; H, 3.98; N, 15.81. Found: C, 71.26; H, 4.02; N, 15.70.

2a
IR (KBr): 1660, 1602, 1493, 1437, 1386, 881, 819, 755, 729, 715 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 9.14 (s, 2 H, ArH), 8.82 (d, *J* = 8.0 Hz, 2 H, ArH), 8.51 (s, 2 H, pyridyl-H), 8.36 (d, *J* = 8.0 Hz, 2 H, ArH), 8.21 (d, *J* = 8.0 Hz, 2 H, ArH), 7.85–7.90 (m, 2 H, ArH), 7.66 (d, *J* = 8.0 Hz, 2 H, ArH).

Anal. Calcd for $C_{23}H_{14}ClN_3O_4$: C, 63.97; H, 3.27; N, 9.73. Found: C, 64.04; H, 3.17; N, 9.88.

2b
IR (KBr): 1602, 1578, 1542, 1492, 1421, 1384, 875, 786 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.22 (d, *J* = 8.0 Hz, 4 H, ArH), 8.13 (s, 2 H, pyridyl-H), 8.08 (d, *J* = 8.4 Hz, 2 H, ArH), 7.61 (d, *J* = 8.0 Hz, 2 H, ArH), 7.35 (d, *J* = 8.0 Hz, 2 H, ArH), 2.39 (s, 6 H, 2 CH_3).

Anal. Calcd for $C_{25}H_{20}ClN$: C, 81.18; H, 5.45; N, 3.79. Found: C, 81.26; H, 5.50; N, 3.87.

2c
IR (KBr): 1605, 1577, 1545, 1494, 1476, 1441, 1386, 890, 824, 768 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 7.95–7.98 (m, 2 H, ArH), 7.80 (s, 2 H, pyridyl-H), 7.75–7.77 (m, 2 H, ArH), 7.59–7.63 (m, 4 H, ArH), 7.48–7.52 (m, 4 H, ArH).

Anal. Calcd for $C_{23}H_{14}Cl_3N$: C, 67.26; H, 3.44; N, 3.41. Found: C, 67.42; H, 3.54; N, 10.47.

2d
IR (KBr): 1607, 1546, 1493, 1423, 1384, 828, 780, 750 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.37–8.41 (m, 2 H, ArH), 8.21 (s, 2 H, pyridyl-H), 8.09–8.13 (m, 2 H, ArH), 7.59–7.64 (m, 2 H, ArH), 7.35–7.39 (m, 4 H, ArH).

Anal. Calcd for $C_{23}H_{14}ClF_2N$: C, 73.12; H, 3.73; N, 3.71. Found: C, 73.20; H, 3.83; N, 3.79.

2e
IR (KBr): 1655, 1605, 1510, 1491, 1406, 1312, 817, 780 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.17–8.19 (m, 4 H, ArH), 8.01 (s, 2 H, pyridyl-H), 7.92–7.96 (m, 2 H, ArH), 7.52–7.54 (m, 4 H, ArH), 7.09–7.11 (m, 2 H, ArH), 3.88 (s, 6 H, 2 OCH_3).

Anal. Calcd for $C_{25}H_{20}ClNO_2$: C, 74.72; H, 5.02; N, 3.49. Found: C, 74.83; H, 4.99; N, 3.57.

2f
IR (KBr): 1602, 1551, 1493, 1473, 1423, 1365, 888, 858, 786 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.04 (s, 2 H, pyridyl-H), 7.96–7.98 (m, 2 H, ArH), 7.79–7.81 (m, 4 H, ArH), 7.59–7.64 (m, 4 H, ArH).

Anal. Calcd for $C_{23}H_{12}Cl_5N$: C, 57.60; H, 2.52; N, 2.92. Found: C, 57.58; H, 2.63; N, 2.87.

2g
IR (KBr): 1606, 1546, 1516, 1428, 1346, 832 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.29–8.39 (m, 8 H, ArH), 8.15 (s, 2 H, pyridyl-H), 7.09–7.12 (m, 4 H, ArH), 3.88 (s, 6 H, 2 OCH_3).

