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Propylphosphonium hydrogen carbonate ionic liquid supported on nano-silica as a reusable catalyst for the efficient multicomponent synthesis of fully substituted pyridines and bis-pyridines†

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A new supported phosphonium based ionic liquid, propylphosphonium hydrogen carbonate ionic liquid supported on nano-silica (PPHC–nSiO$_2$), was prepared and characterized by FT-IR, TGA, SEM and ICP techniques. The resulting catalyst was used for the efficient synthesis of fully substituted pyridines *via* a one-pot multicomponent reaction of aldehydes, malononitrile, and thiols under solvent-free conditions. Expedient synthesis of bis-pyridines from dialdehydes and/or dithiols by using this catalytic system can be considered as a noteworthy advantage of this method. Furthermore, there was no obvious loss of catalytic activity even after 5th cycle.

Introduction

Heterocyclic systems containing pyridine rings have received great attention, because this framework is present in a great number of pharmaceuticals, biologically active molecules, naturally occurring and synthetic compounds.[1–4] Among the pyridine derivatives, 2-amino-4-aryl-6-sulfanylpyridine-3,5-dicarbonitriles are of particular importance due to their therapeutic applications in the treatment of urinary incontinence,[5] Parkinson's disease, hypoxia, asthma, kidney and Creutzfeldt–Jakob diseases.[4,6–8] Also, some of these compounds display anti-prion,[9] anti-hepatitis B virus,[10,11] anti-bacterial[12,13] and anti-cancer[14–16] activities. The synthesis of these pyridine derivatives, therefore, has attracted enormous attention of synthetic organic chemists and a substantial number of methods for the preparation of 2-amino-4-aryl-6-sulfanylpyridine-3,5-dicarbonitriles have been developed of which the three-component reaction of aldehyde, malononitrile, and thiol is the most important.[17–29] However, many of these methods suffer from one or more of the disadvantages such as long reaction times, low yields, formation of side products, high temperature, tedious workup, and the use of non-reusable catalysts and toxic organic solvents, which led to serious environmental and safety problems.

Consequently, it is still vitally needed to introduce a more environmental friendly and efficient method using a recoverable catalyst for the synthesis of these important heterocyclic compounds.

During the recent years, ionic liquids (ILs) have received significant attention due to their unique properties such as negligible volatility, high thermal stability, good conductivity and low flammability.[30–32] On the other hand, a great deal of attention has been paid to the phosphonium based ILs as potential substitutes for the corresponding ammonium based ILs.[33–40] It was found that the phosphonium ILs displayed higher thermal stability and ionic conductivity than those of the corresponding ammonium counterparts. These characteristic aspects seem to be noteworthy advantages of phosphonium ILs, so these ILs have been efficiently used as solvents/catalysts in a wide variety of chemical transformations such as etherification,[41] synthesis of isoindolin-1-one,[42] reductive carbonylation of nitrobenzenes,[43] thiocarbonylation,[44] palladium catalyzed Heck reactions,[45] Buchwald–Hartwig amination,[46] hydroformylation,[47] palladium mediated Suzuki cross-coupling reactions,[48] esterification,[49] Diels–Alder reaction,[50] asymmetric phase-transfer alkylation,[51] Rh-catalyzed asymmetric hydrogenation of enamides,[52] synthesis of cyclic carbonate,[53] degradation of phenols,[54] Michael addition of mercaptans to α,β-unsaturated ketones,[55] Baylis–Hillman reaction,[56] asymmetric fluorination of 3-substituted benzofuran-2(3*H*)-ones,[57] Halex reactions[58] and synthesis of highly substituted imidazoles.[59]

In continuation of our study on the application of supported catalysts for the development of valuable synthetic methodologies,[60–63] herein we report an efficient synthesis of fully substituted pyridines and bis-pyridines catalyzed by propylphosphonium hydrogen carbonate ionic liquid supported on

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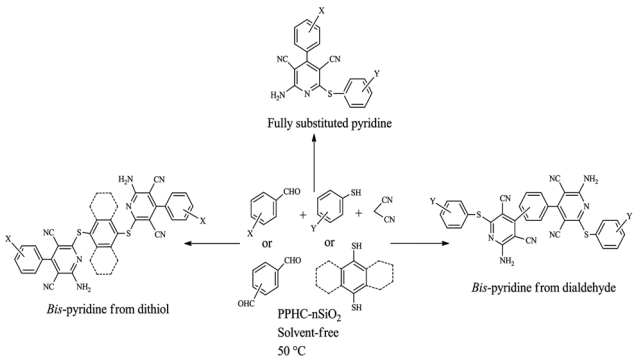


Scheme 1 Synthesis of fully substituted pyridines and bis-pyridines catalyzed by PPHC–nSiO$_2$.

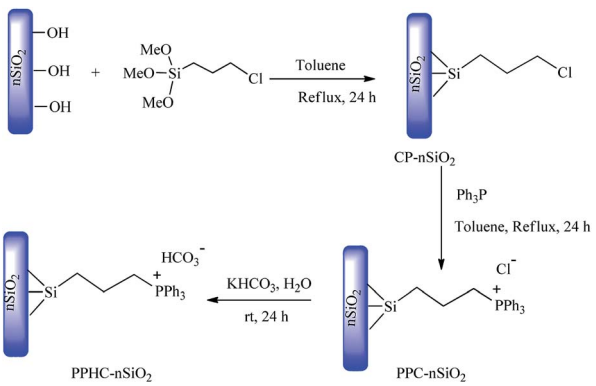
nano-silica (PPHC–nSiO$_2$) under solvent-free conditions (Scheme 1).

Results and discussion

Synthesis and characterization of propylphosphonium hydrogen carbonate ionic liquid supported on nano-silica (PPHC–nSiO$_2$)

The procedure for synthesis of PPHC–nSiO$_2$ is depicted in Scheme 2. First, nano-silica was reacted with 3-chloropropyltrimethoxysilane (CPTS) in dry toluene to produce the CP–nSiO$_2$. Then, the reaction of CP–nSiO$_2$ with triphenylphosphine was carried out in dry toluene under reflux conditions to afford propylphosphonium chloride supported on nano-silica (PPC–nSiO$_2$). Finally, the desired basic ionic liquid, propylphosphonium hydrogen carbonate supported on nano-silica (PPHC–nSiO$_2$) was prepared by treatment of PPC–nSiO$_2$ with solid potassium hydrogen carbonate in distilled water at room temperature. The catalyst was characterized by FT-IR, TGA, SEM and ICP techniques.

The FT-IR spectra of nano-silica (Fig. 1a) and PPHC–nSiO$_2$ (Fig. 1b) exhibit characteristic peaks at around 1100, 810, and 465 cm^{-1} which are assigned Si–O–Si stretching, and the band at about 3425 cm^{-1} belongs to the Si–OH groups and adsorbed water. Moreover, in the FT-IR spectrum of PPHC–nSiO$_2$ (Fig. 1b), the distinctive bands at around 3053 cm^{-1} (sp^2 C–H), 2938 (C–H



Scheme 2 Synthesis of propylphosphonium hydrogen carbonate ionic liquid supported on nano-silica (PPHC–nSiO$_2$).

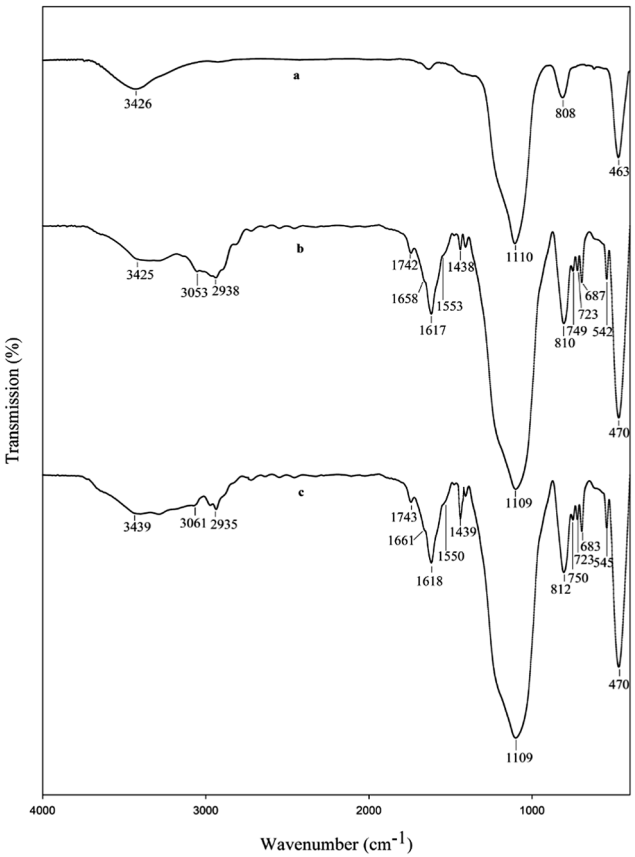


Fig. 1 FT-IR spectra of: (a) nano-SiO$_2$; (b) PPHC–nSiO$_2$ and (c) the 5-times reused catalyst.

stretching of the alkyl chain), 1742 cm^{-1} (C=O), 1658, 1617 and 1553 cm^{-1} (C=C), 1438 cm^{-1} (P–Ar), 749 cm^{-1} (P–C), 723 and 687 cm^{-1} (aromatic C–H bending vibrations) were observed which are absent in the nano-silica. The above results indicate that the ionic liquid was successfully grafted onto the nano-silica.

