Metal-free synthesis of *N*-(pyridine-2-yl)amides from ketones via selective oxidative cleavage of C(O)-C(alkyl) bond in water

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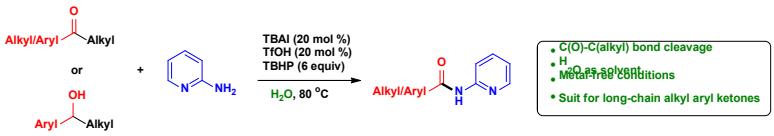
Supporting Information

ABSTRACT: The TBHP/TBAI-mediated synthesis of *N*-(pyridine-2-yl)amides in water from ketones and 2-aminopyridine via direct oxidative C-C bond cleavage has been developed. A series of ketones, including more challenging inactive aromatic ketones substituted with diverse long-chain alkyl groups were selectively converted to *N*-(pyridine-2-yl)amides. Furthermore, the protocol can be applied to aryl alkyl carbinols to afford the corresponding amides in moderate to good yields.



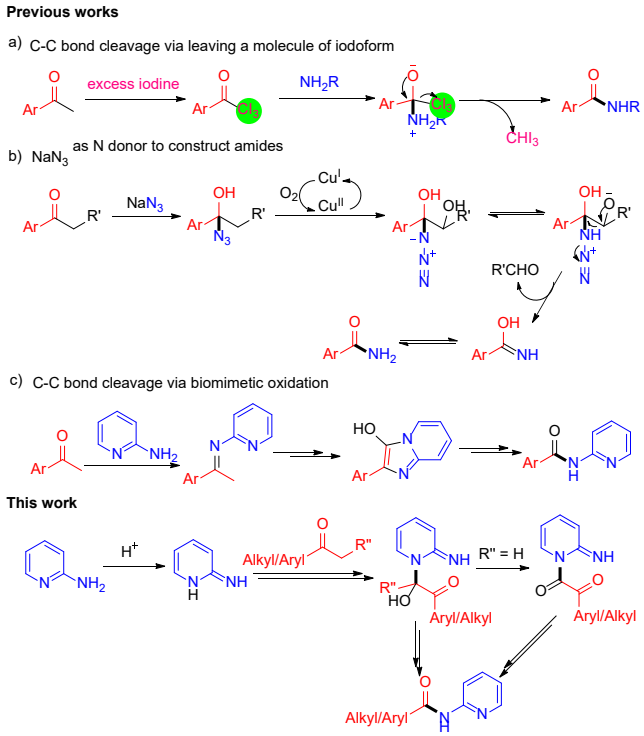
■ INTRODUCTION

Amides are ubiquitous building blocks in many natural products and pharmaceutical agents.[1] Conventionally, amides used to be prepared from carboxylic acid derivatives, such as acids, acyl halides, anhydrides and esters. However, this method has limitations as some compounds are not suitable for the chemical transformation to active carboxylic acid derivatives. In order to circumvent this problem, alternative strategies towards the synthesis of amides have been explored. In recent years, oxidative amidation of aromatic aldehyde or benzyl alcohol with *N*,*N*-disubstituted formamides,[2] amines,[3] aminofluorenes[4] and 2-animopyridines[5] has been studied. Methylarenes as acyl donors for oxidative amidation have also been reported.[6]

Carbon-carbon bonds are fundamental in organic compounds, construction of functional groups directly via C-C bond cleavage is extremely attractive and challenging. Direct synthesis of esters through highly selective C(O)-C(alkyl) bond cleavage has been reported by Jiao's group.[7] However, strategies for the construction of amides from ketones via C-C bond cleavage encountered many limitations: (1) unique resources of amines. Most of the reported methods constructed primary amine from aqueous ammonia.[8] (2) using excess volatile heavy atoms. A common pathway to construct amides via C-C bond cleavage needs excess of iodine, with iodoform as the extra side product (Scheme 1a).[8a,9] (3) using toxic and reactive agents. Some methodologies use strong nucleophilic NaN_3 as N donor to form primary amides (Scheme 1b).[9b,10] (4) Using metals. The group of Kaliappan reported the synthesis of *N*-heterocyclic amides from methyl ketones using 20% Cu-catalyzed biomimetic oxidation (Scheme 1c).[11]

Therefore, development of new green methodology of amidation via C-C bond cleavage is always an attractive research interest.

Scheme 1. Construction of amides via C-C bond cleavage

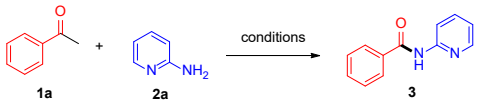


2-Aminopyridine has been used as a key substrate involved in the C-C bond cleavage for the synthesis of pyridyl benzamides.[11,12] Herein we report a mild and green methodology to construct *N*-(pyridine-2-yl)amides from ketones or aryl alkyl carbinols via direct C-C bond cleavage in water. More challenging substrates with long-chain alkyl substituents on ketones can also be used to convert to the corresponding amides.

■ RESULTS AND DISCUSSION

Initially, acetophenone (**1a**) and 2-aminopyridine (**2a**) were selected as model substrates, and to our delight, when they were treated in a reaction system containing a catalytic amount of I_2 and excess TBHP in toluene at 80 °C, *N*-(pyridin-2-yl)benzamide (**3**) was obtained in 24% yield (Table 1, entry 1). Subsequent screening of solvents showed that H_2O was the best solvent with a yield of 42% without any additional reagent (Table 1, entry 6). The yield slightly increased to 46% when TBAI was used as a catalyst to replace I_2 (Table 1, entry 10). While the reactions using DTBP, $K_2S_2O_8$ or O_2 (balloon) as the oxidant were not satisfactory (Table 1, entries 11-13). A significant enhancement in product yield was observed when acids (20 mol %) were used as additives (Table 1, entries 14-16), but no more improvement was observed when increasing TfOH quantity to 1.2 equivalent (Table 1, entry 17) or altering reaction temperature (Table 1, entries 18, 19). In summary, acetophenone and 2-aminopyridine could be transformed to the corresponding amide with a yield of 84% under the following optimized conditions: TBAI (0.2 equiv), TfOH (0.2 equiv), TBHP (6 equiv) in H_2O (2 mL) with stirring at 80 °C for 6 h (Table 1, entry 16).

