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Palladium-catalyzed highly regioselective 2-arylation of 2,*x*-dibromopyridines and its application in the efficient synthesis of a 17β-HSD1 inhibitor

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ABSTRACT

2,3- and 2,5-Dibromopyridines reacted with arylboronic acids, catalyzed by $Pd(OAc)_2/PPh_3$ in the presence of K_2CO_3 in CH_3CN/MeOH (2:1) at 50 °C for 24 h, to afford 2-arylpyridines in good to high yields, while 2,4-dibromopyridine reacted with arylboronic acid pinacol esters, catalyzed by $Pd(OAc)_2/PPh_3$ in the presence of KOH in CH_3CN at 70 °C for 24 h, to afford 2-arylpyridines in good to high yields. To expand this methodology, a 17β-HSD1 inhibitor was synthesized in good yield.

1. Introduction

Pyridines are significant components of many drugs and natural products.[1–3] 2-Arylpyridines are widely used as substrates for C–H activation.[4] Substituted 2-arylpyridines are found in a wide range of fluorescent probes,[5] organic conjugated materials,[6] metal complexing ligands,[7] pharmaceuticals,[8] and natural products.[9] (Fig. 1). Substituted 2-arylpyridines can be prepared by selective Suzuki coupling from 2,*x*-dihalopyridines, such as 2,5-,[10] 2,4-,[11] or 2,3-dibromopyridines,[12] and arylboronic acids followed by other reactions, but the yields are usually low and high temperature may be required.[12b] Previously, we have reported the copper-catalyzed highly regioselective 2-aryloxylation of 2,*x*-dihalopyridines.[13] Herein, we describe a highly regioselective and efficient palladium-catalyzed arylation of 2,*x*-dibromopyridines and its application in the efficient synthesis of a 17β-HSD1 inhibitor.

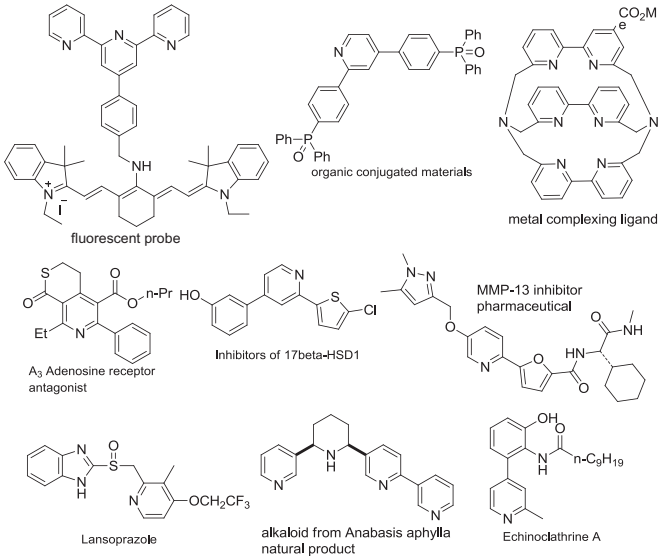

Fig. 1. The substituted 2-pyridyl motif is found in many important small molecules.

2. Results and discussion

First, a set of experiments was performed using 2,5-dibromopyridine and phenylboronic acid as model substrates in the presence of different ligands or bases in different temperatures to explore the optimized reaction conditions (Table 1). In MeOH with PPh_3 as ligand and K_2CO_3 as base, the reaction afforded **3a**, **A**, and **B** in 73%, 4%, and 23% isolated yields, respectively (entry 3), while in MeCN a better selectivity was achieved (entry 4). Encouraged by these results, the reaction was investigated in a mixture of acetonitrile and alcohol. In MeCN/EtOH (2:1) at 50 °C, the three products were obtained in 93%, 2%, and 0% yields, respectively (entry 19), and in MeCN/MeOH (2:1), the yield of **3a** could be further improved to 97% (entry 22). We thus established the optimized

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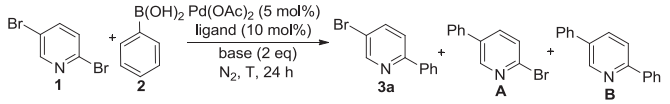
Table 1
Palladium-catalyzed 2-arylation of 2,5-dibromopyridine with phenylboronic acid: parametric study[a,b]



Entry	Ligand	Base	Solvent	T (°C)	Yield (%) (**3a**/**A**/**B**)
1[c]	PPh_3	K_2CO_3	$ClCH_2CH_2Cl$	Reflux	30:12:10
2[c]	PPh_3	K_2CO_3	THF	Reflux	38:7:36
3[c]	PPh_3	K_2CO_3	MeOH	Reflux	73:4:23
4[c]	PPh_3	K_2CO_3	CH_3CN	Reflux	41:8:0
5[c]	PPh_3	K_2CO_3	Toluene	Reflux	43:8:5
6[c]	PPh_3	K_2CO_3	DME	Reflux	50:10:24
7[c]	PPh_3	K_2CO_3	Dioxane	Reflux	0:0:0
8[c]	PPh_3	K_2CO_3	DMAc	110	40:9:18
9[c]	PPh_3	K_2CO_3	DMSO	110	26:7:8
10[c]	PPh_3	K_2CO_3	DMF	110	41:13:12
11		K_2CO_3	MeOH	30	54:22:12
12	PPh_3	K_2CO_3	MeOH	30	67:8:18
13	Sphos	K_2CO_3	MeOH	30	15:5:50
14	Xphos	K_2CO_3	MeOH	30	24:13:10
15	BINAP	K_2CO_3	MeOH	30	53:9:3
16	Xantphos	K_2CO_3	MeOH	30	0:0:0
17	PPh_3	K_2CO_3	CH_3CN/EtOH (1:1)	30	75:8:3
18	PPh_3	K_2CO_3	CH_3CN/EtOH (2:1)	40	80:0:0
19	PPh_3	K_2CO_3	CH_3CN/EtOH[d]	50	93:2:0
20[e]	PPh_3	K_2CO_3	CH_3CN/EtOH[d]	50	85:3:0
21	PPh_3	K_2CO_3	CH_3CN/MeOH[d]	50	91:1:7
22[f]	**PPh_3**	**K_2CO_3**	**CH_3CN/MeOH**[d]	**50**	**97:2:0**
23	PPh_3	K_2CO_3	CH_3CN/*n*-BuOH[d]	50	85:2:9
24	PPh_3	K_2CO_3	CH_3CN/*i*-BuOH[d]	50	65:3:1
25	PPh_3	KOH	CH_3CN/MeOH[d]	50	73:13:12
26	PPh_3	K_3PO_4	CH_3CN/MeOH[d]	50	86:12:0
27	PPh_3	Cs_2CO_3	CH_3CN/MeOH[d]	50	90:5:5