The thermal stability of PPHC–nSiO$_2$ catalyst was examined by thermogravimetric analysis (TGA). The TG curve indicates that the weight loss starts from about 205 °C, and the complete loss of the IL and decomposition of the organic moities mainly occur in the temperature range from 205–640 °C (Fig. 2). Consequently, the PPHC–nSiO$_2$ catalyst exhibited good thermal stability below 205 °C. The shape and surface morphology of the nano-silica and PPHC–nSiO$_2$ were investigated by scanning electron microscopy (SEM). As shown in Fig. 3, the surface morphology of these two samples is different, which is a good indication of supporting the IL on nano-silica. The P content of PPHC–nSiO$_2$ catalyst, measured by ICP, was 5.643 mg L^{-1}. This result reveals that the amount of HCO_3^- on the nano-silica is 0.455 mmol g^{-1} of the catalyst.

Synthesis of fully substituted pyridines and bis-pyridines catalyzed by propylphosphonium hydrogen carbonate ionic liquid supported on nano-silica (PPHC–nSiO$_2$)

At the commencement, the three-component reaction of 3,4-dimethoxybenzaldehyde (1 mmol), malononitrile (2 mmol) and

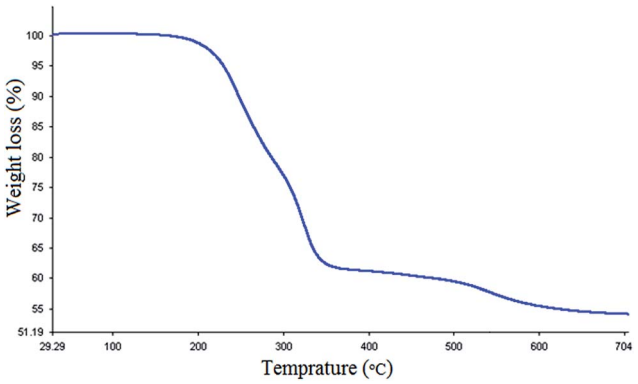


Fig. 2 TGA curve of PPHC–nSiO$_2$ catalyst.

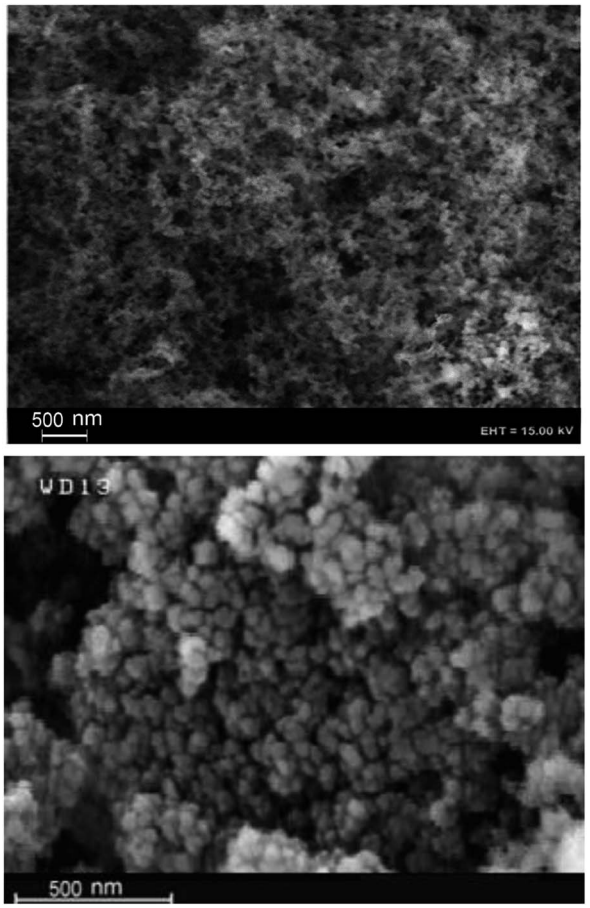
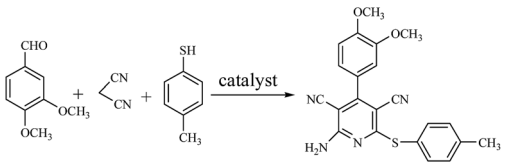


Fig. 3 SEM images of: (a) nano-silica and (b) PPHC–nSiO$_2$ catalyst.

4-methylthiophenol (1 mmol) was selected as a model for the optimization of the reaction conditions. As depicted in Table 1, no yield of the product was obtained when the reaction was performed in the absence of the catalyst, even after prolonged reaction time, indicating the necessity of the catalyst for the reaction to proceed (Table 1, entry 1). To improve the reaction efficiency and yield of the desired product, the model reaction was examined in the presence of various catalysts such as nano-SiO$_2$, KHCO$_3$, 1-methyl-3-propylimidazolium hydrogen carbonate supported on nano-silica (PMIMHC–nSiO$_2$), PPC–nSiO$_2$, and PPHC–nSiO$_2$ at 50 °C under solvent-free conditions. Among the screened catalysts, PPHC–nSiO$_2$ exhibited excellent catalytic activity (Table 1, entry 6). We then proceeded further to optimize the catalyst loading and temperature for this reaction. To determine the optimum amount of PPHC–nSiO$_2$ catalyst, the model reaction was carried out using 0.5, 0.7 and 1 mol% of the catalyst, which afforded the desired product in 70%, 95% and 95% yields, respectively. Increasing the amount of the catalyst beyond 0.7 mol% did not show any improvement. Finally, the effect of temperature was evaluated; increasing the temperature from 50 to 75 °C did not improve the yield, whereas decreasing the temperature resulted in lower yield of the desired product. Based on the obtained results, the optimal conditions were identified as 3,4-dimethoxybenzaldehyde (1 mmol), malononitrile (2 mmol) and 4-methylthiophenol (1 mmol) in the presence of 0.7 mol% PPHC–nSiO$_2$ at 50 °C under solvent-free conditions.

Table 1 Optimization of the reaction conditions for the synthesis of fully substituted pyridines[a]

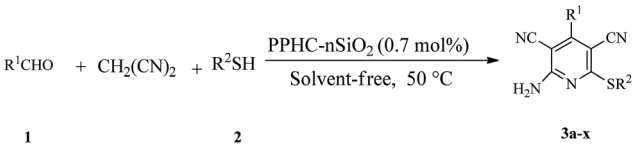


Entry	Catalyst (mol%)	Time (min)	Yield[b] (%)
1	—	210	0
2	Nano-SiO$_2$ (15 mg)	150	30
3	KHCO$_3$ (3)	100	35
4	PMIMHC–nSiO$_2$ (0.7)	50	71
5	PPC–nSiO$_2$ (0.7)	150	35
6	PPHC–nSiO$_2$ (0.7)	20	95
7	PPHC–nSiO$_2$ (0.5)	35	70
8	PPHC–nSiO$_2$ (1)	20	95
9[c]	PPHC–nSiO$_2$ (0.7)	40	42
10[d]	PPHC–nSiO$_2$ (0.7)	20	95

[a] 3,4-Dimethoxybenzaldehyde (1 mmol), malononitrile (2 mmol), 4-methylthiophenol (1 mmol), at 50 °C under solvent-free conditions. [b] Isolated yield. [c] Reaction was performed at room temperature. [d] Reaction was performed at 75 °C.

With the above mentioned optimized conditions, the generality and scope of this method for the synthesis of a series of fully substituted pyridines were explored. As shown in Table 2, a variety of aromatic aldehydes with electron-donating and electron-withdrawing substituents at the *ortho*, *meta*, and *para* positions of aromatic ring were reacted smoothly with malononitrile and various thiols in the presence of catalytic amounts of PPHC–nSiO$_2$ to afford the corresponding fully substituted pyridines in high yields (Table 2, entries 1–14). Under the same conditions, polycyclic aldehydes such as naphthalene-2-carbaldehyde and anthracene-9-carbaldehyde took part in this three-component reaction to give the desired products in high yields (Table 2, entries 15–20). The reaction of heterocyclic aldehydes such as pyridine-3-carbaldehyde and 5-methylfuran-2-carbaldehyde with thiols and malononitrile was also proceeded smoothly to furnish the corresponding fully

Table 2 Synthesis of fully substituted pyridines in the presence of PPHC–nSiO$_2$ catalyst