Anal. Calcd for $C_{25}H_{20}N_2O_4$: C, 72.80; H, 4.89; N, 6.79. Found: C, 72.93; H, 4.77; N, 6.63.

2h
IR (KBr): 1602, 1525, 1350, 874, 818, 802, 727 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 9.17 (s, 2 H, ArH), 8.94–8.95 (m, 1 H, ArH), 8.85–8.87 (m, 2 H, ArH), 8.63 (s, 2 H, pyridyl-H), 8.60–8.61 (m, 1 H, ArH), 8.37–8.41 (m, 3 H, ArH), 7.88–7.95 (m, 3 H, ArH).

Anal. Calcd for $C_{23}H_{14}N_4O_6$: C, 62.45; H, 3.19; N, 12.66; Found: C, 62.53; H, 3.08; N, 12.57.

2i
IR (KBr): 1602, 1554, 1514, 1472, 1429, 1365, 885, 857, 843, 798 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 7.97 (s, 2 H, pyridyl-H), 7.87–7.89 (m, 2 H, ArH), 7.77–7.79 (m, 4 H, ArH), 7.57–7.59 (m, 2 H, ArH), 7.09–7.11 (m, 2 H, ArH), 3.84 (s, 3 H, OCH_3).

Anal. Calcd for $C_{24}H_{15}Cl_4NO$: C, 60.66; H, 3.18; N, 2.95. Found: C, 60.62; H, 3.21; N, 2.87.

2j
IR (KBr): 1608, 1543, 1510, 1461, 1427, 1392, 823 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.21 (m, 4 H, ArH), 8.02 (s, 2 H, pyridyl-H), 7.99–8.01 (m, 2 H, ArH), 7.08–7.12 (m, 6 H, ArH), 3.85 (s, 9 H, 3 OCH_3).

Anal. Calcd for $C_{26}H_{23}NO_3$: C, 78.57; H, 5.83; N, 3.52. Found: C, 78.49; H, 5.76; N, 3.56.

2k
IR (KBr): 1598, 1555, 1534, 1472, 1436, 1407, 1366, 894, 835, 786 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 7.81 (s, 2 H, pyridyl-H), 7.77–7.79 (m, 2 H, ArH), 7.61–7.67 (m, 4 H, ArH), 7.49–7.53 (m, 6 H, ArH).

Anal. Calcd for $C_{23}H_{14}Cl_3N$: C, 67.26; H, 3.44; N, 3.41. Found: C, 67.20; H, 3.45; N, 3.54.

2l

IR (KBr): 1610, 1541, 1474, 1433, 1398, 1085, 1052, 1034, 987, 890 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.85 (s, 2 H, pyridyl-H), 7.79–7.82 (m, 4 H, ArH), 7.61–7.67 (m, 2 H, ArH), 7.57–7.60 (m, 2 H, ArH), 7.51–7.54 (m, 2 H, ArH).

Anal. Calcd for $C_{23}H_{12}Cl_5N$: C, 57.60; H, 2.52; N, 2.92. Found: C, 57.62; H, 2.49; N, 2.89.

2m

IR (KBr): 1600, 1571, 1541, 1473, 1422, 1364, 888, 835, 811 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.03 (s, 2 H, pyridyl-H), 7.88–7.90 (m, 2 H, ArH), 7.78–7.81 (m, 4 H, ArH), 7.74–7.76 (m, 2 H, ArH), 7.58–7.61 (m, 2 H, ArH).

Anal. Calcd for $C_{23}H_{12}BrCl_4N$: C, 52.71; H, 2.31; N, 2.67. Found: C, 52.67; H, 2.40; N, 2.81.

2n

IR (KBr): 1605, 1577, 1540, 1490, 1459, 1423, 1384, 1361, 819 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.27 (d, *J* = 8.0 Hz, 2 H, ArH), 8.06 (s, 2 H, pyridyl-H), 8.00 (d, *J* = 8.0 Hz, 2 H, ArH), 7.75 (d, *J* = 8.0 Hz, 2 H, ArH), 7.08 (d, *J* = 8.0 Hz, 2 H, ArH), 7.08 (d, *J* = 8.0 Hz, 2 H, ArH), 3.85 (s, 6 H, 2 OCH_3).