The bold signifies the best reaction condition.
[a] Reaction conditions: **1** (0.5 mmol), **2** (0.6 mmol), $Pd(OAc)_2$ (5 mol %), ligand (10 mol %), base (1 mmol), 24 h.
[b] Isolated yield.
[c] Compounds **1** (0.6 mmol), **2** (0.5 mmol), $Pd(OAc)_2$ (5 mol %), ligand (10 mol %), base (1 mmol), 24 h.
[d] CH_3CN/alcohol (2:1).
[e] Compounds **1** (0.5 mmol), **2** (0.6 mmol), $Pd(OAc)_2$ (2.5 mol %), ligand (5 mol %), base (1 mmol), 24 h.
[f] Compounds **1** (0.5 mmol), **2** (0.55 mmol), $Pd(OAc)_2$ (5 mol %), PPh_3 (10 mol %), K_2CO_3 (1 mmol), 24 h.

conditions for this reaction: $Pd(OAc)_2/PPh_3$ as the catalysis system, K_2CO_3 as the base, CH_3CN/MeOH (2:1) as the solvent and at 50 °C.

With the optimized reaction condition available, the scope of the reaction was then investigated (Table 2). It can be found that phenylboronic acids bearing electron-rich groups generally afforded products (**3a**–**3e**, **3i**–**3m**, **3r**–**3t**) in good to high yields (80–97%). 4-Fluorophenylboronic acid also gave rise to good to high yields (82–90%, **3f** and **3n**). Even 4-methoxyphenylboronic acid reacted with 2,6-dibromopyridine to give a good yield (73%, **3x**). Furthermore, substituted 2,3-dichloropyridines also reacted with phenylboronic acid to give good yields (82–88%, **3u**,**3v**). In contrast, electron-withdrawing CF_3- or NO_2-substituted phenylboronic acid gave low yields (21–50%, **3g**, **3o**,**3p**) and 4-pyridylboronic acid did not afford any products (entries 8 and 17). Clearly, the new methodology has the advantages of higher regioselectivity, higher yields, more generality, simpler and cheaper catalyst system.[10,12]

The reaction of 2,4-dibromopyridine and phenylboronic acid only gave a 68% yield of the product (**3w**). To further improve the yield of the reaction, phenylboronic acid pinacol ester was used as the coupling partner (Table 3).[14] After an extensive investigation of the reaction conditions, we found that with KOH as base, the reaction could produce the required product selectively in 16% yield in MeCN at 30 °C (entry 3). Further screening of the ligands revealed that PPh_3 is still a suitable ligand leading to the highest yield of **3w** (89%) and the best regioselectivity at 70 °C. The yields for the side products **C** and **D** were as low as 6% and 2%, respectively (entry 14).

After the optimized reaction condition was established, the reactions of 2,4-dibromopyridine with other phenylboronic acid pinacol esters were investigated and the results are shown in Table 4. Again, the pinacol esters bearing electron-donating groups afforded good to high yields (81–95%, entries 1–8), while the nitro-substituted substrate only gave the coupling product in 31% yield (entry 9) and 2-cyano-5-pyridylboronic acid pinacol ester did not give rise to the required product.

Why the regioselectivity is so high for the arylation of 2,3-, 2,5-, and 2,4-dibromopyridines? We can explain that the 2-bromo of 2,*x*-dibromopyridines is more reactive than the 4-bromo, 5-bromo, and 3-bromo of 2,*x*-dibromopyridines.[11a,13,15]

The high regioselectivity of the new method made it possible to conveniently conduct the step-by-step coupling reactions for 2,*x*-dibromopyridines. To demonstrate this, we studied the Suzuki, Sonogashira, Ullmann, and Ullmann-typed coupling reactions of **3w** with different substrates (Scheme 1), which all afforded the coupling products **6**–**9** in excellent yields.

The method can also be expanded to prepare compound **11**, a 17β-HSD1 inhibitor (Scheme 2). 2,4-Dibromopyridine reacted with 2-chlorothiophene pinacoborate under the standard condition to give compound **10** in 82% yield and its coupling with 3-hydroxyphenylboronic acid produced **11** in 90% yield. The total yield (74%) is substantially higher than the route previously reported (12%).[8b]

3. Conclusion

In summary, we have described a highly regioselective approach to bromo-2-arylpyridines, which involves palladium-catalyzed direct 2-arylation of 2,5-, 2,3-, and 2,4-dibromopyridines in high yields. The practicality of the new method has been demonstrated by using it to synthesize a 17β-HSD1 inhibitor. Step-by-step coupling reaction of other dihalopyridines is being investigated and the results will be reported in due course.

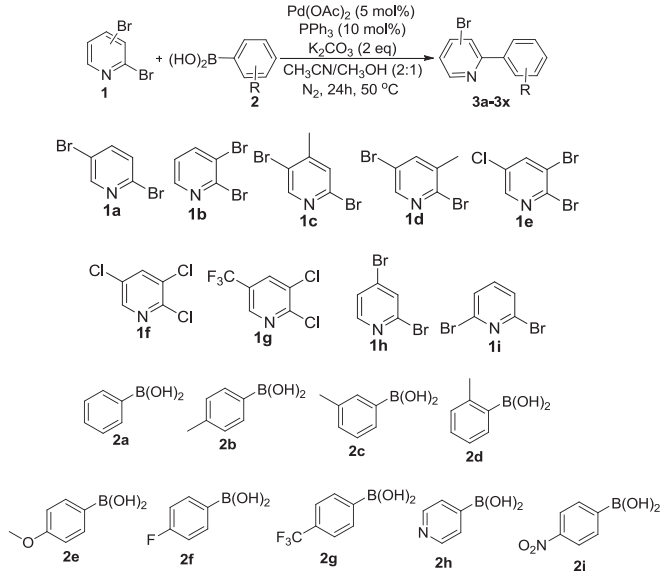
4. Experimental section

4.1. General

Typical procedure for the 2-arylation of 2,5- and 2,3-dibromopyridines: 2,5-dibromopyridine (0.12 g, 0.50 mmol), phenylboronic acid (67 mg, 0.55 mmol), K_2CO_3 (0.14 g, 1.0 mmol), $Pd(OAc)_2$ (11 mg, 5 mol %), PPh_3 (26 mg, 10 mol %) were dissolved in CH_3CN/CH_3OH (2:1, 6 mL). The solution was stirred at 50 °C under nitrogen atmosphere for 24 h and then cooled and the solid was filtered off. The filtrate was then concentrated and the resulting crude product was dissolved in CH_2Cl_2 (10 mL). The solution was washed with water (10 mL×3) and brine (10 mL), and dried over sodium sulfate. Upon removal of the solvent with a rotavapor, the resulting residue was subjected to column chromatography (petroleum ether/AcOEt, 400:1) to give the desired product **3a** (114 mg, 97%) as a white solid.