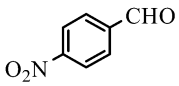
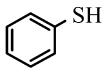
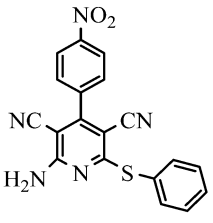
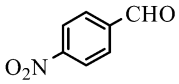
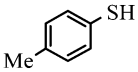
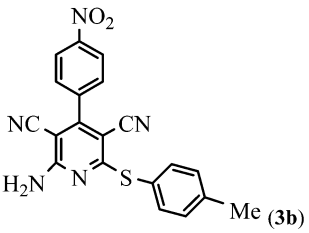
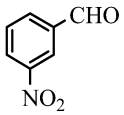
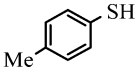
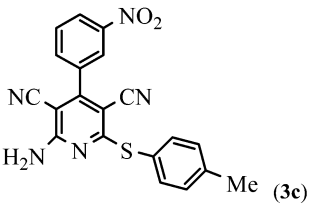
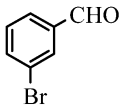
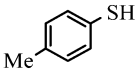
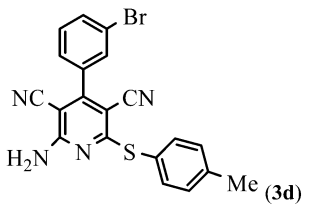
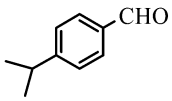
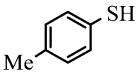
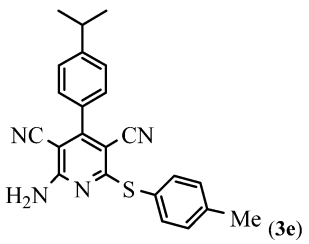
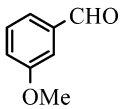
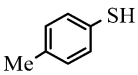
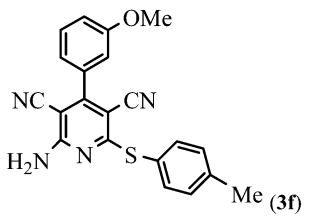
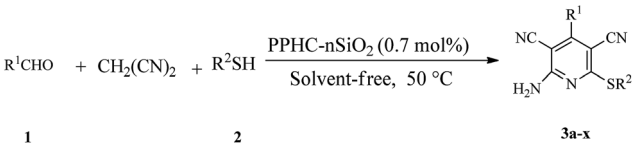
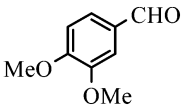
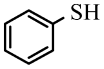
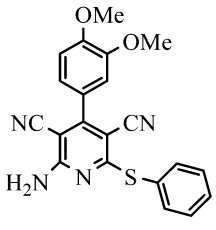
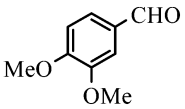
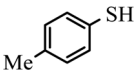
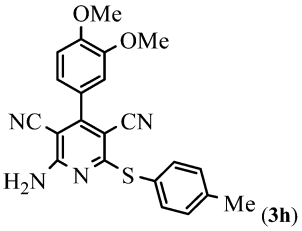
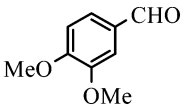
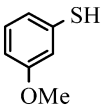
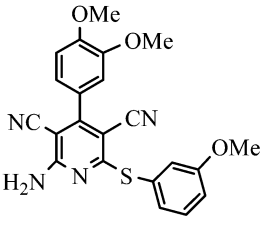
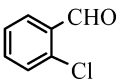
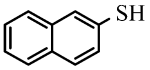
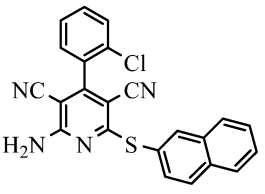
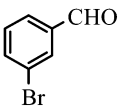
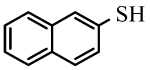
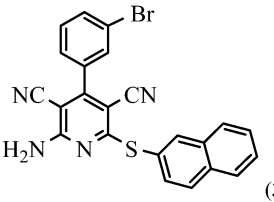
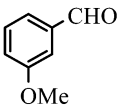
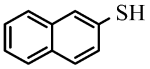
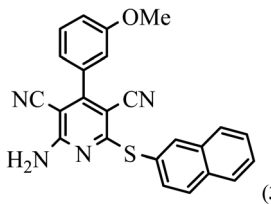
Entry	Aldehyde	Thiol	Product	Time (min)	Yield[a] (%)
1			 (3a)	20	94
2			 (3b)	22	95
3			 (3c)	30	90
4			 (3d)	23	88
5			 (3e)	40	83
6			 (3f)	25	87

Table 2 (*Contd.*)



1 2 3a-x

Entry	Aldehyde	Thiol	Product	Time (min)	Yield[a] (%)
7			 (3g)	23	90
8			 (3h)	20	95
9			 (3i)	22	92
10			 (3j)	20	86
11			 (3k)	25	80
12			 (3l)	25	88

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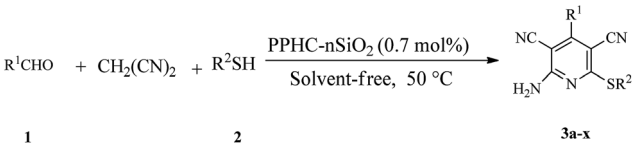


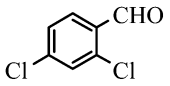
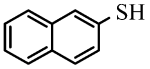
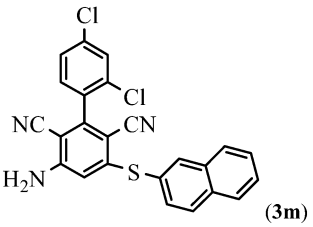
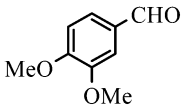
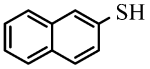
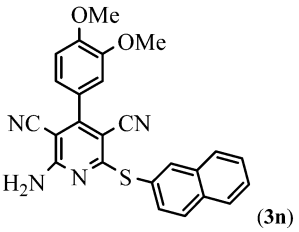
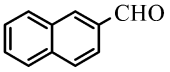
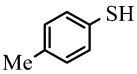
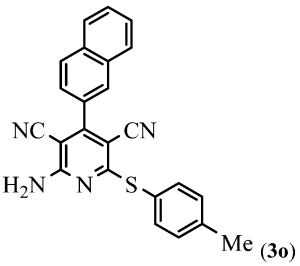
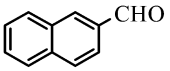
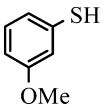
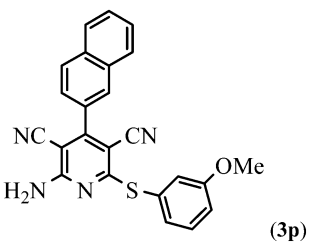
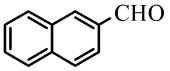
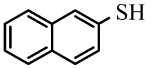
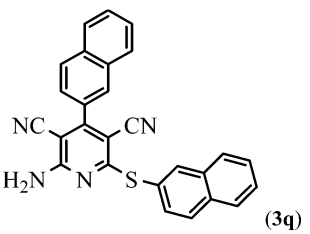
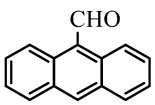
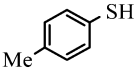
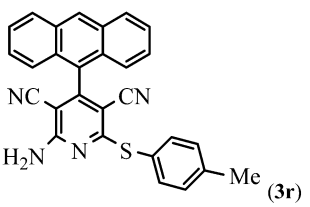
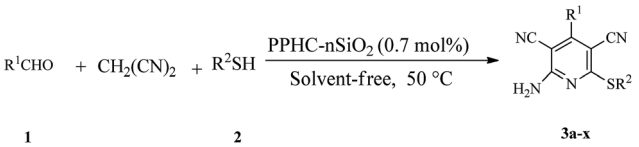
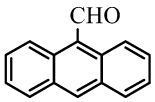
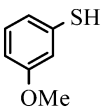
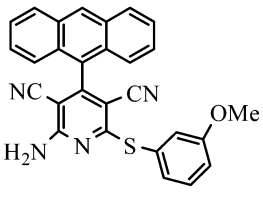
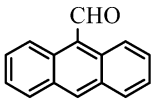
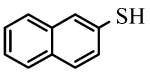
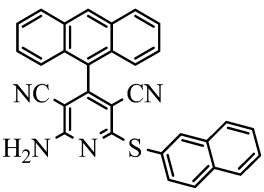
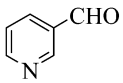
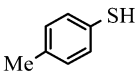
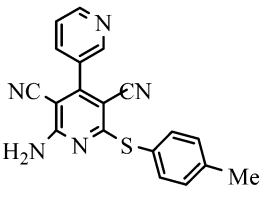
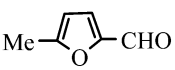
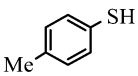
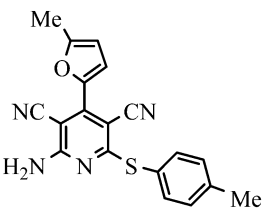
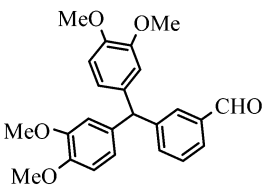
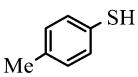
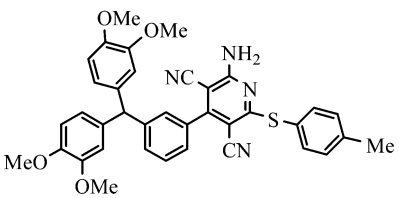
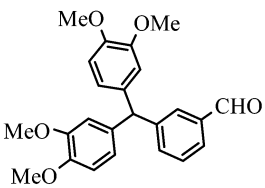
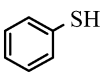
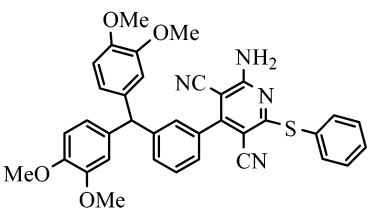
Entry	Aldehyde	Thiol	Product	Time (min)	Yield[a] (%)
13			 (3m)	25	80
14			 (3n)	25	88
15			 (3o)	30	83
16			 (3p)	25	90
17			 (3q)	33	80
18			 (3r)	25	85

Table 2 (*Contd.*)



1 2 3a-x

Entry	Aldehyde	Thiol	Product	Time (min)	Yield[a] (%)
19			 (3s)	30	80
20			 (3t)	27	85
21			 (3u)	30	80
22			 (3v)	20	83
23			 (3w)	30	94
24			 (3x)	30	92