Table 1. **Optimization of the reaction conditions**[a]

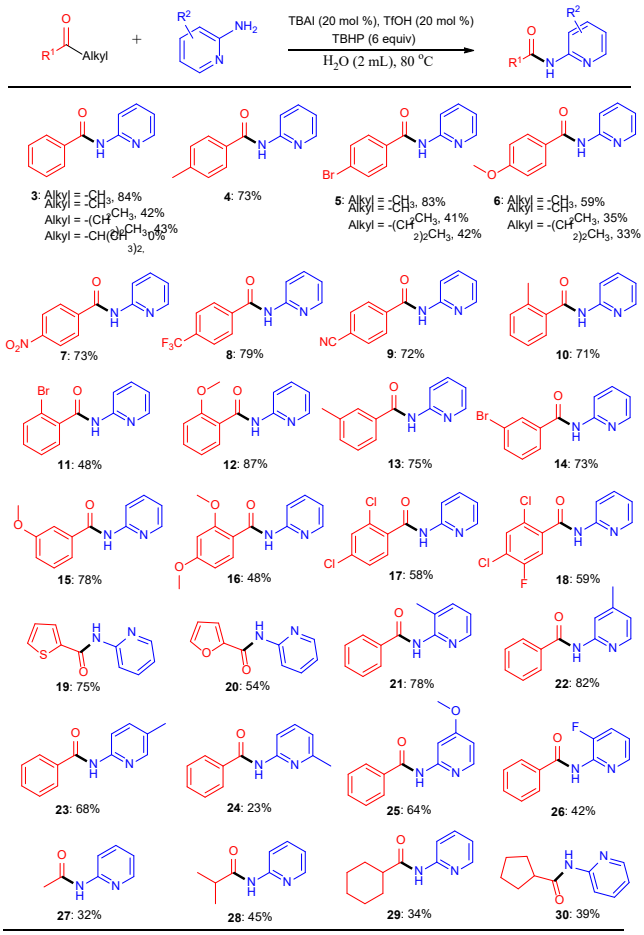


Entry	Solvent	Catalyst (20 mol%)	Oxidant (6 equiv)	Additive (20 mol%)	Temp (°C)	Yield (%)
1	Toluene	I_2	TBHP	-	80	24
2	DMSO	I_2	TBHP	-	80	13
3	DMF	I_2	TBHP	-	80	8
4	DCE	I_2	TBHP	-	80	16
5	Dioxane	I_2	TBHP	-	80	15
6	H_2O	I_2	TBHP	-	80	42
7	H_2O	KI	TBHP	-	80	41
8	H_2O	CuI	TBHP	-	80	5
9	H_2O	NIS	TBHP	-	80	42
10	H_2O	TBAI	TBHP	-	80	46
11	H_2O	TBAI	DTBP	-	80	3
12	H_2O	TBAI	$K_2S_2O_8$	-	80	-
13	H_2O	TBAI	O_2	-	80	-
14	H_2O	TBAI	TBHP	CH_3COOH	80	73
15	H_2O	TBAI	TBHP	CF_3COOH	80	75
16	**H_2O**	**TBAI**	**TBHP**	**TfOH**	**80**	**84**
17[b]	H_2O	TBAI	TBHP	TfOH	80	82
18	H_2O	TBAI	TBHP	TfOH	60	74
19	H_2O	TBAI	TBHP	TfOH	100	81

[a]Reaction conditions: **1a** (0.6 mmol), **2** (1.2 mmol), catalyst (0.12 mmol), additive (0.12 mmol), oxidant (3.6 mmol), solvent (2 mL), 6 h.
[b]1.2 equivalent of TfOH was used.

With the optimized conditions in hand, the scope of reactants using in the amidation via C-C bond cleavage was explored (Scheme 2). First, various phenyl ketones with diverse long-chain alkyl substituents were investigated. Under our conditions, all tested substrates could be converted to the corresponding amide products (**3**) via selective C(O)-C(alkyl) bond cleavage except the isobutyrophenone, but the yields decreased obviously when alkyl chains contain two and more carbons. Consequently, we studied the effect of substituents in benzene. As shown in Scheme 2, the position of methyl on benzene ring had no obvious effect on the reactivity (**4**, **10** and **13**). Although 4-methoxyl or 2-bromo substituted benzene may cause a relatively low yield in this reaction (**6** and **11**), electron withdrawing groups substituted at 4-position generally provided the products with satisfying yields (**7**-**9**). Multi-substitutions could also afforded the desired products with acceptable yields of 48%-59% (**16**-**18**). Additionally, five-membered heterocyclic ketones were examined and the corresponding amide products (**19** and **20**) were successfully obtained. On the other hand, substituted 2-aminopyridines were also examined. The substituent at 6-position of 2-aminopyridine had a negative effect to the reactivity (**24**). Delightfully, alkyl methyl ketones could equally be converted to the amide products selectively on the methyl ketone side with acceptable yields (**27**-**30**).

Scheme 2. **Amidation of ketones by C(O)-C bond cleavage**

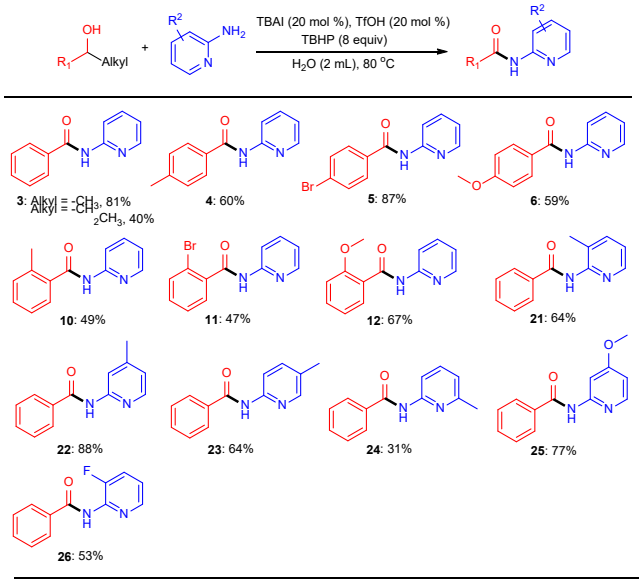


(Unless otherwise stated, Alkyl = -CH_3)

We hypothesized that this reaction system might be applicable to aryl alkyl carbinols.[8] thus, we studied the reactivity of some representative aryl alkyl carbinols. As shown in Scheme

3, the reactivity of aryl alkyl carbinols was broadly consistent with aryl alkyl ketones, but the substituents in ortho position of aryl alkyl carbinols had higher negative impact on reactivity than that in aryl alkyl ketones (**10**, **11**, and **12**).