Typical procedure for the 2-arylation of 2,4-dibromopyridine: 2,4-dibromopyridine (0.12 g, 0.50 mmol), phenylboronic acid pinacol ester (0.11 g, 0.55 mmol), KOH (56 mg, 1.0 mmol), $Pd(OAc)_2$ (11 mg, 5 mol %), PPh_3 (52 mg, 20 mol %) were dissolved in CH_3CN (6 mL). The reaction was stirred at 70 °C under nitrogen atmosphere for 24 h and then cooled. The solid was filtrated off and the filtrate was concentrated. The crude product was then dissolved in CH_2Cl_2 (10 mL) and the solution was washed with water (10 mL×3) and brine (10 mL), and dried over sodium sulfate. Upon evaporation, the resulting residue was subjected to column

Table 2
Scope of Pd-catalyzed 2-arylation of 2,*x*-dibromopyridines[a,b]



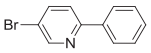
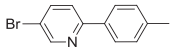
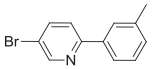
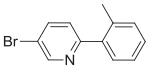
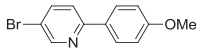
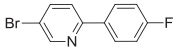
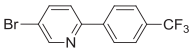
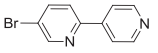
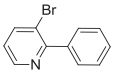
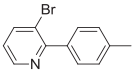
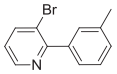
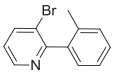
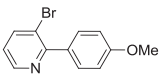
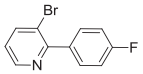
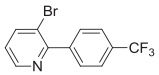
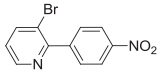
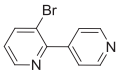
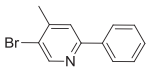
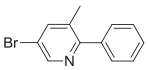
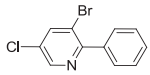
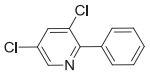
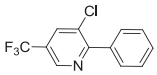
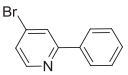
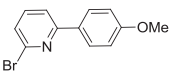
Entry	1	2	Products	Yield (%)
1	**1a**	**2a**	 **3a**	97
2	**1a**	**2b**	 **3b**	91
3	**1a**	**2c**	 **3c**	91
4	**1a**	**2d**	 **3d**	94
5	**1a**	**2e**	 **3e**	85
6	**1a**	**2f**	 **3f**	90
7	**1a**	**2g**	 **3g**	50
8	**1a**	**2h**	 **3h**	0
9	**1b**	**2a**	 **3i**	95
10	**1b**	**2b**	 **3j**	83
11	**1b**	**2c**	 **3k**	94
12	**1b**	**2d**	 **3l**	93
13	**1b**	**2e**	 **3m**	80

Table 2 (*continued*)

Entry	1	2	Products	Yield (%)
14	**1b**	**2f**	 **3n**	82
15	**1b**	**2g**	 **3o**	46
16	**1b**	**2i**	 **3p**	21
17	**1b**	**2h**	 **3q**	0
18	**1c**	**2a**	 **3r**	82
19	**1d**	**2a**	 **3s**	88
20	**1e**	**2a**	 **3t**	90
21	**1f**	**2a**	 **3u**	86
22	**1g**	**2a**	 **3v**	96
23	**1h**	**2a**	 **3w**	68
24	**1i**	**2e**	 **3x**	73

[a] Reaction condition: **1** (0.5 mmol), **2** (0.55 mmol), $Pd(OAc)_2$ (5 mol %), PPh_3 (10 mol %), K_2CO_3 (1 mmol) in CH_3CN/CH_3OH (2:1, 6 mL) at 50 °C under N_2 for 24 h.
[b] Isolated yield.

chromatography (petroleum ether/AcOEt, 400:1) to give **3w** (104 mg, 89%) as a colorless liquid.

*4.1.1. 5-Bromo-2-phenylpyridine (**3a**).* Compound **3a**: white solid, mp 74–75 °C; ^1H NMR ($CDCl_3$, 400 MHz): 8.74 (d, J=1.6 Hz, 1H), 7.95–7.97 (m, 2H), 7.87 (dd, J_1=2.4 Hz, J_2=2.8 Hz, 1H), 7.62 (d, J=8.4 Hz, 1H), 7.43–7.49 (m, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 156.1, 150.9, 139.7, 138.3, 129.7, 129.2, 127.1, 122.0, 119.6; MS (ESI): 234.1 $[M+H]^+$; HRMS (ESI) $[M+H]^+$ calcd for $C_{11}H_9BrN$: 233.99129, found: 233.99171.

*4.1.2. 2-Bromo-5-phenylpyridine (**A**).* Compound **A**: white solid, mp 76–77 °C; ^1H NMR ($CDCl_3$, 400 MHz): 8.57 (d, J=2.4 Hz, 1H), 7.71 (dd, J_1=2.4 Hz, J_2=2.4 Hz, 1H), 7.39–7.54 (m, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz): 148.7, 141.1, 137.2, 136.7, 136.2, 129.5, 128.7, 128.2, 127.2; MS (EI): 233.0 (M^+); HRMS (EI) calcd for $C_{11}H_8BrN$: 232.9840, found: 232.9846.

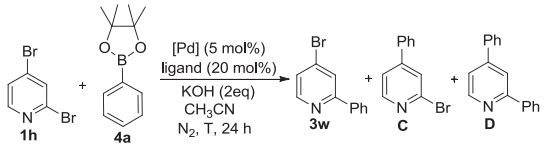
*4.1.3. 2,5-Diphenylpyridine (**B**).* Compound **B**: white solid, mp 173–174 °C; ^1H NMR ($CDCl_3$, 400 MHz): 8.93 (d, J=2.0 Hz, 1H), 8.04 (d, J=7.2 Hz, 2H), 7.91 (dd, J_1=2.0 Hz, J_2=2.0 Hz, 1H), 7.77 (d, J=8.0 Hz, 1H), 7.61 (d, J=7.2 Hz, 2H), 7.37–7.49 (m, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz): 156.4, 148.3, 139.2, 137.9, 135.3, 135.1, 129.3, 129.2, 129.0, 128.3, 127.2, 127.1, 120.6; MS (EI): 231.0 (M^+); HRMS (EI) calcd for $C_{17}H_{13}N$: 231.1048, found: 231.1053.