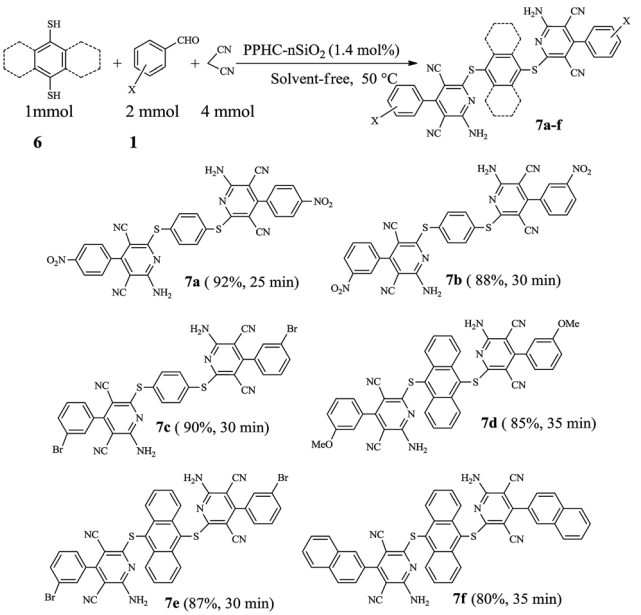
[a] Isolated yield.

substituted pyridines in high yields (Table 2, entries 21 and 22). In addition, sterically hindered aldehyde such as 3-(bis(3,4-dimethoxyphenyl)methyl)benzaldehyde performed this reaction rapidly and smoothly to give the desired products in excellent yields (Table 2, entries 23 and 24). The results showed that the presence of electron-withdrawing or electron-donating substituents on the aromatic rings of the starting materials had no significant effect on the yields of the products and reaction times.

The experimental procedure is very simple and the reactions were generally clean and no side products were produced; in all cases, fully substituted pyridines were obtained as the sole products.

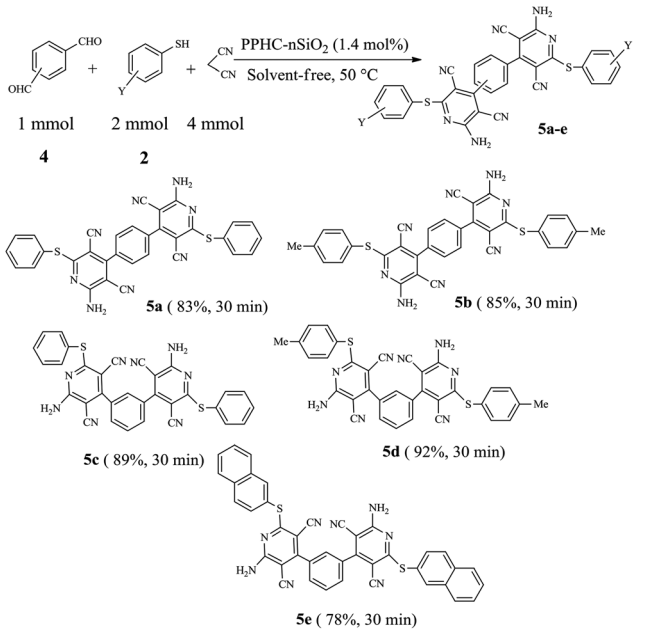
Another outstanding advantage of this catalytic system lies in the synthesis of bis-pyridines from dialdehydes and dithiols. The results are summarized in Schemes 3 and 4. The reaction of dialdehydes such as terephthaldialdehyde and isophthaldialdehyde with thiols and malononitrile was performed efficiently in the presence of PPHC–nSiO$_2$ catalyst and the corresponding fully substituted bis-pyridines were obtained in 78–92% yields (Scheme 3). In an alternative route, dithiols such as benzene-1,4-dithiol and anthracene-9,10-dithiol were reacted with aldehydes and malononitrile in the presence of catalytic amounts of PPHC–nSiO$_2$ to generate the desired fully substituted bis-pyridines in 80–92% yields (Scheme 4). The synthesis of bis-pyridines through such a one-pot multicomponent reaction using this catalytic system can be regarded as a useful practical attainment in the preparation of these widely used heterocyclic compounds.

A plausible mechanism for the synthesis of fully substituted pyridines by using PPHC–nSiO$_2$ is depicted in Scheme 5. Initially, aldehyde undergoes Knoevenagel condensation with

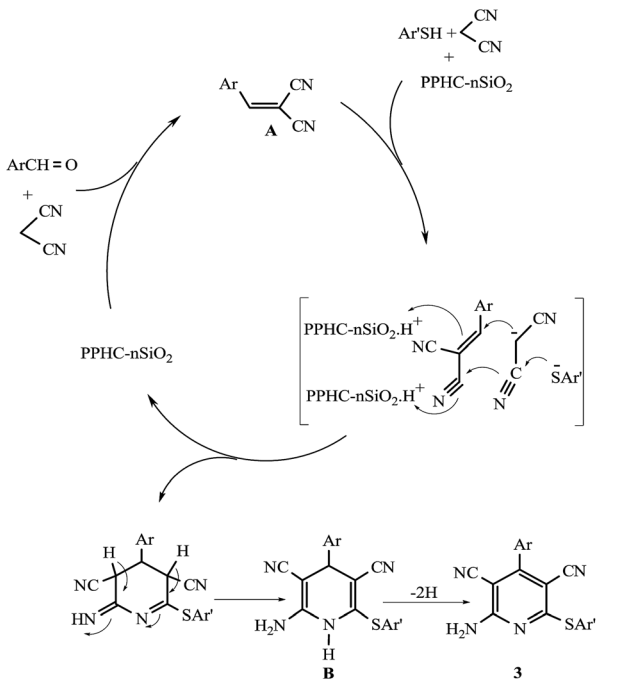


Scheme 4 Synthesis of bis-pyridines from dithiols catalyzed by PPHC–nSiO$_2$.

malononitrile in the presence of the catalyst to give the intermediate **A**. Then, the base-catalyzed Michael addition of the second molecule of malononitrile to **A** followed by concurrent addition of thiolate to the nitrile group and cyclization leads to the formation of dihydropyridine **B** and regenerates the catalyst for the next catalytic cycle. Finally, Oxidative aromatization (air)



Scheme 3 Synthesis of bis-pyridines from dialdehydes catalyzed by PPHC–nSiO$_2$.



Scheme 5 Plausible mechanism for the synthesis of fully substituted pyridines catalyzed by PPHC–nSiO$_2$.

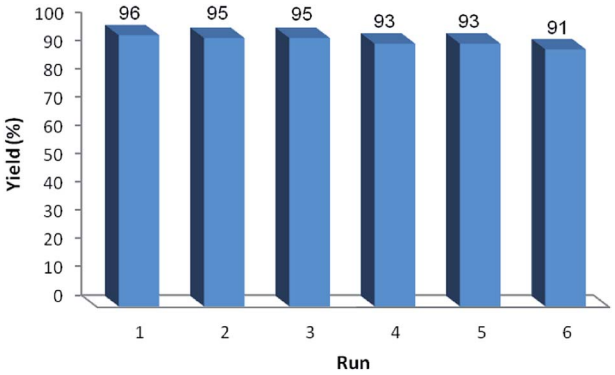


Fig. 4 Reusability of the PPHC–nSiO$_2$ catalyst.

of dihydropyridine **B** affords the desired fully substituted pyridine **3**.

Recyclability of the catalyst

Finally, the recyclability and reusability, as an attractive property of the catalyst, was examined in the three-component reaction of 3,4-dimethoxybenzaldehyde, malononitrile and 4-methylthiophenol. After the reaction was completed, EtOH (10 mL) was added. The catalyst was easily separated by simple filtration, washed with EtOH (10 mL), dried *in vacuo* and then reused for the next cycle. The data shown in Fig. 4 illustrate that the PPHC–nSiO$_2$ catalyst can be reused at least five times without any significant loss of its efficiency and activity. Comparison of the FT-IR spectra of the fresh and reused catalyst shows no obvious change in the structure of the catalyst and characteristic bands, suggesting the stability of the catalyst during the reaction (Fig. 1c).

Conclusions

In conclusion, we have disclosed a convenient, efficient and straightforward protocol for the synthesis of fully substituted pyridines *via* a one-pot multicomponent reaction of a wide range of aldehydes, malononitrile, and thiols using heterogeneous and reusable PPHC–nSiO$_2$ catalyst under solvent-free conditions. The present methodology is also applicable to the synthesis of bis-pyridines from dialdehydes and/or dithiols. In addition, mild conditions, avoidance of toxic solvent, short reaction times, high yields, recyclability without losing catalytic activity, easy work-up and ease of catalyst separation are the important features of this procedure. These advantages render this protocol facile and suitable to generate a diversified library of fully substituted pyridine and bis-pyridine derivatives.

Experimental

General information

Melting points were determined using a Stuart Scientific SMP2 apparatus. FT-IR spectra were recorded on a Nicolet-Impact 400D instrument in the range of 400–4000 cm^{-1}. ^{1}H and ^{13}C NMR (400 and 100 MHz) spectra were recorded in $CDCl_3$ or DMSO-d_6 solution on a Bruker-Avance 400 spectrometer. Elemental analysis was done on LECO, CHNS-932 analyzer. Thermogravimetric analysis (TGA) was carried out on a Mettler TG50 instrument under air flow at a uniform heating rate of 5 °C min^{-1} in the range of 30–700 °C. The P content of the catalyst was measured by an inductively coupled plasma optical emission spectrometry (ICP-OES), using a Perkin-Elmer 7300DV ICP analyzer. Scanning electron microscopy measurements were performed on a Carl Zeiss EVO MA 10 scanning electron microscope (SEM).