Anal. Calcd for $C_{25}H_{20}BrNO_2$: C, 67.27; H, 4.52; N, 3.14. Found: C, 67.32; H, 4.46; N, 3.08.

2o

IR (KBr): 1597, 1556, 1541, 1474, 1411, 1368, 816 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.06 (s, 2 H, pyridyl-H), 7.91–7.93 (m, 2 H, ArH), 7.79–7.82 (m, 4 H, ArH), 7.50–7.61 (m, 5 H, ArH).

Anal. Calcd for $C_{23}H_{13}Cl_4N$: C, 62.05; H, 2.94; N, 3.15; Found: C, 62.10; H, 2.87; N, 3.24.

2p

IR (KBr): 1598, 1557, 1538, 1471, 1414, 1363, 1050, 872, 813 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 7.87 (s, 2 H, pyridyl-H), 7.79–7.82 (m, 4 H, ArH), 7.75–7.53 (m, 1 H, ArH), 7.68–7.70 (m, 1 H, ArH), 7.58–7.61 (m, 3 H, ArH).

Anal. Calcd for $C_{23}H_{11}Cl_6N$: C, 53.74; H, 2.16; N, 2.72. Found: C, 53.62; H, 2.10; N, 2.81.

2q

IR (KBr): 1665, 1603, 1551, 1473, 1420, 1389, 1363, 1322, 993, 857, 813 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 7.79–7.82 (m, 5 H, ArH), 7.78 (s, 2 H, pyridyl-H), 7.57–7.71 (m, 5 H, ArH), 7.37–7.48 (m, 3 H, ArH).

Anal. Calcd for $C_{23}H_{11}Cl_6N$: C, 53.74; H, 2.16; N, 2.72. Found: C, 53.70; H, 2.21; N, 2.63.

2r

IR (KBr): 3135, 3105, 2829, 1599, 1512, 1458, 1421, 1342, 880, 801 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 11.75 (s, 1 H, indolyl-NH), 8.24–8.27 (m, 5 H, ArH), 8.08–8.11 (m, 1 H, ArH), 8.08 (s, 2 H, pyridyl-H), 7.51–7.58 (m, 2 H, ArH), 7.22–7.24 (m, 2 H, ArH), 7.10–7.12 (m, 4 H, ArH), 3.86 (s, 6 H, OCH_3).

Anal. Calcd for $C_{27}H_{22}N_2O_2$: C, 79.78; H, 5.46; N, 6.89. Found: C, 79.85; H, 5.66; N, 6.78.

3a

IR (KBr): 3512, 1599, 1563, 1518, 1460, 842, 771, 773 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 9.31 (s, 1 H, OH), 8.11 (d, *J* = 7.2 Hz, 2 H, 5,6-H), 7.64 (d, *J* = 7.6 Hz, 2 H, Aryl 5,6-H), 7.51 (t, *J* = 7.2 Hz, 2 H, 3,8-H), 7.44 (t, *J* = 7.2 Hz, 2 H, 4,7-H), 7.23 (s, 1 H, ArH), 7.20 (d, *J* = 8.0 Hz, 1 H, 2-H), 6.97 (d, *J* = 7.6 Hz, 1 H, 9-H), 3.97 (s, 4 H, 1,10-H), 3.84 (s, 3 H, OCH_3).

Anal. Calcd for $C_{27}H_{20}O_2$: C, 86.14; H, 5.36; Found: C, 86.22; H, 5.46.

3b

IR (KBr): 1612, 1561, 1517, 1464, 1440, 1288, 1025, 859, 831, 776 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.11 (d, *J* = 7.2 Hz, 2 H, 5,6-H), 7.76 (d, *J* = 8.0 Hz, 2 H, Aryl 2,6-H), 7.63 (d, *J* = 7.2 Hz, 2 H, 2,9-H), 7.51 (t, *J* = 7.2 Hz, 2 H, 3,8-H), 7.45 (t, *J* = 7.2 Hz, 2 H, 4,7-H), 7.14 (d, *J* = 8.0 Hz, 2 H, Aryl 3,5-H), 3.95 (s, 4 H, 1,10-H), 3.87 (s, 3 H, OCH_3).