*4.1.4. 5-Bromo-2-(4-methylphenyl)pyridine (**3b**).* Compound **3b**: white solid, mp 109–110 °C; ^1H NMR ($CDCl_3$, 400 MHz): 8.70 (d, J=1.6 Hz, 1H), 7.90–7.86 (m, 3H), 7.57 (d, J=8.4 Hz, 1H), 7.26 (d, J=8.0 Hz, 2H), 2.39 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 156.1, 150.8, 139.7, 139.4, 135.7, 129.8, 126.9, 121.5, 119.1, 21.5; MS (ESI): 248.0 $[M+H]^+$; HRMS (ESI) $[M+H]^+$ calcd for $C_{12}H_{11}BrN$: 248.0069, found: 248.0067.

*4.1.5. 5-Bromo-2-(3-methylphenyl)pyridine (**3c**).* Compound **3c**: white solid, mp 40–41 °C; ^1H NMR ($CDCl_3$, 400 MHz): 8.72 (d, J=2.4 Hz, 1H), 7.70–7.84 (m, 3H), 7.58 (dd, J_1=2.4 Hz, J_2=2.4 Hz, 1H), 7.34 (t, J=7.6 Hz, 1H), 7.23 (d, J=7.6 Hz, 1H), 2.42 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 156.3, 150.7, 139.6, 138.4, 138.3, 130.4, 129.0, 127.7, 124.2, 122.0, 119.5, 21.8; MS (ESI): 248.1 $[M+H]^+$; HRMS (ESI) $[M+H]^+$ calcd for $C_{12}H_{11}BrN$: 248.0069, found: 248.0058.

*4.1.6. 5-Bromo-2-(2-methylphenyl)pyridine (**3d**).* Compound **3d**: yellow liquid; ^1H NMR ($CDCl_3$, 400 MHz): 8.75 (d, J=2.4 Hz, 1H), 7.85 (dd, J_1=2.8 Hz, J_2=2.4 Hz, 1H), 7.24–7.37 (m, 5H), 2.35 (s, 3H); ^{13}C

Table 3
Pd-catalyzed 2-arylation of 2,4-dibromopyridine: parametric study[a,b]



Entry	Catalyst	Ligand	T/°C	Yield (%) (**3w**/**C**/**D**)
1	$Pd(PPh_3)_4$		30	14:0:0
2	$Pd(dba)_3$	PPh_3	30	25:4:0
3	$Pd(OAc)_2$	PPh_3	30	16:0:0
4	$Pd(dppe)_2Cl_2$	PPh_3	30	28:14:7
5	$Pd(TFA)_2$	PPh_3	30	37:13:9
6	$Pd(OAc)_2$	1038-95-5	Reflux	27:18:0
7	$Pd(OAc)_2$	855-38-9	Reflux	44:20:0
8	$Pd(OAc)_2$	37943-90-1	Reflux	65:2:9
9	$Pd(OAc)_2$	5518-53-5	Reflux	56:7:10
10	$Pd(OAc)_2$	18437-78-0	Reflux	40:5:0
11	$Pd(OAc)_2$	13406-29-6	Reflux	56:4:8
12	$Pd(OAc)_2$	1259-35-4	Reflux	0:0:0
13	$Pd(OAc)_2$	PPh_3	Reflux	88:6:2
14	$Pd(OAc)_2$	PPh_3	**70**	**89**:**6**:**2**
15	$Pd(OAc)_2$	PPh_3	65	77:13:0
16	$Pd(OAc)_2$	PPh_3	60	38:7:0

The bold signifies the best reaction condition.
[a] Compounds **1h** (0.5 mmol), **4a** (0.55 mmol), [Pd] (5 mol %), ligand (20 mol %), KOH(1 mmol), CH_3CN, 24 h.
[b] Isolated yield. 1038-95-5: Tri-*p*-tolyphosphine; 855-38-9: Tris(4-methoxyphenyl)phosphine; 37943-90-1: diphenyl-2-pyridylphosphine; 5518-53-5: Tri(2-furyl) phosphine; 18437-78-0: Tris(*p*-fluorophenyl) phosphine; 13406-29-6: Tris(*p*-trifluoromethylphenyl) phosphine; 1259-35-4: Tris(pentafluorophenyl) phosphine.

NMR ($CDCl_3$, 100 MHz): 158.6, 150.3, 139.2, 139.1, 136.0, 131.1, 129.7, 128.9, 126.2, 125.6, 119.2, 20.5; MS (ESI): 248.0 $[M+H]^+$; HRMS (ESI) $[M+H]^+$ calcd for $C_{12}H_{11}BrN$: 248.0069, found: 248.0058.

*4.1.7. 5-Bromo-2-(4-methyloxyphenyl)pyridine (**3e**).* Compound **3e**: white solid, mp 136–137 °C; ^1H NMR ($CDCl_3$, 400 MHz): 8.69 (d, J=2.0 Hz, 1H), 7.92 (d, J=8.4 Hz, 2H), 7.82 (dd, J_1=2.4 Hz, J_2=2.0 Hz, 1H), 7.55 (d, J=8.4 Hz, 1H), 6.98 (d, J=8.8 Hz, 2H), 3.86 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 161.1, 155.7, 150.5, 139.7, 130.8, 128.4, 121.2, 118.7, 114.5, 55.7; MS (ESI): 264.0 $[M+H]^+$; HRMS (ESI) $[M+H]^+$ calcd for $C_{12}H_{11}BrNO$: 264.0019, found: 264.0012.