Preparation of propylphosphonium hydrogen carbonate ionic liquid supported on nano-silica (PPHC–nSiO$_2$). To a suspension of nano-silica (2 g) in dry toluene (25 mL) was added 3-chloropropyltrimethoxysilane (3 mL) and the resulting mixture was stirred under reflux conditions for 24. The reaction mixture was cooled to room temperature, filtered and the solid material was washed with toluene and a mixture of water–ethanol. The resulting chloropropyl functionalized nano-silica (CP–nSiO$_2$) was dried under vacuum at 60 °C. Then, to a mixture of CP–nSiO$_2$ (2 g) in dry toluene (25 mL) was added triphenylphosphine (8 g) and the resulting mixture was stirred under reflux conditions for 24 h. After cooling to room temperature, the mixture was filtered, and the solid material was washed with toluene and ethanol. The resulting propylphosphonium chloride supported on nano-silica (PPC–nSiO$_2$) was dried under vacuum at 50 °C. Finally, A mixture of PPC–nSiO$_2$ (2 g) and solid potassium hydrogen carbonate (5 g) in distilled water (40 mL) was stirred vigorously at room temperature for 24 h. The mixture was filtrated and the solid material was washed with distilled water until neutral and then dried under vacuum at 70 °C to afford the desired ionic liquid, propylphosphonium hydrogen carbonate supported on nano-silica (PPHC–nSiO$_2$).

General procedure for synthesis of fully substituted pyridines in the presence of PPHC–nSiO$_2$ catalyst. A mixture of aldehyde (1 mmol), malononitrile (2 mmol), thiol (1 mmol) and PPHC–nSiO$_2$ catalyst (15 mg, containing 0.7 mol% HCO_3^-) was stirred at 50 °C under solvent-free conditions for the desired time according to Table 2. The progress of the reaction was monitored by TLC (eluent: petroleum ether/EtOAc, 5 : 3). After completion of the reaction, the mixture was cooled to room temperature and then EtOH (10 mL) was added. The catalyst was separated by filtration and washed with EtOH (10 mL). The filtrate was evaporated and the crude product was purified by recrystallization from EtOAc or EtOH to afford the pure product.

2-Amino-4-(4-nitrophenyl)-6-(phenylsulfanyl)pyridine-3,5-dicarbonitrile (Tables 2, 3a). Mp 291–292 °C (ref. 17 287–289 °C). IR (KBr): ν_{max} = 3348, 3320, 2217, 1640, 1553, 1534, 1354, 1248, 1164, 823 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ = 8.44 (d, J = 8.8 Hz, 2H), 7.69 (br s, 2H), 7.89 (d, J = 8.8 Hz, 2H), 7.61–7.63 (m, 2H), 7.51–7.53 (m, 3H).

2-Amino-4-(4-nitrophenyl)-6-(4-methylphenylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3b). Mp 300–302 °C. IR (KBr): ν_{max} = 3438, 3328, 2215, 1623, 1545, 1525, 1448, 1383, 1266, 1116, 809, 760 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ = 8.43 (d, J = 8.8 Hz, 2H), 7.88 (d, J = 8.8 Hz, 2H), 7.48 (d, J = 8.0 Hz, 2H), 7.32 (d, J = 8.0 Hz, 2H), 7.07 (br s, 2H), 2.38 (s, 3H). ^{13}C NMR (100 MHz,

DMSO-d_6) δ = 166.0, 159.7, 158.3, 150.3, 148.2, 128.1, 126.6, 121.5, 119.6, 115.8, 112.3, 111.5, 93.4, 87.0, 24.9. Anal. calcd for $C_{20}H_{13}N_5O_2S$; C, 62.00; H, 3.38; N, 18.08; S, 8.28. Found: C, 62.09; H, 3.40; N, 18.02; S, 8.36%.

2-Amino-4-(3-nitrophenyl)-6-(4-methylphenylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3c). Mp 225–227 °C. IR (KBr): ν_{max} = 3484, 3348, 2213, 1619, 1544, 1525, 1446, 1356, 1265, 1160, 1069, 889, 735 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ = 8.34 (s, 1H), 8.23 (d, J = 8.0 Hz, 2H), 7.86 (d, J = 7.6 Hz, 2H), 7.72 (t, J = 8.0 Hz, 3H), 5.22 (br s, 2H), 1.23 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 172.0, 166.5, 160.1, 149.0, 147.9, 147.0, 136.0, 131.6, 129.0, 128.4, 120.9, 115.3, 114.9, 112.8, 111.7, 93.1, 21.0. Anal. calcd for $C_{20}H_{13}N_5O_2S$; C, 62.00; H, 3.38; N, 18.08; S, 8.28. Found: C, 62.09; H, 3.35; N, 18.01; S, 8.38%.

2-Amino-4-(3-bromophenyl)-6-(4-methylphenylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3d). Mp 230–232 °C. IR (KBr): ν_{max} = 3433, 3325, 2214, 1640, 1527, 1426, 1339, 1233, 1143, 1017, 810, 763 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ = 7.85 (br s, 2H), 7.78–7.82 (m, 2H), 7.54–757 (m, 2H), 7.48 (d, J = 8.1 Hz, 2H), 7.32 (d, J = 7.9 Hz, 2H), 2.38 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 167.1, 159.6, 157.9, 148.4, 146.7, 140.5, 135.0, 131.7, 130.2, 129.0, 128.4, 120.9, 115.3, 112.8, 110.8, 93.2, 23.0. Anal. calcd for $C_{20}H_{13}BrN_4S$; C, 57.02; H, 3.11; N, 13.30; S, 7.61. Found: C, 56.93; H, 3.09; N, 13.25; S, 7.72%.

2-Amino-4-(4-isopropylphenyl)-6-(4-methylphenylsulfanyl)-pyridine-3,5-dicarbonitrile (Table 2, 3e). Mp 193–196 °C. IR (KBr): ν_{max} = 3355, 3212, 2214, 1621, 1542, 1510, 1454, 1305, 1261, 1015, 807, 732 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ = 7.78 (br s, 2H), 7.44–750 (m, 4H), 7.26–7.37 (m, 4H), 2.97–3.04 (m, 1H), 2.38 (s, 3H), 1.27 (d, J = 6.8 Hz, 6H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 167.7, 160.6, 156.0, 143.7, 139.5, 135.0, 130.1, 123.6, 118.2, 117.7, 116.0, 115.5, 109.9, 109.3, 30.5, 22.0, 20.9. Anal. calcd for $C_{23}H_{20}N_4S$; C, 71.85; H, 5.24; N, 14.57; S, 8.34. Found: C, 71.93; H, 5.27; N, 14.51; S, 8.44%.

2-Amino-4-(3-methoxyphenyl)-6-(4-methylphenylsulfanyl)-pyridine-3,5-dicarbonitrile (Table 2, 3f). Mp 250–253 °C. IR (KBr): ν_{max} = 3363, 2218, 1634, 1551, 1498, 1314, 1256, 1181, 1019, 839, 803 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ = 7.80 (br s, 2H), 7.48–7.52 (m, 3H), 7.31 (d, J = 8.0 Hz, 2H), 7.16 (d, J = 4.0 Hz, 2H), 7.09 (d, J = 7.7 Hz, 1H), 3.82 (s, 3H), 2.38 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 170.1, 160.1, 159.6, 158.3, 150.3, 149.3, 131.1, 128.1, 126.6, 121.5, 119.6, 115.8, 112.3, 111.4, 95.0, 86.9, 55.3, 24.5. Anal. calcd for $C_{21}H_{16}N_4OS$; C, 67.72; H, 4.33; N, 15.04; S, 8.61. Found: C, 67.82; H, 4.37; N, 14.96; S, 8.75%.

2-Amino-4-(3,4-dimethoxyphenyl)-6-(phenylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3g). Mp 223–225 °C (ref. 25 227 °C). IR (KBr): ν_{max} = 3414, 3326, 3227, 2211, 1644, 1545, 1520, 1317, 1245, 1235, 1012, 814, 708 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ = 7.77 (br s, 2H), 7.60–7.62 (m, 2H), 7.50–7.52 (m, 3H), 7.22 (s, 1H), 7.15 (s, 2H), 3.86 (s, 3H), 3.81 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 165.9, 160.5, 160.2, 158.3, 151.3, 148.2, 130.2, 126.6, 122.0, 119.9, 116.0, 115.3, 112.2, 111.6, 94.0, 88.1, 55.5, 55.3.

2-Amino-4-(3,4-dimethoxyphenyl)-6-(4-methylphenylsulfanyl)-pyridine-3,5-dicarbonitrile (Table 2, 3h). Mp 229–232 °C. IR (KBr): ν_{max} = 3435, 3310, 2210, 1617, 1546, 1525, 1417, 1317, 1264, 1160, 885, 742 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ = 7.66 (br s, 2H), 7.38 (d, J = 8.0 Hz, 2H), 7.22 (d, J = 8.0 Hz, 2H), 7.12 (s, 1H), 7.04 (s, 2H), 3.76 (s, 3H), 3.71 (s, 3H), 2.29 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 165.9, 159.8, 159.6, 150.3, 148.2, 130.5, 126.7, 125.7, 121.5, 119.6, 116.0, 115.3, 112.2, 110.9, 93.4, 88.6, 55.6, 55.3, 25.1. Anal. calcd for $C_{22}H_{18}N_4O_2S$; C, 65.65; H, 4.51; N, 13.92; S, 7.97. Found: C, 65.73; H, 4.54; N, 13.82; S, 8.09%.