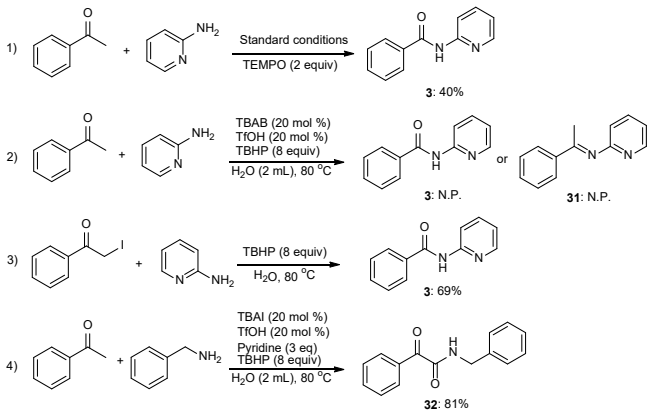
Scheme 3. Amidation of aryl alkyl carbinols by C(OH)-C bond cleavage



(Unless otherwise stated, Alkyl = -CH_3)

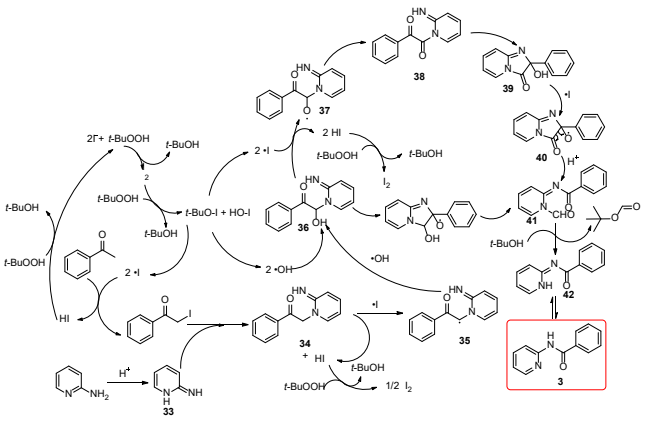
In order to elucidate the mechanism of this reaction, some control experiments were conducted. TEMPO, a well-known radical trapping reagent, was added into the standard reaction system, the yield of *N*-(pyridin-2-yl)benzamide (**3**) was decreased to 40%, this indicates that it's a free radical reaction (Scheme 4, entry 1). Whereas no amide product **3** nor imine **31** could be detected by replacing TBAI with TBAB, suggesting this reaction did not initiate from the formation of imine **31** (Scheme 4, entry 2). Then, amide **3** could be successfully synthesized from α-iodoacetophenone under oxidation of TBHP (Scheme 4, entry 3), suggesting the existence of α-iodoacetophenone as an intermediate (Scheme 4, entry 3). Furthermore, dicarbonyl compound **32** was synthesized with a yield of 81% using benzylamine as starting material when 3 equivalent of pyridine was added into standard conditions, indicating how ketone and amine were connected.

Scheme 4. Control experiments



Based on the above results, a plausible mechanism was proposed (Scheme 5). First, acetophenone would be transformed into α-iodoacetophenone, which subsequently reacts with **33** to form **34**.[13] Then, with the attendance of iodine radical, **34** was transferred to **35**, which encountered a series of reaction to form dicarbonyl compound **38**. And **39** was formed from **38**, through the reaction with iodine radical, **39** was transferred to **40**, which encountered C-C bond cleavage to form the aldehyde 41.[7,10,11] Finally, *tert*-butyl formate can be released from **36**, leading to the formation of amide **42**,[14] which undergoes isomerization to afford the desired amide **3**.

Scheme 5. Proposed mechanism



■ CONCLUSION

In summary, we have developed a mild and environmentally benign methodology to construct *N*-(pyridin-2-yl)amides via selective cleavage of C-C bond. A series of ketones or aryl alkyl carbinols could be efficiently converted to the corresponding amides with moderate to good yields. The construction of amides via C-C bond cleavage is still a developing field where new strategies are needed. The wide substrate scope, readily available starting materials and simple operation process demonstrated in our methodology may provide promising synthetic application potentials in the preparation of *N*-heterocyclic amides.

■ EXPERIMENTAL SECTION

General Information. All chemicals were of chemical pure grade quality and used without further purification, all organic solvents were analytical pure grade quality, water was ordinary domestic water and without further purification, *tert*-butyl hydroperoxide (TBHP) was 70% aqueous solution purchased from Sinopharm Chemical Reagent Co.,Ltd. Reactions were monitored by TLC (Merck silica gel 60 F_{254}), column chromatography was performed on silica gel 200~300 mesh. All ^{1}H NMR (300 MHz), ^{13}C{^{1}H} NMR (75 MHz) spectra were recorded on a Bruker Avance 300 spectrometer in $CDCl_3$ with tetramethylsilane as an internal standard and reported in parts per million (ppm, δ). High-resolution mass spectrums (HRMS) was measured on Finnigan MAT 95 spectrometer (Finnigan, Germany).

General Procedure for the Synthesis of *N*-heterocyclic Amides from Ketone. To a solution of ketone (0.6 mmol), 2-aminopyridine (1.2 mmol) and TBAI (0.12 mmol) in water in sealed tube, was added triflic acid (TfOH) (0.12 mmol) and TBHP (3.6 mmol). The solution was heated at 80 ℃ for 5-6 h

and monitored by thin layer chromatography. The reaction mixture was cooled to room temperature and added saturated sodium thiosulfate, then the inorganic layer was extracted and separated with dichloromethane for 3 times. The combined organic layer was dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (petroleum ether/ethyl acetate as the eluent, typically 100:5-100:10).