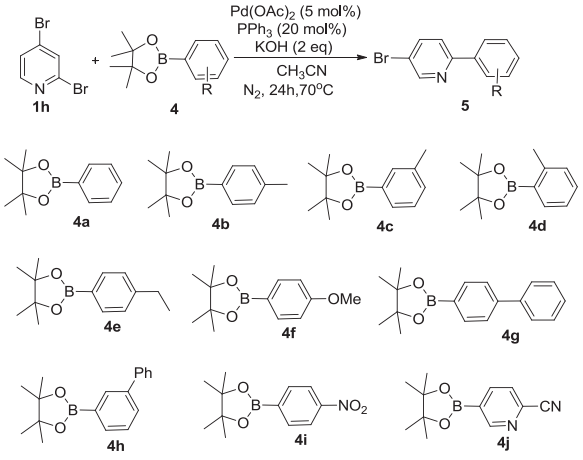
*4.1.8. 5-Bromo-2-(4-fluorophenyl)pyridine (**3f**).* Compound **3f**: white solid, mp 73–74 °C; ^1H NMR ($CDCl_3$, 400 MHz): 8.71 (d, J=2.4 Hz, 1H), 7.92–7.96 (m, 2H), 7.84 (dd, J_1=2.4 Hz, J_2=2.0 Hz, 1H), 7.55 (d, J=8.4 Hz, 1H), 7.14 (t, J=8.8 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz): 164.0 (d, J=247.6 Hz), 155.1, 150.9, 139.6, 134.6 (d, J=3.2 Hz), 128.9 (d, J=9.2 Hz), 121.5, 119.5, 116.1 (d, J=20.9 Hz); MS (ESI): 252.0 $[M+H]^+$; HRMS (ESI) $[M+H]^+$ calcd for $C_{11}H_8BrFN$: 251.9819, found: 251.9817.

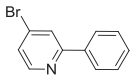
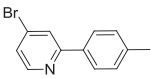
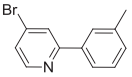
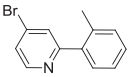
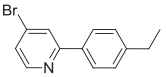
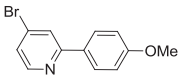
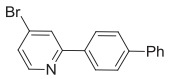
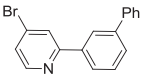
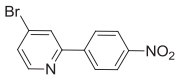
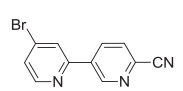
*4.1.9. 5-Bromo-2-(4-trifluoromethylphenyl)pyridine (**3g**).* Compound **3g**: white solid, mp 109–110 °C; ^1H NMR ($CDCl_3$, 400 MHz): 8.76 (d, J=1.6 Hz, 1H), 8.07 (d, J=8.0 Hz, 2H), 7.90 (dd, J_1=2.0 Hz, J_2=2.4 Hz, 1H), 7.68 (dd, J_1=8.4 Hz, J_2=8.4 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 154.5, 151.3, 141.8, 139.8, 131.5 (q, J=33.2 Hz), 127.3, 126.1 (q, J=3.6 Hz), 124.4 (d, J=270.4 Hz), 122.1, 120.6; MS (EI): 303.0 (M^+); HRMS (EI) calcd for $C_{12}H_7BrF_3N$: 300.9714, found: 300.9711.

*4.1.10. 3-Bromo-2-phenylpyridine (**3i**).* Compound **3i**: yellow liquid; ^1H NMR ($CDCl_3$, 400 MHz): 8.62 (dd, J_1=1.2 Hz, J_2=1.2 Hz, 1H), 7.98 (dd, J_1=1.6 Hz, J_2=1.6 Hz, 1H), 7.68 (dd, J_1=1.6 Hz, J_2=1.2 Hz, 2H), 7.40–7.48 (m, 3H), 7.12 (dd, J_1=4.8 Hz, J_2=4.8 Hz, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): 158.3, 148.2, 141.6, 139.6, 129.5, 129.0, 128.2, 123.5, 122.1; MS (EI): 233.0 (M^+); HRMS (EI) calcd for $C_{11}H_8BrN$: 232.9840, found: 232.9844.

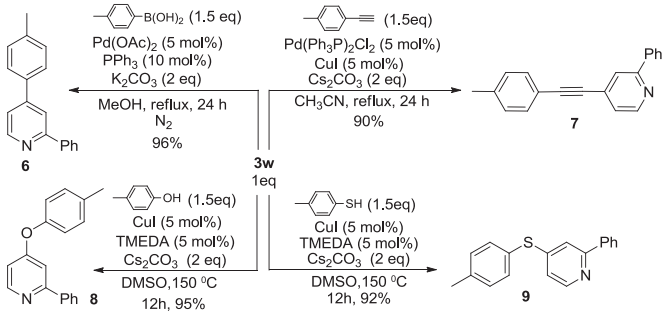
*4.1.11. 3-Bromo-2-(4-methylphenyl)pyridine (**3j**).* Compound **3j**: yellow liquid; ^1H NMR ($CDCl_3$, 400 MHz): 8.60 (dd, J_1=1.2 Hz, J_2=1.6 Hz, 1H), 7.96 (dd, J_1=1.6 Hz, J_2=1.6 Hz, 1H), 7.59 (d, J=8.0 Hz,

Table 4
Scope of Pd-catalyzed 2-arylation of 2,4-dibromopyridine[a,b]

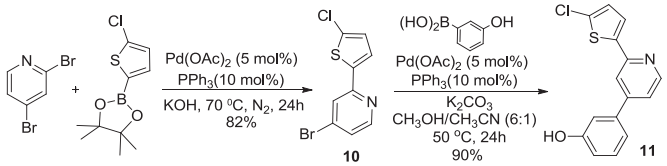


Entry	**4**	Products	Yield (%)
1	**4a**	 **3w**	89
2	**4b**	 **5a**	91
3	**4c**	 **5b**	86
4	**4d**	 **5c**	95
5	**4e**	 **5d**	84
6	**4f**	 **5e**	93
7	**4g**	 **5f**	89
8	**4h**	 **5g**	81
9	**4i**	 **5h**	31
10	**4j**	 **5i**	0

[a] Compound **1h** (0.5 mmol), compound **4** (0.55 mmol), $Pd(OAc)_2$ (5 mol %), PPh_3 (20 mol %), KOH(1 mmol), CH_3CN, 24 h.
[b] Isolated yield.



Scheme 1. Application of the 4-bromo-2-phenyl-pyridine to the other reactions.



Scheme 2. Application of the 2,4-dibromopyridine to the inhibitor of 17β-HSD1 (**11**).

2H), 7.26 (d, J=7.6 Hz, 2H), 7.08–7.11 (m, 1H); 2.41 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 158.4, 148.2, 141.6, 139.0, 136.8, 129.5, 128.9, 123.3, 120.1, 21.6; MS (EI): 247.0 (M^+); HRMS (EI) calcd for $C_{12}H_{10}BrN$: 246.9997, found: 246.9998.