2-Amino-4-(3,4-dimethoxyphenyl)-6-(3-methoxyphenylsulfanyl) pyridine-3,5-dicarbonitrile (Table 2, 3i). Mp 213–215 °C. IR (KBr): ν_{max} = 3353, 3338, 3159, 2210, 1626, 1545, 1522, 1465, 1399, 1244, 1098, 1013, 816 cm^{-1}. ^{1}H-NMR (400 MHz, DMSO-d_6): δ = 7.80 (br s, 2H), 7.40 (t, J = 8.1 HZ, 1H), 7.21 (d, J = 1.4 Hz, 1H), 7.14–7.18 (m, 4H), 7.08 (dd, ^1J = 2.5 Hz, ^2J = 0.8 Hz, 1H), 3.86 (s, 3H), 3.81 (s, 3H), 3.80 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 165.9, 159.7, 159.5, 158.3, 150.3, 148.2, 130.2, 128.1, 126.6, 125.8, 121.5, 119.6, 115.8, 115.6, 115.3, 112.2, 111.4, 93.4, 86.9, 55.6, 55.5, 55.3. Anal. calcd for $C_{22}H_{18}N_4O_3S$; C, 63.14; H, 4.34; N, 13.39; S, 7.66. Found: C, 63.19; H, 4.36; N, 13.32; S, 7.77%.

2-Amino-4-(2-chlorophenyl)-6-(β-naphthylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3j). Mp 253–255 °C. IR (KBr): ν_{max} = 3393, 3130, 2217, 1650, 1611, 1447, 1337, 1260, 1206, 1117, 1019, 873, 759 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ = 8.29 (s, 1H), 8.03 (t, J = 8.7 Hz, 3H), 7.95 (br s, 2H), 7.58–7.74 (m, 7H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 167.0, 159.6, 159.5, 158.6, 132.2, 131.4, 130.2, 128.4, 128.0, 127.7, 127.6, 127.1, 126.7, 125.3, 120.1, 115.9, 115.3, 114.9, 94.1, 87.3. Anal. calcd for $C_{23}H_{13}ClN_4S$; C, 66.90; H, 3.17; N, 13.57; S, 7.77. Found: C, 66.98; H, 3.15; N, 13.51; S, 7.89%.

2-Amino-4-(3-bromophenyl)-6-(β-naphthylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3k). Mp 207–208 °C. IR (KBr): ν_{max} = 3438, 3327, 2216, 1623, 1547, 1337, 1257, 1152, 1051, 1027, 820, 763 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ = 8.26 (d, J = 1.4 Hz, 1H), 8.00–8.04 (m, 3H), 7.80–7.85 (m, 2H), 7.79–7.80 (m, 1H), 7.56–7.64 (m, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 171.1, 166.5, 161.1, 159.4, 148.4, 147.1, 146.7, 140.1, 136.0, 134.9, 130.1, 129.0, 127.9, 123.3, 120.9, 115.3, 114.9, 112.8, 111.6, 93.0. Anal. calcd for $C_{23}H_{13}BrN_4S$; C, 60.40; H, 2.87; N, 12.25; S, 7.01. Found: C, 60.49; H, 2.89; N, 12.19; S, 7.12%.

2-Amino-4-(3-methoxyphenyl)-6-(β-naphthylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3l). Mp 204–206 °C. IR (KBr): ν_{max} = 3405, 3326, 3227, 2213, 1645, 1546, 1521, 1426, 1339, 1245, 1143, 1017, 810, 761 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ = 8.26 (d, J = 1.2 Hz, 1H), 8.00–8.04 (m, 3H), 7.79 (br s, 2H), 7.60–7.65 (m, 3H), 7.49–7.53 (m, 1H), 7.14–7.17 (m, 3H), 3.84 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 166.7, 160.1, 159.5, 157.1, 134.9, 134.3, 133.9, 133.7, 133.0, 131.4, 130.4, 130.3, 128.9, 127.9, 127.6, 127.4, 126.7, 124.5, 114.9, 114.6, 54.6. Anal. calcd for $C_{24}H_{16}N_4OS$; C, 70.57; H, 3.95; N, 13.72; S, 7.85. Found: C, 70.51; H, 3.97; N, 13.65; S, 7.94%.

2-Amino-4-(2,4-dichlorophenyl)-6-(β-naphthylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3m). Mp 146–147 °C. IR (KBr): ν_{max} = 3332, 3226, 3086, 2210, 1634, 1603, 1482, 1417, 1315, 1243, 1181, 1017, 839, 810 cm^{-1}. ^{1}H NMR (400 MHz, DMSO-d_6) δ = 8.30 (s, 1H), 8.08 (d, J = 8.5 Hz, 1H), 7.99–8.04 (m, 3H), 7.63–7.66 (m, 2H), 7.59 (dd, ^1J = 8.4 Hz, ^2J = 1.4 Hz, 2H), 7.39 (d, J = 1.6, 1H), 7.30 (dd, ^1J = 8.4 Hz, ^2J = 1.6 Hz, 2H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 173.9, 171.9, 171.2, 166.2, 159.8, 159.6, 157.0,

130.6, 130.4, 129.3, 128.8, 128.3, 128.1, 127.6, 126.5, 125.7, 124.4, 119.5, 116.1, 114.6, 114.3. Anal. calcd for $C_{23}H_{12}Cl_2N_4S$; C, 61.75; H, 2.70; N, 12.52; S, 7.17. Found: C, 61.69; H, 2.71; N, 12.57; S, 7.29%.

2-Amino-4-(3,4-dimethoxyphenyl)-6-(β-naphthylsulfanyl)-pyridine-3,5-dicarbonitrile (Table 2, 3n). Mp 192–193 °C. IR (KBr): ν_{max} = 3409, 3309, 2210, 1619, 1547, 1509, 1446, 1356, 1264, 1161, 1063, 881, 742 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ = 8.26 (d, J = 1.2 Hz, 1H), 8.02 (t, J = 8.4 Hz, 3H). 7.74 (br s, 2H), 7.59–7.66 (m, 3H), 7.23 (s, 1H), 7.16 (s, 2H), 3.86 (s, 3H), 3.81 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 174.3, 172.9, 172.6, 166.2, 159.8, 159.6, 157.0, 130.6, 130.3, 129.4, 128.7, 127.6, 127.5, 126.5, 125.6, 124.3, 119.5, 116.0, 114.7, 113.9, 55.5, 55.4. Anal. calcd for $C_{25}H_{18}N_4O_2S$; C, 68.48; H, 4.14; N, 12.78; S, 7.31. Found: 68.40; H, 4.17; N, 12.72; S, 7.44%.

2-Amino-4-(β-naphthyl)-6-(4-methylphenylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3o). Mp 238–241 °C. IR (KBr): ν_{max} = 3403, 3318, 2217, 1642, 1528, 1426, 1312, 1243, 1027, 811, 762 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ = 8.06–8.17 (m, 4H), 7.87 (br s, 2H), 7.64–7.70 (m, 3H), 7.51 (d, J = 7.3 Hz, 2H), 7.33 (d, J = 7.6 Hz, 2H), 2.39 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 167.1, 161.1, 160.0, 134.3, 132.1, 131.4, 130.3, 128.4, 127.7, 127.6, 126.7, 125.3, 119.6, 116.0, 115.3, 114.6, 94.1, 88.9, 23.5. Anal. calcd for $C_{24}H_{16}N_4S$; C, 73.45; H, 4.11; N, 14.28; S, 8.17. Found: C, 73.52; H, 4.09; N, 14.22; S, 8.29%.

2-Amino-4-(β-naphthyl)-6-(3-methoxyphenylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3p). Mp 175–180 °C. IR (KBr): ν_{max} = 3403, 3325, 3150, 2214, 1648, 1547, 1516, 1427, 1339, 1294, 1145, 1017, 813, 768 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 8.12–8.17 (m, 2H), 8.07 (s, 2H), 7.93 (br s, 2H), 7.67 (s, 3H), 7.41–7.43 (m, 1H), 7.21 (s, 2H), 7.09 (d, J = 7.1 Hz, 1H), 3.82 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 166.0, 159.6, 159.5, 158.6, 133.3, 132.2, 131.4, 130.2, 128.46, 128.41, 128.3, 128.0, 127.7, 127.6, 127.0, 126.7, 125.3, 119.6, 115.9, 115.3, 115.0, 93.5, 87.2, 55.3. Anal. calcd for $C_{24}H_{16}N_4OS$; C, 70.57; H, 3.95; N, 13.72; S, 7.85. Found: C, 70.65; H, 3.92; N, 13.67; S, 7.79%.

2-Amino-4-(β-naphthyl)-6-(β-naphthylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3q). Mp 208–211 °C. IR (KBr): ν_{max} = 3414, 3325, 2217, 1643, 1522, 1417, 1339, 1238, 1116, 809, 703 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ = 8.29 (s, 1H), 8.19 (s, 1H), 8.14 (d, J = 8.4 Hz, 1H), 8.02–8.07 (m, 5H), 7.86 (br s, 2H), 7.63–7.68 (m, 6H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 159.7, 156.9, 134.7, 134.1, 133.3, 132.8, 131.3, 130.7, 129.4, 128.8, 128.2, 127.8, 127.6, 127.3, 127.0, 126.6, 125.9, 125.7, 124.9, 124.3, 114.9, 114.4. Anal. calcd for $C_{27}H_{16}N_4S$; C, 75.68; H, 3.76; N, 13.07; S, 7.48. Found: C, 75.60; H, 3.73; N, 13.00; S, 7.59%.