General Procedure for the Synthesis of *N*-heterocyclic Amides from Aryl Alkyl Carbinols. To a solution of aryl alkyl alcohol (0.6 mmol), 2-aminopyridine (1.2 mmol) and TBAI (0.12 mmol) in water in sealed tube, was added TfOH (0.12 mmol) and TBHP (4.8 mmol). The solution was heated at 80 ℃ for 5-6 h and monitored by thin layer chromatography. The reaction mixture was cooled to room temperature and added saturated sodium thiosulfate, then the inorganic layer was extracted and separated with dichloromethane for 3 times. The combined organic layer was dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (petroleum ether/ethyl acetate as the eluent, typically 100:5-100:10).

Spectral and Analytical Data of products. ^{1}H NMR and ^{13}C NMR data as well as HR-MS data are reported.

*N-(Pyridin-2-yl)benzamide (**3**)*. White solid; 99.8 mg, 84% yield; m.p. 85-87 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.81 (s, 1H), 8.42 (d, J = 8.4 Hz, 1H), 7.92 (d, J = 7.9 Hz, 3H), 7.67 (t, J = 7.3 Hz, 1H), 7.50 (t, J = 7.3 Hz, 1H), 7.41 (t, J = 7.5 Hz, 2H), 6.94 (t, J = 6.1 Hz, 1H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 166.4, 152.0, 147.7, 138.4, 134.6, 132.0, 128.6, 127.5, 119.7, 114.6; HR-MS (ESI-TOF) m/z: calcd for $C_{12}H_{11}N_2O$ $[M+H]^+$ 199.0866, found 199.0862.

*4-Methyl-N-(pyridin-2-yl)benzamide (**4**)*. White solid; 92.7 mg, 73% yield; m.p. 106-108 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.07 (s, 1H), 8.40 (dq, J = 8.4, 0.9 Hz, 1H), 8.19-8.16 (m, 1H), 7.83 (d, J = 7.9 Hz, 2H), 7.77-7.71 (m, 1H), 7.29-7.26 (m, 2H), 7.05-7.00 (m, 1H), 2.41 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 166.0, 151.9, 147.9, 142.9, 138.5, 131.5, 129.5, 127.4, 119.8, 114.4, 21.6; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{13}N_2O$ $[M+H]^+$ 213.1022, found 213.1018.

*4-Bromo-N-(pyridin-2-yl)benzamide (**5**)*. White solid; 137.8 mg, 83% yield; m.p. 132-135 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.96 (s, 1H), 8.36 (dt, J = 8.5, 1.0 Hz, 1H), 8.21-8.18 (m, 1H), 7.81-7.73 (m, 3H), 7.64-7.60 (m, 2H), 7.09-7.04 (m, 1H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 165.0, 151.5, 148.0, 138.7, 133.3, 132.2, 129.0, 127.2, 120.3, 114.4; HR-MS (ESI-TOF) m/z: calcd for $C_{12}H_{10}BrN_2O$ $[M+H]^+$ 276.9971, found 276.9969.

*4-Methoxy-N-(pyridin-2-yl)benzamide (**6**)*. Yellow solid; 80.8 mg, 59% yield; m.p. 89-91 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.99 (s, 1H), 8.37 (d, J = 8.4 Hz, 1H), 8.17 (d, J = 3.1 Hz, 1H), 7.89 (d, J = 8.9 Hz, 2H), 7.74-7.68 (m, 1H), 7.00 (t, J = 6 Hz, 1H), 6.94 (d, J = 8.8 Hz, 2H), 3.84 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 165.5, 162.8, 152.0, 147.9, 138.5, 129.4, 126.5, 119.7, 114.4, 114.0, 55.5; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{13}N_2O_2$ $[M+H]^+$ 229.0972, found 229.0968.

*4-Nitro-N-(pyridin-2-yl)benzamide (**7**)*. Yellow solid; 106.6 mg, 73%; m.p. 234-236 ºC; ^{1}H NMR (300 MHz, DMSO-d_6): δ 11.16 (s, 1H), 8.41 (d, J = 3.8 Hz, 1H), 8.33 (m, 2H), 8.24-8.18 (m, 3H), 7.87 (t, J = 7.6 Hz, 1H), 7.21 (t, J = 7.5 Hz, 1H); ^{13}C{^{1}H} NMR (75 MHz, DMSO-d_6): δ 165.1, 152.3, 149.7, 148.5, 140.3, 138.8, 130.0, 123.9, 120.7, 115.3; HR-MS (ESI-TOF) m/z: calcd for $C_{12}H_{10}N_3O_3$ $[M+H]^+$ 244.0717, found 244.0713.

*N-(Pyridin-2-yl)-4-(trifluoromethyl)benzamide (**8**)*. White solid; 126.4 mg, 79%; m.p. 136-138 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.80 (s, 1H), 8.38 (d, J = 8.4 Hz, 1H), 8.01 (d, J = 8.1 Hz, 2H), 7.95 (d, J = 3.5 Hz, 1H), 7.75-7.66 (m, 3H), 6.99 (t, J = 6.0 Hz, 1H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 165.1, 151.7, 147.8, 138.7, 137.9, 133.8 (q, J = 32.7 Hz), 128.1, 125.8 (q, J = 3.8 Hz), 123.65 (q, J = 272.8 Hz), 120.3, 114.8; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{10}F_3N_2O$ $[M+H]^+$ 267.0740, found 267.0743.

*4-Cyano-N-(pyridin-2-yl)benzamide (**9**)*. White solid; 96.4 mg, 72% yield; m.p. 202-204 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.20 (s, 1H), 8.36 (d, J = 8.4 Hz, 1H), 8.17 (d, J = 5.0 Hz, 1H), 8.03 (d, J = 7.95 Hz, 2H), 7.78 (m, 3H), 7.09 (t, J = 6.0 Hz, 1H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 164.2, 151.3, 148.0, 138.9, 138.3, 132.7, 128.1, 120.6, 118.0, 115.9, 114.7; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{10}N_3O$ $[M+H]^+$ 224.0818, found 213.0818.