*4.1.12. 3-Bromo-2-(3-methylphenyl)pyridine (**3k**).* Compound **3k**: yellow liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.61 (dd, J_1=1.2 Hz, J_2=1.2 Hz, 1H), 7.96 (dd, J_1=1.2 Hz, J_2=1.2 Hz, 1H), 7.48 (d, J=6.8 Hz, 2H), 7.34 (t, J=7.6 Hz, 1H), 7.24 (d, J=8.0 Hz, 1H), 7.11 (dd, J_1=4.8 Hz, J_2=4.8 Hz, 1H), 2.42 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 158.5, 148.1, 141.5, 139.6, 137.9, 130.1, 129.7, 128.0, 126.6, 123.4, 120.1, 21.7; MS (EI): 247.0 (M^+); HRMS (EI) calcd for $C_{12}H_{10}BrN$: 246.9997, found: 247.0001.

*4.1.13. 3-Bromo-2-(2-methylphenyl)pyridine (**3l**).* Compound **3l**: yellow liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.62 (dd, J_1=1.2 Hz, J_2=1.2 Hz, 1H), 7.98 (dd, J_1=0.8 Hz, J_2=1.2 Hz, 1H), 7.15–7.35 (m, 5H), 2.14 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 159.8, 148.0, 140.7, 139.9, 135.9, 130.4, 128.9, 128.8, 125.8, 123.7, 121.6, 19.6; MS (EI): 247.0 (M^+); HRMS (EI) calcd for $C_{12}H_{10}BrN$: 246.9997, found: 246.9996.

*4.1.14. 3-Bromo-2-(4-methoxyphenyl)pyridine (**3m**).* Compound **3m**: yellow solid, mp 61–62 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.59 (dd, J_1=1.2 Hz, J_2=1.2 Hz, 1H), 7.96 (dd, J_1=1.2 Hz, J_2=1.6 Hz, 1H), 7.66–7.69 (m, 2H), 7.08 (dd, J_1=4.8 Hz, J_2=4.8 Hz, 1H), 6.98 (d, J=8.4 Hz, 2H), 3.85 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 160.3, 157.9, 148.1, 141.7, 132.1, 131.0, 123.0, 119.9, 113.6, 55.5; MS (EI): 263.0 (M^+); HRMS (EI) calcd for $C_{12}H_{10}BrNO$: 262.9946, found: 262.9950.

*4.1.15. 3-Bromo-2-(4-fluorophenyl)pyridine (**3n**).* Compound **3n**: white solid, mp 90–91 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.61 (dd, J_1=1.2 Hz, J_2=1.2 Hz, 1H), 7.98 (dd, J_1=1.2 Hz, J_2=1.2 Hz, 1H), 7.67–7.71 (m, 2H), 7.11–7.17 (m, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 163.2 (d, J=247.3 Hz), 157.3, 148.3, 141.7, 135.7 (d, J=3.2 Hz), 131.6 (d, J=8.2 Hz), 123.6, 120.0, 115.2 (d, J=22.0 Hz); MS (EI): 251.0 (M^+); HRMS (EI) calcd for $C_{11}H_7BrNF$: 250.9746, found: 250.9744.

*4.1.16. 3-Bromo-2-(4-trifluoromethylphenyl)pyridine (**3o**).* Compound **3o**: white solid, mp 51–52 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.64 (dd, J_1=1.2 Hz, J_2=1.2 Hz, 1H), 8.02 (dd, J_1=1.2 Hz, J_2=1.2 Hz, 1H), 7.68 (dd, J_1=8.0 Hz, J_2=8.4 Hz, 4H), 7.19 (dd, J_1=4.4 Hz, J_2=4.4 Hz, 1H), ^{13}C NMR ($CDCl_3$, 100 MHz): 157.0, 148.4, 143.1, 141.9, 131.0 (q, J=32.4 Hz), 130.1, 125.3 (q, J=3.6 Hz), 124.4 (d, J=270.4 Hz), 124.2, 120.0; MS (EI): 301.0 (M^+); HRMS (EI) calcd for $C_{12}H_7BrF_3N$: 300.9714, found: 300.9716.

*4.1.17. 3-Bromo-2-(4-nitrophenyl)pyridine (**3p**).* Compound **3p**: white solid, mp 148–149 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.67 (d, J=4.4 Hz, 1H), 8.32 (d, J=6.8 Hz, 2H), 8.04 (d, J=8.4 Hz, 1H), 7.88 (d, J=7.6 Hz, 2H), 7.23–7.27 (m, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): 156.1, 148.7, 148.1, 145.8, 141.9, 130.8, 124.6, 123.5, 120.0, MS (EI): 278 (M^+); HRMS (EI) calcd for $C_{11}H_7BrN_2O_2$: 277.9691, found: 277.9690.

*4.1.18. 5-Bromo-4-methyl-2-phenylpyridine (**3r**).* Compound **3r**: colorless liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.68 (s, 1H), 7.93–7.95 (s, 2H), 7.57 (s, 1H), 7.38–7.47 (m, 3H), 2.43 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 156.3, 151.2, 147.7, 138.4, 129.4, 129.0, 127.0, 122.9, 122.3, 22.7; MS (EI): 249.1 (M^+); HRMS (EI) calcd for $C_{12}H_{10}BrN$: 246.9997, found: 246.9999.

*4.1.19. 5-Bromo-3-methyl-2-phenylpyridine (**3s**).* Compound **3s**: colorless liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.58 (d, J=2.0 Hz, 1H), 7.73 (d, J=2.4 Hz, 1H), 7.39–7.50 (m, 5H), 2.34 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 157.4, 148.1, 140.9, 139.7, 132.9, 129.0, 128.5, 119.1, 20.1; MS (EI): 248.1 (M^+); HRMS (EI) calcd for $C_{12}H_9BrN$: 245.9918, found: 245.9921.

*4.1.20. 5-Chloro-3-bromo-2-phenylpyridine (**3t**).* Compound **3t**: white solid, mp 60–61 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.58 (d, J=1.6 Hz, 1H), 8.00 (d, J=2.0 Hz, 1H), 7.64–7.67 (m, 2H), 7.42–7.48 (m, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 156.6, 147.1, 140.7, 138.7, 130.7, 129.5, 129.3, 128.3, 119.6; MS (EI): 268.9 (M^+); HRMS (EI) calcd for $C_{11}H_7BrClN$: 266.9450, found: 266.9453.

*4.1.21. 3,5-Dichloro-2-phenylpyridine (**3u**).* Compound **3u**: white solid, mp 50–51 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.55 (d, J=2.4 Hz, 1H), 7.80 (d, J=2.0 Hz, 1H), 7.68–7.71 (m, 2H), 7.42–7.48 (m, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 154.9, 146.7, 137.7, 137.3, 130.7, 130.4, 129.5, 129.4, 128.4; MS (EI): 223.0 (M^+); HRMS (EI) calcd for $C_{11}H_7Cl_2N$: 222.9956, found: 222.9954.