2-Amino-4-(anthracene-9-yl)-6-(4-methylphenylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3r). Mp 254–256 °C. IR (KBr): ν_{max} = 3438, 3327, 2216, 1623, 1416, 1394, 1257, 1098, 1015, 817 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ = 8.57 (s, 1H), 8.03 (dd, ^1J = 6.1 Hz, ^2J = 3.4 Hz, 2H), 7.45–7.48 (m, 8H), 7.25 (d, J = 8.0 Hz, 2H), 5.49 (br s, 2H), 2.39 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 162.8, 160.4, 160.2, 149.8, 135.9, 132.4, 132.3, 131.8, 131.6, 130.9, 130.5, 129.6, 129.5, 128.8, 125.6, 119.0, 114.5, 112.5, 23.7. Anal. calcd for $C_{28}H_{18}N_4S$; C, 75.99; H, 4.10; N, 12.66; S, 7.25. Found: C, 75.89; H, 4.14; N, 12.72; S, 7.14%.

2-Amino-4-(anthracene-9-yl)-6-(3-methoxyphenylsulfanyl)-pyridine-3,5-dicarbonitrile (Table 2, 3s). Mp 250–252 °C. IR (KBr): ν_{max} = 3324, 3270, 2217, 1640, 1510, 1446, 1337, 1254, 1152, 1051, 1026, 820, 763 cm^{-1}. ^1H-NMR (400 MHz, DMSO-d_6): δ = 8.87 (s, 1H), 8.24 (dd, ^1J = 7.12 Hz, ^2J = 2.3 Hz, 2H), 8.03 (br s, 2H), 7.60–7.70 (m, 7H), 7.44 (t, J = 7.9 Hz, 1H), 7.28–7.33 (m, 1H), 7.12 (dd, ^1J = 7.1 Hz, ^2J = 1.8 Hz, 1H), 3.85 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 175.0, 171.3, 166.2, 159.8, 159.6, 157.0, 130.6, 130.2, 129.4, 128.8, 128.2, 128.1, 127.6, 126.5, 125.8, 124.3, 119.5, 116.0, 114.7, 114.4, 55.4. Anal. calcd for $C_{28}H_{18}N_4OS$; C, 73.34; H, 3.96; N, 12.22; S, 6.99. Found: C, 73.28; H, 3.92; N, 12.16; S, 7.12%.

2-Amino-4-(anthracene-9-yl)-6-(β-naphthylsulfanyl)pyridine-3,5-di carbonitrile (Table 2, 3t). Mp 267–270 °C. IR (KBr): ν_{max} = 3355, 3212, 2214, 1621, 1415, 1308, 1261, 1114, 789 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6) δ = 8.88 (s, 1H), 8.35 (s, 1H), 8.24–8.35 (m, 2H), 8.03–8.09 (m, 5H), 7.80 (dd, ^1J = 8.5 Hz, ^2J = 1.8 Hz, 1H), 7.70–7.73 (m, 2H), 7.60–7.66 (m, 6H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 166.0, 159.6, 159.5, 158.6, 133.3, 132.2, 131.4, 130.2, 128.46, 128.41, 128.3, 128.0, 127.7, 127.6, 127.0, 126.7, 125.3, 119.6, 115.9, 115.3, 115.0, 93.5, 87.2. Anal. calcd for $C_{31}H_{18}N_4S$; C, 77.80; H, 3.79; N, 11.71; S, 6.70. Found: C, 77.71; H, 3.75; N, 11.63; S, 6.82%.

2-Amino-4-(3-pyridine)-6-(4-methylphenylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3u). Mp 310–312 °C. IR (KBr): ν_{max} = 3438, 3327, 3216, 2216, 1624, 1549, 1510, 1426, 1337, 1259, 1154, 1019, 813 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ = 8.81–8.84 (m, 1H), 7.88–7.91 (m, 1H), 7.53 (dd, ^1J = 7.9 Hz, ^2J = 4.8 Hz, 2H), 7.45 (d, J = 8.0 Hz, 2H), 7.29 (d, J = 9.2 Hz, 2H), 5.55 (br s, 2H), 2.45 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 162.8, 160.5, 160.2, 132.4, 132.3, 131.9, 131.6, 130.9, 130.6, 129.6, 129.5, 128.8, 125.9, 118.7, 114.4, 26.2. Anal. calcd for $C_{19}H_{13}N_5S$; C, 66.45; H, 3.82; N, 20.39; S, 9.34. Found: C, 66.54; H, 3.78; N, 20.33; S, 9.27%.

2-Amino-4-(5-methylfuryl)-6-(methylphenylsulfanyl)pyridine-3,5-dicarbonitrile (Table 2, 3v). Mp 189–192 °C. IR (KBr): ν_{max} = 3402, 3316, 2210, 1628, 1545, 1514, 1409, 1343, 1263, 1016, 825 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 7.69 (br s, 2H), 7.46 (d, J = 8.0 Hz, 2H), 7.36 (d, J = 3.5 Hz, 1H), 7.30 (d, J = 8.0 Hz, 2H), 6.49 (t, J = 2.6 Hz, 1H), 2.41 (s, 3H), 2.37 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 167.6, 160.1, 155.6, 144.0, 143.1, 139.5, 135.2, 130.0, 123.6, 118.2, 117.3, 116.2, 109.8, 108.9, 20.8, 13.4. Anal. calcd for $C_{19}H_{14}N_4OS$; C, 65.88; H, 4.07; N, 16.17; S, 9.26. Found: C, 65.80; H, 4.06; N, 16.13; S, 9.39%.

2-Amino-4-(3-(bis(3,4-dimethoxyphenyl)methyl)phenyl)-6-(*p*-tolythio)pyridine-3,5-dicarbonitrile (Table 2, 3w). Mp 238–240 °C. IR (KBr): ν_{max} = 3432, 3236, 2983, 2217, 1628, 1545, 1514, 1425, 1342, 1262, 1116, 1015, 810 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 7.79 (br s, 2H), 7.47–7.51 (m, 4H), 7.30 (t, J = 8.0 Hz, 4H), 6.92 (d, J = 8.4 Hz, 2H), 6.73 (d, J = 1.7 Hz, 2H), 6.63 (dd, ^1J = 8.2 Hz, ^2J = 1.7 Hz, 2H), 5.60 (s, 1H), 3.73 (s, 6H), 3.65 (s, 6H), 2.37 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 170.9, 166.6, 159.5, 158.4, 148.5, 147.3, 146.7, 139.6, 135.9, 134.9, 131.6, 130.1, 129.1, 129.0, 128.4, 123.4, 120.9, 115.3, 115.0, 112.8, 111.7, 93.0, 55.4, 55.2, 54.5, 20.9. Anal. calcd for

C_{37} $H_{32}N_4O_4S$; C, 70.68; H, 5.13; N, 8.91; S, 5.10. Found: C, C, 70.79; H, 5.16; N, 8.83; S, 5.22%.

2-Amino-4-(3-(bis(3,4-dimethoxyphenyl)methyl)phenyl)-6-(phenylthio)pyridine-3,5-dicarbonitrile (Table 2, 3x). Mp 203–205 °C. IR (KBr): ν_{max} = 3405, 3325, 2214, 1643, 1538, 1433, 1347, 1216, 1124, 1019, 821 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 7.50 (br s, 2H), 7.34 (d, J = 7.8 Hz, 4H), 7.20 (d, J = 8.2 Hz, 2H), 6.90 (d, J = 8.4 Hz, 4H), 6.72 (d, J = 8.5 Hz, 3H), 6.63 (d, J = 8.3 Hz, 2H), 5.56 (s, 1H), 3.72 (s, 6H), 3.63 (s, 6H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 173.0, 166.5, 159.5, 158.4, 148.4, 147.2, 146.7, 139.5, 135.8, 134.9, 131.6, 131.1, 129.0, 128.4, 123.3, 120.9, 116.0, 115.0, 112.8, 111.6, 92.9, 55.7, 55.4, 54.4. Anal. calcd for $C_{36}H_{30}N_4O_4S$; C, 70.34; H, 4.92; N, 9.11; S, 5.22. Found: C, 70.43; H, 4.90; N, 9.05; S, 5.35%.

1,4-Bis(2-amino-6-phenylsufanyl-4-pyridyl-3,5-dicarbonitrile)-benzene (Scheme 3, 5a). Mp 309–310 °C. (ref. 28 310–311 °C) IR (KBr): ν_{max} = 3405, 3326, 3227, 2213, 1645, 1521, 1546, 1465, 1343, 1245, 1117, 803 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 7.81 (br s, 4H), 7.60–7.63 (m, 4H), 7.45–7.58 (m, 4H), 7.49–7.51 (m, 6H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 175.6, 171.1, 170.5, 159.8, 159.6, 134.8, 129.6, 129.4, 128.7, 127.0, 115.2, 114.9. Anal. calcd for $C_{32}H_{18}N_8S_2$; C, 66.42; H, 3.14; N, 19.36; S, 11.08. Found: C, 66.49; H, 3.12; N, 19.30; S, 11.17%.