*2-Methyl-N-(pyridin-2-yl)benzamide (**10**)*. White solid; 90.4%; 71% yield; m.p. 110-113 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 10.29 (s, 1H), 8.41 (d, J = 8.4 Hz, 1H), 7.71-7.65 (m, 1H), 7.49 (d, J = 7.3 Hz, 1H), 7.36 (td, J = 7.5, 1.4 Hz, 1H), 7.29-7.26 (m, 1H), 7.24-7.18 (m, 2H), 6.84-6.80 (m, 1H), 2.48 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 169.1, 152.1, 147.5, 138.5, 136.5, 136.2, 131.2, 130.4, 127.2, 126.0, 119.6, 114.5, 19.8; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{13}N_2O$ $[M+H]^+$ 213.1022, found 213.1028.

*2-Bromo-N-(pyridin-2-yl)benzamide (**11**)*. White solid; 79.7 mg, 48% yield; m.p. 160-162 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.70 (s, 1H), 8.38 (d, J = 8.3 Hz, 1H), 7.77-7.70 (m, 2H), 7.62-7.57 (m, 2H), 7.40-7.28 (m, 2H), 6.96-6.92 (m, 1H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 166.4, 151.6, 147.6, 138.7, 138.0, 133.7, 131.7, 129.5, 127.8, 120.2, 119.7, 114.7; HR-MS (ESI-TOF) m/z: calcd for $C_{12}H_{10}BrN_2O$ $[M+H]^+$ 276.9971, found 276.9971.

*2-Methoxy-N-(pyridin-2-yl)benzamide (**12**)*. White solid; 119.2 mg, 87% yield; m.p. 58-60 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 10.34 (s, 1H), 8.44 (d, J = 8.4 Hz, 1H), 8.33 (d, J = 4.6 Hz, 1H), 8.27 (dd, J = 7.9, 1.9 Hz, 1H), 7.73 (t, J = 7.8 Hz, 1H), 7.55-7.49 (m, 1H), 7.13 (t, J = 7.6 Hz, 1H), 7.06-7.03 (m, 2H), 7.09 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 163.8, 157.7, 152.2, 148.1, 138.4, 133.8, 132.7, 121.7, 121.6, 119.8, 115.0, 111.7, 56.4; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{13}N_2O_2$ $[M+H]^+$ 229.0972, found 229.0970.

*3-Methyl-N-(pyridin-2-yl)benzamide (**13**)*. White solid; 95.5 mg, 75% yield; m.p. 78-81 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.43 (s, 1H), 8.42 (dt, J = 8.5, 1.0 Hz, 1H), 8.08 (dt, J = 4.0, 1.0 Hz, 1H), 7.76-7.70 (m, 3H), 7.35-7.33 (m, 2H), 7.02-6.98 (m, 1H), 2.37 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 166.4, 151.9, 147.8, 138.6, 138.5, 134.4, 132.9, 128.7, 128.1, 124.5, 119.8, 114.4, 21.4; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{13}N_2O$ $[M+H]^+$ 213.1022, found 213.1025.

*3-Bromo-N-(pyridin-2-yl)benzamide (**14**)*. White solid; 121.4 mg, 73% yield; m.p. 109-111 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.29 (s, 1H), 8.36 (dt, J = 8.3, 1.0 Hz, 1H), 8.14-8.12 (m, 1H), 8.07 (t, J = 1.9 Hz, 1H), 7.84-7.80 (m, 1H), 7.78-7.72 (m, 1H), 7.68-7.64 (m, 1H), 7.33 (t, J = 7.9 Hz, 1H), 7.06-7.02 (m, 1H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 164.7, 151.6, 147.9, 138.7, 136.4, 135.2, 130.8, 130.4, 125.9, 123.1, 120.3, 114.6; HR-MS (ESI-TOF) m/z: calcd for $C_{12}H_{10}BrN_2O$ $[M+H]^+$ 276.9971, found 276.9970.

*3-Methoxy-N-(pyridin-2-yl)benzamide (**15**)*. White semisolid; 106.9 mg, 78% yield; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.03 (s, 1H), 8.39 (d, J = 8.8 Hz, 1H), 8.20 (d, J = 3.5 Hz, 1H), 7.75 (t, J = 7.9 Hz, 1H), 7.48-7.45 (m, 2H), 7.36 (t, J = 7.8 Hz, 1H), 7.10-7.02 (m, 2H), 3.84 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz,

Chloroform-*d*): δ 165.9, 160.0, 151.8, 147.9, 138.6, 135.9, 129.9, 120.0, 119.2, 118.7, 114.4, 112.5, 55.5; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{13}N_2O_2$ $[M+H]^+$ 229.0972, found 229.0975.

2,4-Dimethoxy-N-(pyridin-2-yl)benzamide ***(16)***. Yellow solid; 74.4 mg, 48% yield; m.p. 148-151 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 10.26 (s, 1H), 8.42 (d, J = 8.3 Hz, 1H), 8.32-8.23 (m, 2H), 7.72 (t, J = 7.9 Hz, 1H), 7.04-7.00 (m, 1H), 6.65 (d, J = 8.8 Hz, 1H), 6.53 (s, 1H), 4.05 (s, 3H), 3.87 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 164.2, 163.5, 159.0, 152.3, 148.0, 138.3, 134.3, 119.5, 114.8, 114.3, 105.8, 98.7, 56.3, 55.7; HR-MS (ESI-TOF) m/z: calcd for $C_{14}H_{15}N_2O_3$ $[M+H]^+$ 259.1077, found 259.1077.

2,4-Dichloro-N-(pyridin-2-yl)benzamide ***(17)***. White solid; 92.8 mg, 58% yield; m.p. 124-126 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 10.14 (s, 1H), 8.36 (d, J = 8.3 Hz, 1H), 7.77-7.68 (m, 2H), 7.58 (d, J = 8.2 Hz, 1H), 7.39 (d, J = 2.0 Hz, 1H), 7.32-7.27 (m, 1H), 6.97-6.93 (m, 1H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 164.6, 151.5, 147.3, 138.8, 137.1, 134.1, 132.1, 130.7, 130.2, 127.6, 120.2, 114.9; HR-MS (ESI-TOF) m/z: calcd for $C_{12}H_9Cl_2N_2O$ $[M+H]^+$ 267.0086, found 267.0086.