*4.1.22. 3-Chloro-5-trifluoromethyl-2-phenylpyridine (**3v**).* Compound **3v**: colorless liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.85 (s, 1H), 8.04 (d, J=1.6 Hz, 1H), 7.74–7.77 (m, 2H), 7.48–7.52 (m, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 160.2, 144.5 (m), 137.2 (d, J=2.2 Hz), 135.6, 130.5, 130.0, 129.7, 128.5, 126.4 (q, J=13.2 Hz), 123.0 (d, J=261.9 Hz); MS (EI): 257.1 (M^+); HRMS (EI) calcd for $C_{12}H_7ClF_3N$: 257.0219, found: 257.0214.

*4.1.23. 4-Bromo-2-phenylpyridine (**3w**).* Compound **3w**: colorless liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.48 (d, J=5.2 Hz, 1H), 7.87–7.96 (m, 3H), 7.36–7.48 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): 159.0, 150.5, 138.1, 133.8, 129.9, 129.1, 127.2, 125.5, 124.1; MS (EI): 233.1 (M^+); HRMS (EI) calcd for $C_{11}H_8BrN$: 232.9840, found: 232.9843.

*4.1.24. 6-Bromo-2-(4-methoxyphenyl)pyridine (**3x**).* Compound **3x**: white solid, mp 113–114 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 7.91–7.94 (m, 2H), 7.50–7.59 (m, 2H), 7.31–7.33 (m, 1H), 6.94–6.97 (m, 2H), 3.84 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 161.2, 158.5, 142.3, 139.1, 130.5, 128.6, 125.7, 118.4, 114.4, 55.6; MS (EI): 263.0 (M^+); HRMS (EI) calcd for $C_{12}H_{10}BrNO$: 262.9946, found: 262.9951.

*4.1.25. 2-Bromo-4-phenylpyridine (**C**).* Compound **C**: white solid, mp 62–63 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.40 (d, J=5.2 Hz, 1H), 7.69 (d, J=0.8 Hz, 1H), 7.59 (dd, J_1=2.0 Hz, J_2=1.6 Hz, 2H), 7.44–7.51 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): 151.5, 150.6, 143.2, 137.0, 129.9, 129.5, 127.3, 126.1, 121.1; MS (EI): 233.0 (M^+); HRMS (EI) calcd for $C_{11}H_8BrN$: 232.9840, found: 232.9842.

*4.1.26. 2,4-Diphenylpyridine (**D**).* Compound **D**: yellow liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.71 (d, J=5.6 Hz, 1H), 8.04 (d, J=7.2 Hz, 2H), 7.90 (s, 1H), 7.65–7.90 (m, 2H), 7.39–7.49 (m, 7H); ^{13}C NMR ($CDCl_3$, 100 MHz): 158.3, 150.3, 149.5, 139.7, 138.8, 129.3 (d,

J=9.0 Hz), 129.0, 127.3 (d, J=3.1 Hz), 120.5, 119.0; MS (EI): 230.0 (M^+); HRMS (EI) calcd for $C_{17}H_{13}N$: 231.1048, found: 231.1045.

*4.1.27. 4-Bromo-2-(4-methylphenyl)pyridine (**5a**).* Compound **5a**: white solid, mp 60–61 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.46 (d, J=5.2 Hz, 1H), 7.84–7.86 (m, 3H), 7.25–7.34 (m, 3H), 2.40 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 159.0, 150.4, 140.0, 135.3, 133.7, 129.8, 127.1, 125.2, 123.8, 21.5; MS (EI): 249.1 (M^+); HRMS (EI) calcd for $C_{12}H_{10}BrN$: 246.9997, found: 246.9999.

*4.1.28. 4-Bromo-2-(3-methylphenyl)pyridine (**5b**).* Compound **5b**: yellow liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.48 (d, J=5.2 Hz, 1H), 7.87 (d, J=1.6 Hz, 1H), 7.79 (s, 1H), 7.72 (d, J=7.6 Hz, 1H), 7.33–7.37 (m, 2H), 7.24 (d, J=7.6 Hz, 1H), 2.42 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 159.2, 150.4, 138.8, 138.1, 133.8, 130.7, 129.0, 127.9, 125.4, 124.4, 124.2, 21.7; MS (EI): 247.1 (M^+); HRMS (EI) calcd for $C_{12}H_{10}BrN$: 246.9997, found: 246.9995.

*4.1.29. 4-Bromo-2-(2-methylphenyl)pyridine (**5c**).* Compound **5c**: colorless liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.50 (d, J=5.2 Hz, 1H), 7.59 (d, J=1.6 Hz, 1H), 7.25–7.43 (m, 5H), 2.36 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 161.5, 150.0, 139.2, 136.1, 133.2, 131.1, 129.8, 129.1, 127.7, 126.2, 125.2, 20.5; MS (EI): 248.1 (M^+); HRMS (EI) calcd for $C_{12}H_9BrN$: 245.9918, found: 245.9920.

*4.1.30. 4-Bromo-2-(4-ethylphenyl)pyridine (**5d**).* Compound **5d**: colorless liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.47 (d, J=5.6 Hz, 1H), 7.86–7.89 (m, 3H), 7.25–7.35 (m, 3H), 2.70 (q, J=8.0 Hz, 2H), 1.26 (t, J=7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 159.2, 150.5, 146.3, 135.7, 133.6, 128.7, 127.2, 125.2, 123.8, 28.9, 15.7; MS (EI): 261 (M^+); HRMS (EI) calcd for $C_{13}H_{12}BrN$: 261.0153, found: 261.0155.

*4.1.31. 4-Bromo-2-(4-methoxyphenyl)pyridine (**5e**).* Compound **5e**: yellow liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.44 (d, J=5.2 Hz, 1H), 7.91 (d, J=8.4 Hz, 2H), 7.82 (s, 1H), 7.30–7.32 (m, 1H), 6.98 (d, J=8.4 Hz, 2H), 3.84 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 161.2, 158.7, 150.4, 133.6, 130.8, 128.6, 124.7, 123.3, 114.5, 55.6; MS (EI): 263.1 (M^+); HRMS (EI) calcd for $C_{12}H_{10}BrNO$: 262.9946, found: 262.9950.