1,4-Bis(2-amino-6-(4-methylphenylsulfanyl)-4-pyridyl-3,5-dicarbonitrile)benzene (Scheme 3, 5b). Mp 310–313 °C. IR (KBr): ν_{max} = 3403, 3150, 2214, 1648, 1547, 1516, 1463, 1342, 1294, 1115, 849 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ = 7.52 (d, J = 8.2 Hz, 4H), 7.46 (d, J = 8.2 Hz, 4H), 7.35 (d, J = 8.1 Hz, 2H), 7.20 (d, J = 7.6 Hz, 2H), 5.45 (br s, 4H), 2.36 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ = 172.9, 170.9, 159.2, 140.4, 135.8, 135.7, 133.8, 130.2, 129.9, 129.5, 115.1, 111.9, 21.4. Anal. calcd for $C_{34}H_{22}N_8S_2$; C, 67.31; H, 3.65; N, 18.47; S, 10.57. Found: C, 67.21; H, 3.69; N, 18.40; S, 10.70%.

1,3-Bis(2-amino-6-phenylsulfanyl-4-pyridyl-3,5-dicarbonitrile) benzene (Scheme 3, 5c). Mp 280–283 °C. IR (KBr): ν_{max} = 3438, 3327, 3216, 2216, 1623, 1545, 1554, 1475, 1339, 1257, 1115, 823 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 7.84 (br s, 4H), 7.60–7.65 (m, 3H), 7.57–7.59 (m, 3H), 7.48–7.54 (m, 8H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 167.7, 160.1, 159.5, 150.2, 134.8, 133.9, 131.5, 130.5, 130.1, 129.7, 129.4, 126.8, 114.9, 114.6. Anal. calcd for $C_{32}H_{18}N_8S_2$; C, 66.42; H, 3.14; N, 19.36; S, 11.08. Found: C, 66.52; H, 3.11; N, 19.28; S, 11.19%.

1,3-Bis(2-amino-6-(4-methylphenylsufanyl)-4-pyridyl-3,5-dicarbonitrile)benzene (Scheme 3, 5d). Mp 289–291 °C. IR (KBr): ν_{max} = 3348, 3270, 2217, 1582, 1409, 1345, 1216, 1117, 842 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 7.84 (br s, 4H), 7.61 (d, J = 8.0 Hz, 3H), 7.48–7.54 (m, 6H), 7.32 (d, J = 8.0 Hz, 3H), 2.38 (s, 6H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 166.7, 160.1, 159.5, 157.0, 139.6, 135.1, 134.9, 133.9, 131.6, 131.5, 130.3, 130.1, 123.2, 114.9, 114.6, 20.9. Anal. calcd for $C_{34}H_{22}N_8S_2$; C, 67.31; H, 3.65; N, 18.47; S, 10.57. Found: C, 67.20; H, 3.64; N, 18.41; S, 10.68%.

1,3-Bis(2-amino-6-β-naphthylsulfanyl-4-pyridyl-3,5-dicarbonitrile)benzene (Scheme 3, 5e). Mp 287–290 °C. IR (KBr): ν_{max} = 3437, 3377, 3216, 2216, 1623, 1525, 1545, 1464, 1338, 1257, 1116, 829 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 8.64 (s, 1H), 8.27 (s, 1H), 8.21 (d, J = 6.7 Hz, 2H), 8.00–8.06 (m 7H), 7.87–7.91 (m, 6H), 7.63–7.66 (m, 5H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 166.5, 160.1, 135.1, 134.3, 133.9, 133.2, 133.0, 131.6, 131.5, 131.4, 130.3, 130.2, 128.9, 127.9, 127.6, 127.4, 126.7, 124.5, 115.0, 114.6, 93.1, 87.0. Anal. calcd for $C_{40}H_{22}N_8S_2$; C, 70.78; H, 3.27; N, 16.51; S, 9.45. Found: C, 70.86; H, 3.22; N, 16.44; S, 9.37%.

1,4-Bis(2-amino-4-(4-nitrophenyl-3,5-dicyano)-4-pyridyl)dithiophenol (Scheme 4, 7a). Mp 173–175 °C. IR (KBr): ν_{max} = 3422, 3335, 3227, 2217, 1632, 1550, 1350, 1264, 1116, 822 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 8.25 (dd, ^1J = 6.8 Hz, ^2J = 2.0 Hz, 4H), 7.52 (dd, ^1J = 6.8 Hz, ^2J = 6.4 Hz, 4H), 7.10 (s, 4H), 4.53 (s, 4H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 183.1, 151.8, 151.78, 151.73, 150.8, 149.6, 129.9, 127.9, 124.1, 123.5, 118.4, 114.1, 113.5. Anal. calcd for $C_{32}H_{16}N_{10}O_4S_2$; C, 57.48; H, 2.41; N, 20.95; S, 9.59. Found: C, 57.39; H, 2.45; N, 20.90; S, 9.69%.

1,4-Bis(2-amino-4-(3-nitrophenyl-3,5-dicyano)-4-pyridyl)dithiophenol (Scheme 4, 7b). Mp 145–156 °C. IR (KBr): ν_{max} = 3423, 3333, 3229, 2214, 1632, 1550, 1510, 1348, 1265, 1114, 825 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 8.34 (s, 2H), 8.23 (d, J = 8.1 Hz, 2H), 7.86 (d, J = 7.6 Hz, 2H), 7.72 (t, J = 7.9 Hz, 2H), 7.07 (s, 4H), 4.78 (br s, 4H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 182.5, 166.0, 160.1, 159.5, 134.8, 133.9, 131.5, 130.3, 130.1, 129.7, 129.4, 126.8, 114.9, 114.6. Anal. calcd for $C_{32}H_{16}N_{10}O_4S_2$; C, 57.48; H, 2.41; N, 20.95; S, 9.59. Found: C, 57.40; H, 2.43; N, 20.88; S, 9.48%.

1,4-(2-Amino-4-(3-boromophenyl-3,5-dicyano)-4-pyridyl)dithiophenol (Scheme 4, 7c). Mp 140–142 °C. IR (KBr): ν_{max} = 3415, 3326, 3231, 2217, 1632, 1450, 1387, 1262, 1113, 810 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 7.47 (d, J = 7.9 Hz, 2H), 7.32–7.38 (m, 4H), 7.25 (d, J = 7.8 Hz, 2H), 7.01 (s, 4H), 4.35 (s, 4H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 180.7, 166.7, 160.1, 159.5, 157.0, 139.6, 135.1, 134.9, 133.9, 131.5, 130.3, 130.1, 123.2, 114.9. Anal. calcd for $C_{32}H_{16}Br_2N_8S_2$; C, 52.19; H, 2.19; N, 15.22; S, 8.71. Found: C, 52.08; H, 2.23; N, 15.17; S, 8.84%.

9,10-Bis(2-amino-4-(3-methoxybenzyl)-3,5-dicyano-4-pyridyl)-anthracene dithiol (Scheme 4, 7d). Mp 280–283 °C. IR (KBr): ν_{max} = 3401, 3327, 3150, 2212, 1643, 1453, 1296, 1143, 1016, 843, 765 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 7.89–7.93 (m, 4H), 7.67–7.73 (m, 8H), 7.49–7.57 (m, 2H), 6.86 (d, J = 4.8 Hz, 2H), 4.14 (s, 4H), 3.58 (s, 6H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 180.1, 160.17, 160.11, 159.0, 158.5, 158.2, 153.5, 150.0, 138.5, 129.0, 128.5, 119.4, 115.2, 113.2, 113.0, 89.6, 55.0. Anal. calcd for $C_{42}H_{26}N_8O_2S_2$; C, 68.28; H, 3.55; N, 15.17; S, 8.68. Found: C, 68.39; H, 3.58; N, 15.10; S, 8.79%.

9,10-Bis(2-amino-4-(3-boromophenyl-3,5-dicyano)-4-pyridyl)-anthracene dithiol (Scheme 4, 7e). Mp 152–154 °C. IR (KBr): ν_{max} = 3335, 3246, 3121, 2217, 1632, 1442, 1387, 1263, 1116, 811, 783 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 7.66–7.72 (m, 6H), 7.24–756 (m, 10H), 4.13 (s, 4H). ^{13}C NMR (100 MHz, DMSO-d_6) δ = 165.9, 158.3, 150.3, 130.2, 128.1, 126.6, 125.7, 121.5, 119.6, 115.8, 115.6, 115.3, 112.2, 111.4, 93.4, 86.9. Anal. calcd for $C_{40}H_{20}Br_2N_8S_2$; C, 57.43; H, 2.41; N, 13.39; S, 7.67. Found: C, 57.51; H, 2.38; N, 13.34; S, 7.77%.

9,10-Bis(2-amino-4-(β-naphthyl-3,5-dicyano)-4-pyridyl)anthracene dithiol (Scheme 4, 7f). Mp 228–231 °C. IR (KBr): ν_{max} = 3405, 3326, 3150, 2214, 1648, 1453, 1343, 1294, 1116, 828 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ = 8.02 (s, 10H), 7.67–7.71 (m, 4H), 6.54 (s, 8H), 4.14 (s, 4H). ^{13}C NMR (100 MHz, DMSO-d_6)

δ = 181.3, 165.8, 159.7, 159.4, 158.3, 150.3, 148.0, 130.5, 128.1, 126.5, 125.7, 121.5, 119.6, 115.8, 115.5, 115.3, 112.2, 111.3, 93.4, 86.8. Anal. calcd for $C_{48}H_{26}N_8S_2$; C, 74.02; H, 3.36; N, 14.39; S, 8.23. Found: C, 74.13; H, 3.32; N, 14.45; S, 8.12%.

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