2,4-Dichloro-5-fluoro-N-(pyridin-2-yl)benzamide ***(18)***. White solid; 100.9 mg, 59% yield; m.p. 90-92 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.80 (s, 1H), 8.33 (d, J = 8.4 Hz, 1H), 7.92-7.90 (m, 1H), 7.80-7.74 (m, 1H), 7.52-7.45 (m, 2H), 7.05-6.99 (m, 1H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 163.2, 156.8 (d, J = 252.3 Hz), 151.3, 147.3, 139.9, 135.1 (d, J = 5.9 Hz), 132.0, 126.5, 124.5 (d, J = 19.0 Hz), 120.5, 117.7 (d, J = 24.0 Hz), 115.0; HR-MS (ESI-TOF) m/z: calcd for $C_{12}H_8Cl_2FN_2O$ $[M+H]^+$ 284.9992, found 284.9987.

N-(Pyridin-2-yl)thiophene-2-carboxamide ***(19)***. White soild; 91.9 mg, 75% yield; m.p. 118-120 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.11 (s, 1H), 8.32 (d, J = 8.4 Hz, 1H), 8.21 (dd, J = 5.0, 1.9 Hz, 1H), 7.77-7.64 (m, 2H), 7.55 (d, J = 4.7 Hz, 1H), 7.09 (t, J = 4.5 Hz, 1H), 7.05-7.01 (m, 1H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 160.3, 151.5, 147.8, 139.1, 138.6, 131.7, 129.1, 128.0, 120.0, 114.6; HR-MS (ESI-TOF) m/z: calcd for $C_{10}H_9N_2OS$ $[M+H]^+$ 205.0430, found 205.0426.

N-(Pyridin-2-yl)furan-2-carboxamide ***(20)***. White solid; 61.0 mg, 54% yield; m.p. 81-84 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.91 (s, 1H), 8.34-8.31 (m, 2H), 7.77-7.70 (m, 1H), 7.52 (s, 1H), 7.28 (m, 1H), 7.09-7.05 (m, 1H), 6.58-6.55 (m, 1H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 156.3, 151.1, 148.1, 147.4, 144.8, 138.5, 120.0, 116.0, 114.3, 112.7; HR-MS (ESI-TOF) m/z: calcd for $C_{10}H_9N_2O_2$ $[M+H]^+$ 189.0659, found 189.0657.

N-(3-Methylpyridin-2-yl)benzamide ***(21)***. Yellow semisolid; 99.3 mg, 78% yield; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.71 (s, 1H), 8.14-8.12 (m, 1H), 7.92 (d, J = 7.3 Hz, 2H), 7.55 (d, J = 7.6 Hz, 1H), 7.48 (t, J = 7.3 Hz, 1H), 7.40-7.35 (m, 2H), 7.09-7.05 (m, 1H), 2.28 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 166.4, 150.2, 145.3, 140.1, 134.1, 132.0, 129.7, 128.5, 127.8, 121.8, 18.4; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{13}N_2O$ $[M+H]^+$ 213.1022, found 213.1024.

N-(4-Methylpyridin-2-yl)benzamide ***(22)***. Yellow solid; 104.4 mg, 82% yield; m.p. 108-110 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.94 (s, 1H), 8.25 (s, 1H), 8.04 (d, J = 5.1 Hz, 1H), 7.94-7.91 (m, 2H), 7.59-7.53 (m, 1H), 7.50-7.45 (m, 2H), 6.87 (d, J = 4.9 Hz, 1H), 2.40 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 166.0, 151.8, 150.1, 147.6, 134.6, 132.3, 128.9, 127.4, 121.2, 114.9, 21.5; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{13}N_2O$ $[M+H]^+$ 213.1022, found 213.1019.

N-(5-Methylpyridin-2-yl)benzamide ***(23)***. Yellow solid; 86.6 mg, 68% yield; m.p. 89-92 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.88 (s, 1H), 8.29 (d, J = 8.5 Hz, 1H), 8.00 (s, 1H), 7.91 (d, J = 7.3 Hz, 2H), 7.57-7.52 (m, 2H), 7.49-7.45 (m, 2H), 2.28 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 166.1, 149.7, 147.8, 139.1, 134.6, 132.1, 129.2, 128.7, 127.4, 113.9, 17.9; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{13}N_2O$ $[M+H]^+$ 213.1022, found 213.1018.

N-(6-Methylpyridin-2-yl)benzamide ***(24)***. Yellow solid; 29.3 mg, 23% yield; m.p. 108-110 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.70 (s, 1H), 8.19 (d, J = 8.3 Hz, 1H), 7.93-7.90 (m, 2H), 7.64 (t, J = 7.9 Hz, 1H), 7.57-7.52 (m, 1H), 7.49-7.44 (m, 2H), 6.91 (d, J = 7.4 Hz, 1H), 2.42 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 165.8, 157.0, 150.9, 138.9, 134.4, 132.3, 128.9, 127.3, 119.6, 111.1, 24.1; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{13}N_2O$ $[M+H]^+$ 213.1022, found 213.1020.

N-(4-Methoxypyridin-2-yl)benzamide ***(25)***. White solid; 87.7 mg, 64% yield; m.p. 60-63 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.90 (s, 1H), 8.08 (t, J = 3 Hz, 1H), 7.93-7.90 (m, 2H), 7.77-7.72 (m, 1H), 7.56-7.51 (m, 1H), 7.47-7.42 (m, 2H), 6.53-6.51 (m, 1H), 3.88 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 167.6, 166.7, 153.7, 148.4, 134.6, 132.2, 128.8, 127.6, 107.9, 99.1, 55.5; HR-MS (ESI-TOF) m/z: calcd for $C_{13}H_{13}N_2O_2$ $[M+H]^+$ 229.0972, found 229.0972.