Anal. Calcd for $C_{27}H_{20}O$: C, 89.97; H, 5.59; Found: C, 90.02; H, 5.48.

3c

IR (KBr): 3292, 1573, 1559, 1491, 767, 794, 738 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 11.68 (s, 1 H, NH), 8.13 (d, *J* = 7.6 Hz, 2 H, 5,6-H), 7.96 (s, 1 H, indolyl 2-H), 7.62 (d, *J* = 7.6 Hz, 2 H, 2,9-H), 7.57 (s, 1 H, indolyl 7-H), 7.55 (s, 1 H, indolyl 4-H), 7.51 (t, *J* = 7.2 Hz, 2 H, 5,6-H), 7.44 (t, *J* = 7.2 Hz, 2 H, 3,8-H), 7.23 (t, *J* = 7.2 Hz, 1 H, indolyl 6-H), 7.10 (t, *J* = 7.2 Hz, 1 H, indolyl 5-H), 3.94 (s, 4 H, 1,10-H).

Anal. Calcd for $C_{28}H_{19}N$: C 91.03; H 5.18; N 3.79; Found: C, 91.00; H, 5.32; N, 3.68.

4a

IR (KBr): 3446, 2926, 2836, 1594, 1511, 1464, 1471, 1266, 1238, 1034, 766 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 9.17 (s, 1 H, OH), 8.44 (d, *J* = 7.6 Hz, 2 H, 6,7-H), 7.41 (d, *J* = 7.6 Hz, 2 H, 5,8-H), 7.34 (t, *J* = 7.6 Hz, 2 H, 4,9-H), 7.28 (d, *J* = 7.2 Hz, 2 H, 3,10-H), 6.67–6.93 (3 H, m, Ar-H), 3.81 (s, 3 H, OCH_3), 2.83–2.92 (m, 4 H, 1,12-H), 2.32–2.70 (m, 4 H, 2,11-H).

Anal. Calcd for $C_{29}H_{24}O_2$: C, 86.11; H, 5.98; Found: C, 86.21; H, 5.88.

4b

IR (KBr): 2949, 2834, 1611, 1549, 1512, 1456, 1274, 1036, 840, 759 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.43 (d, *J* = 7.6 Hz, 2 H, 6,7-H), 7.41 (d, *J* = 7.6 Hz, 2 H, 5,8-H), 7.35 (t, *J* = 7.2 Hz, 2 H, 4,9-H), 7.28 (d, *J* = 7.2 Hz, 2 H, 3,10-H), 7.24 (d, *J* = 8.4 Hz, 2 H, Aryl 2,6-H), 7.09 (d, *J* = 8.4 Hz, 2 H, Aryl 3,5-H), 3.84 (3 H, s, OCH_3), 2.79–2.83 (m, 4 H, 1,12-H), 2.60–2.64 (m, 4 H, 2,11-H).

Anal. Calcd for $C_{29}H_{24}O$: C, 89.66; H, 6.23. Found: C, 89.49; H, 6.34.

4c

IR (KBr): 2931, 2887, 1549, 1502, 1489, 1239, 1038, 759 cm^{-1}.

^1H NMR (400 MHz, DMSO-d_6): δ = 8.42 (d, *J* = 7.6 Hz, 2 H, 6,7-H), 7.41 (d, *J* = 7.2 Hz, 2 H, 5,8-H), 7.34 (t, *J* = 7.2 Hz, 2 H, 4,9-H),

7.28 (d, *J* = 7.6 Hz, 2 H, 3,10-H), 6.75–7.08 (m, 3 H, ArH), 6.12 (s, 2 H, OCH_2O), 2.81–2. 85 (m, 4 H, 1,12-H), 2.63–2.67 (m, 4 H, 2,11-H).

Anal. Calcd for $C_{29}H_{22}O_2$: C, 86.54; H, 5.51. Found: C, 86.52; H, 5.46.

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