*4.1.32. 4-Bromo-2-(4-phenylphenyl)pyridine (**5f**).* Compound **5f**: white solid, mp 105–106 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.52 (d, J=4.8 Hz, 1H), 8.04–8.06 (m, 2H), 7.94 (d, J=1.6 Hz, 1H), 7.64–7.73 (m, 4H), 7.38–7.49 (m, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz): 158.7, 150.7, 142.7, 140.6, 137.1, 133.8, 129.1, 128.0, 127.8, 127.7, 127.4, 125.5, 124.0; MS (EI): 309.0 (M^+); HRMS (EI) calcd for $C_{17}H_{12}BrN$: 309.0153, found: 309.0151.

*4.1.33. 4-Bromo-2-(3-phenylphenyl)pyridine (**5g**).* Compound **5g**: colorless liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.52 (d, J=5.2 Hz, 1H), 8.19 (t, J=1.6 Hz, 1H), 7.92–7.95 (m, 2H), 7.66 (d, J=7.2 Hz, 3H), 7.24–7.56 (m, 5H); ^{13}C NMR ($CDCl_3$, 100 MHz): 159.1, 150.7, 142.2, 141.1, 138.8, 133.8, 129.6, 129.1, 128.7, 127.8, 127.5, 126.2, 126.1, 125.7, 124.3; MS (EI): 309 (M^+); HRMS (EI) calcd for $C_{17}H_{12}BrN$: 309.0148, found: 309.0150.

*4.1.34. 4-Bromo-2-(4-nitrophenyl)pyridine (**5h**).* Compound **5h**: yellow solid, mp 168–169 °C; ^{1}H NMR (DMSO-d_6, 400 MHz): 8.63 (d, J=5.2 Hz, 1H), 8.32–8.44 (m, 5H), 7.76 (d, J=3.6 Hz, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz): 155.2, 151.0, 148.0, 143.2, 133.6, 128.1, 126.9, 124.5, 123.9; MS (EI): 278.0 (M^+); HRMS (EI) calcd for $C_{11}H_7BrN_2O_2$: 277.9691, found: 277.9690.

*4.1.35. 2-Phenyl-4-(4-methylphenyl)pyridine (**6**).* Compound **6**: white solid, mp 95–96 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.71 (d, J=5.6 Hz, 1H), 8.04 (d, J=7.6 Hz, 2H), 7.91 (d, J=0.8 Hz, 1H), 7.31–7.59 (m, 6H), 7.26 (d, J=20 Hz, 2H), 2.41 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 158.2, 150.1, 149.6, 139.6, 139.5, 135.7, 130.1, 129.3, 129.0, 127.3, 127.2, 120.3, 118.8, 21.5; MS (EI): 245.2 (M^+); HRMS (EI) calcd for $C_{18}H_{15}N$: 245.1204, found: 245.1209.

*4.1.36. 2-Phenyl-4-(4-methylphenylethynyl)pyridine (**7**).* Compound **7**: white solid, mp 121–122 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.66 (d, J=5.2 Hz, 1H), 8.01 (d, J=7.2 Hz, 2H), 7.82 (s, 1H), 7.42–7.50 (m, 5H), 7.31 (d, J=4.8 Hz, 1H), 7.18 (d, J=8.4 Hz, 2H), 2.38 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 157.6, 149.6, 139.9, 138.8, 133.0, 132.1, 129.6 (d), 129.1, 127.2, 124.1, 122.8, 119.3, 94.7, 86.7, 21.9; MS (EI): 269.2 (M^+); HRMS (EI) calcd for $C_{20}H_{15}N$: 269.1204, found: 269.1205.

*4.1.37. 2-Phenyl-4-(4-methylphenoxy)pyridine (**8**).* Compound **8**: yellow liquid; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.51 (d, J=6.0 Hz, 1H), 7.91 (d, J=7.2 Hz, 2H), 7.36–7.45 (m, 3H), 7.20–7.26 (m, 3H), 7.01 (d, J=8.4 Hz, 2H), 6.74 (dd, J_1=2.4 Hz, J_2=2.8 Hz), 2.37 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 166.1, 159.8, 152.1, 151.3, 139.4, 135.2, 130.9, 129.3, 128.9, 127.2, 120.8, 110.7, 109.1, 21.1; MS (EI): 260.2 (M^+); HRMS (EI) calcd for $C_{18}H_{15}NO$: 261.1154, found: 261.1156.

*4.1.38. 2-Phenyl-4-(p-tolylthio)pyridine (**9**).*[1] Compound **9**: white solid, mp 84–85 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.40 (d, J=5.6 Hz, 1H), 7.86 (d, J=7.2 Hz, 2H), 7.36–7.47 (m, 6H), 7.26 (d, J=8.0 Hz, 2H), 6.83 (dd, J_1=1.2 Hz, J_2=1.2 Hz, 1H), 2.41 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): 157.5, 151.9, 149.4, 140.3, 139.2, 135.5, 131.0, 129.3, 128.9, 127.2, 126.1, 119.3, 117.8, 21.6; MS (EI): 276.1 (M^+); HRMS (EI) calcd for $C_{18}H_{15}NS$: 277.0925, found: 277.0930.

*4.1.39. 4-Bromo-2-(5-chlorothiophen-2-yl)pyridine (**10**).*[1] Compound **10**: yellow solid, mp 69–70 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 8.32 (d, J=5.2 Hz, 1H), 7.70 (d, J=1.6 Hz, 1H), 7.28–7.31 (m, 2H), 6.91 (d, J=4.0 Hz, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): 153.2, 150.5, 142.1, 133.8, 133.6, 127.6, 125.5, 124.6, 121.5; MS (EI): 274.9 (M^+); HRMS (EI) calcd for $C_9H_5BrClNS$: 272.9015, found: 272.9014.

*4.1.40. 4-(3-Hydroxyphenyl)-2-(5-chlorothiophen-2-yl)pyridine (**11**).*[8b] Compound **11**: yellow solid, mp 190–191 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): 9.70 (s, 1H), 8.54 (d, J=5.2 Hz, 1H), 8.18 (s, 1H), ^{1}H NMR 7.91 (d, J=4.4 Hz, 1H), 7.54 (dd, J_1=1.2 Hz, J_2=1.2 Hz, 1H), 7.20–7.37 (m, 4H), 6.91–6.93 (m, 1H); ^{13}C NMR ($CDCl_3$, 100 MHz): 158.9, 152.4, 150.7, 149.4, 144.6, 139.2, 131.4, 131.0, 129.1, 126.2, 121.1, 118.6, 117.3, 116.3, 114.7; MS (EI): 287.0 (M^+); HRMS (EI) calcd for $C_{15}H_{10}ClNOS$: 287.0172, found: 287.0171.

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Supplementary data

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