N-(3-Fluoropyridin-2-yl)benzamide ***(26)***. Yellow solid; 54.5 mg, 42% yield; m.p. 97-99 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.92 (s, 1H), 8.17-8.15 (m, 1H), 7.93 (d, J = 7.5 Hz, 2H), 7.56-7.41 (m, 4H), 7.18-7.12 (m, 1H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 165.6, 151.9 (d, J = 260.4 Hz), 143.7 (d, J = 5.5 Hz), 140.4 (d, J = 12.6 Hz), 133.6, 132.5, 128.8, 127.8, 124.8 (d, J = 18.1 Hz), 122.3 (d, J = 2.7 Hz); HR-MS (ESI-TOF) m/z: calcd for $C_{12}H_{10}FN_2O$ $[M+H]^+$ 217.0772, found 217.0773.

N-(Pyridin-2-yl)acetamide ***(27)***. Yellow solid; 27.8 mg, 32% yield; m.p. 57-59 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 10.01 (s, 1H), 8.29-8.26 (m, 2H), 7.72 (t, J = 9 Hz, 1H), 7.05 (t, J = 6 Hz, 1H), 2.21 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 169.3, 152.1, 147.3, 138.5, 119.6, 114.7, 24.5; HR-MS (ESI-TOF) m/z: calcd for $C_7H_9N_2O$ $[M+H]^+$ 137.0709, found 137.0710.

N-(Pyridin-2-yl)isobutyramide ***(28)***. White solid; 44.3 mg, 45% yield; m.p. 54-56 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.27-8.22 (m, 2H), 8.10 (s, 1H), 7.70 (t, J = 7.7 Hz, 1H), 7.05-7.01 (m, 1H), 2.55 (p, J = 6.9 Hz, 1H), 1.27 (d, J = 4.5 Hz, 6H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 175.8, 151.7, 147.8, 138.6, 119.8, 114.2, 36.8, 19.6; HR-MS (ESI-TOF) m/z: calcd for $C_9H_{13}N_2O$ $[M+H]^+$ 165.1022, found 165.1019.

N-(Pyridin-2-yl)cyclohexanecarboxamide ***(29)***. White solid; 41.7 mg, 34% yield; m.p. 85-87 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.35 (s, 1H), 8.26-8.22 (m, 2H), 7.69 (t, J = 7.8 Hz, 1H), 7.02 (t, J = 6.1 Hz, 1H), 2.25 (t, J = 11.9 Hz, 1H), 1.95 (d, J = 12.5 Hz, 2H), 1.85-1.80 (m, 2H), 1.53 (q, J = 12.1 Hz, 2H), 1.35-1.20 (m, 4H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 175.1, 151.8, 147.7, 138.6, 119.7, 114.3, 46.5, 29.6, 25.74, 25.70; HR-MS (ESI-TOF) m/z: calcd for $C_{12}H_{17}N_2O$ $[M+H]^+$ 205.1335, found 205.1335.

N-(Pyridin-2-yl)cyclopentanecarboxamide ***(30)***. White solid; 44.5 mg, 39% yield; m.p. 86-88 ºC; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.26-8.21 (m, 2H), 8.09 (s, 1H), 7.69 (t, J = 7.6 Hz, 1H), 7.02 (t, J = 7.5 Hz, 1H), 2.72 (p, J = 8.0 Hz, 1H), 1.97-1.86 (m, 4H), 1.84-1.72 (m, 2H), 1.68-1.58 (m, 2H); ^{13}C{^{1}H} NMR (75 MHz, Chloroform-*d*): δ 175.1, 151.8, 147.8, 138.5, 119.7, 114.1, 47.1, 30.5, 26.1; HR-MS (ESI-TOF) m/z: calcd for $C_{11}H_{15}N_2O$ $[M+H]^+$ 191.1179, found 191.1178.

*N-(Pyridin-2-yl)benzamide (**3**)* (made from aryl alkyl carbinol). White solid; 96.3 mg, 81% yield; m.p. 85-87 °C; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.02 (s, 1H), 8.40 (d, J = 8.4 Hz, 1H), 8.18 (d, J = 4.9 Hz, 1H), 7.92 (d, J = 8.2 Hz, 2H), 7.74 (t, J = 7.7 Hz, 1H), 7.54 (t, J = 6.5 Hz, 1H), 7.47 (t, J = 7.4 Hz, 2H), 7.04 (t, J = 6.2 Hz, 1H).

*4-Methyl-N-(pyridin-2-yl)benzamide (**4**)* (made from aryl alkyl carbinol). White solid; 76.4 mg, 60% yield; m.p. 106-108 °C; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.26 (s, 1H), 8.41 (d, J = 8.4 Hz, 1H), 8.13 (d, J = 5.0 Hz, 1H), 7.83 (d, J = 7.7 Hz, 2H), 7.73 (t, J = 8.1 Hz, 1H), 7.25 (d, J = 7.9 Hz, 2H), 7.01 (t, J = 6.2 Hz, 1H), 2.40 (s, 3H).

*4-Bromo-N-(pyridin-2-yl)benzamide (**5**)* (made from aryl alkyl carbinol). White solid; 144.7 mg, 87% yield; m.p. 132-135 °C; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.60 (s, 1H), 8.29 (d, J = 8.4 Hz, 1H), 7.94 (s, 1H), 7.72-7.61 (m, 3H), 7.47 (d, J = 6.5 Hz, 2H), 6.92 (t, J = 6.0 Hz, 1H).

*4-Methoxy-N-(pyridin-2-yl)benzamide (**6**)* (made from aryl alkyl carbinol). Yellow solid; 80.8 mg, 59% yield; m.p. 89-91 °C; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.15 (s, 1H), 8.39 (d, J = 8.4 Hz, 1H), 8.18-8.16 (m, 1H), 7.93-7.90 (m, 2H), 7.73 (t, J = 7.9 Hz, 1H), 7.02 (t, J = 6 Hz, 1H), 6.95 (d, J = 9.3 Hz, 2H), 3.86 (s, 3H).

*2-Methyl-N-(pyridin-2-yl)benzamide (**10**)* (made from aryl alkyl carbinol). White solid; 62.4 mg, 49% yield; m.p. 110-113 °C; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 10.29 (s, 1H), 8.41 (d, J = 8.4 Hz, 1H), 7.71-7.65 (m, 1H), 7.49 (d, J = 7.3 Hz, 1H), 7.36 (td, J = 7.5, 1.4 Hz, 1H), 7.29-7.26 (m, 1H), 7.24-7.18 (m, 2H), 6.84-6.80 (m, 1H), 2.48 (s, 3H)

*2-Bromo-N-(pyridin-2-yl)benzamide (**11**)* (made from aryl alkyl carbinol). White solid; 78.1 mg, 47% yield; m.p. 160-162 °C; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.70 (s, 1H), 8.38 (d, J = 8.3 Hz, 1H), 7.77-7.70 (m, 2H), 7.62-7.57 (m, 2H), 7.40-7.28 (m, 2H), 6.96-6.92 (m, 1H);

*2-Methoxy-N-(pyridin-2-yl)benzamide (**12**)* (made from aryl alkyl carbinol). White solid; 91.8 mg, 67% yield; m.p. 58-60 °C; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 10.29 (s, 1H), 8.34 (d, J = 9.1 Hz, 1H), 8.22-8.20 (m, 1H), 8.17 (dd, J = 7.8, 1.9 Hz, 1H), 7.63 (t, J = 7.4 Hz, 1H), 7.40 (t, J = 8.1 Hz, 1H), 7.03 (t, J = 6.0 Hz, 1H), 6.96-6.91 (m, 2H), 3.96 (s, 3H).

*N-(3-Methylpyridin-2-yl)benzamide (**21**)* (made from aryl alkyl carbinol). Yellow semisolid; 81.5 mg, 64% yield; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.60 (s, 1H), 8.15 (d, J = 3.5 Hz, 1H), 7.92 (d, J = 6.8 Hz, 2H), 7.57 (d, J = 7.5 Hz, 1H), 7.49 (d, J = 7.5 Hz, 1H), 7.40 (t, J = 7.5 Hz, 2H), 7.11-7.17 (m, 1H), 2.29 (s, 3H).

*N-(4-Methylpyridin-2-yl)benzamide (**22**)* (made from aryl alkyl carbinol). Yellow solid; 112.1 mg, 88% yield; m.p. 108-110 °C; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.55 (s, 1H), 8.17 (s, 1H), 7.83 (d, J = 6.9 Hz, 2H), 7.76 (d, J = 4.9 Hz, 1H), 7.44 (t, J = 7.3 Hz, 1H), 7.34 (t, J = 7.6 Hz, 2H), 6.71 (d, J = 5.1 Hz, 1H), 2.27 (s, 3H).

*N-(5-Methylpyridin-2-yl)benzamide (**23**)* (made from aryl alkyl carbinol). Yellow solid; 81.5 mg, 64% yield; m.p. 89-92 °C; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.88 (s, 1H), 8.29 (d, J = 8.5 Hz, 1H), 8.00 (s, 1H), 7.91 (d, J = 7.3 Hz, 2H), 7.57-7.52 (m, 2H), 7.49-7.45 (m, 2H), 2.28 (s, 3H)

*N-(6-Methylpyridin-2-yl)benzamide (**24**)* (made from aryl alkyl carbinol). Yellow solid; 39.5 mg, 31% yield; m.p. 108-110 °C; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.70 (s, 1H), 8.19 (d, J = 8.3 Hz, 1H), 7.93-7.90 (m, 2H), 7.64 (t, J = 7.9 Hz, 1H), 7.57-7.52 (m, 1H), 7.49-7.44 (m, 2H), 6.91 (d, J = 7.4 Hz, 1H), 2.42 (s, 3H)

*N-(4-Methoxypyridin-2-yl)benzamide (**25**)* (made from aryl alkyl carbinol). White solid; 105.5 mg, 77% yield; m.p. 60-63 °C; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 9.88 (s, 1H), 7.98 (s, 1H), 7.82 (d, J = 7.3 Hz, 2H), 7.60 (d, J = 5.9 Hz, 1H), 7.43 (t, J = 7.4 Hz, 1H), 7.34 (t, J = 7.5 Hz, 2H), 6.41 (d, J = 4.4 Hz, 1H), 3.78 (s, 3H).

*N-(3-Fluoropyridin-2-yl)benzamide (**26**)* (made from aryl alkyl carbinol). Yellow solid; 68.8 mg, 53% yield; m.p. 97-99 °C; ^{1}H NMR (300 MHz, Chloroform-*d*): δ 8.92 (s, 1H), 8.17-8.15 (m, 1H), 7.93 (d, J = 7.5 Hz, 2H), 7.56-7.41 (m, 4H), 7.18-7.12 (m, 1H)

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website.

^{1}H and ^{13}C{^{1}H} NMR spectra for all products (PDF)

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Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) (a) Breneman, C. M.; Greenberg, A.; Liebman, J. F. *The Amide Linkage: Structural Significance in Chemistry, Biochemistry, and Materials Science*; John Wiley & Sons, New York, 2002. (b) Ghose, A. K.; Viswanadhan, V. N.; Wendoloski, J. J. *J. Comb. Chem.* **1999**, *1*, 55. (c) Humphrey, J. M.; Chamberlin, A. R. *Chem. Rev.* **1997**, *97*, 2243. (d) Zabicky, J. *Chemistry of Amides*; Wiley-Inter-science, New York, 1970.

(2) Liu, Z. J.; Zhang, J.; Chen, S. L.; Shi, E. B.; Xu, Y.; Wan, X. B. *Angew. Chem. Int. Ed.* **2012**, *51*, 3231.

(3) (a) Tillack, A.; Rudloff, I.; Beller, M. *Eur. J. Org. Chem.* **2001**, *3*, 523. (b) Gowda, R. R.; Chakraborty, D. *Eur. J. Org. Chem.* **2011**, *12*, 2226. (c) Gao, J.; Wang, G. W. *J. Org. Chem.* **2008**, *73*, 2955. (d) Papadopoulos, G. N.; Kokotos, C. G. *J. Org. Chem.* **2016**, *81*, 7023. (e) Rostamnia, S.; Doustkhah, E.; Golchin-Hosseini, H.; Zeynizadeh, B.; Xin, H. C.; Luque, R. *Catal. Sci. Technol.* **2016**, *6*, 4124. (f) Soule J. F.; Miyamura, H.; Kobayashi, S. *Chem. Asian J.* **2013**, *8*, 2614. (g) Yoo, W. J.; Li, C. J. *J. Am. Chem. Soc.* **2006**, *128*, 13064. (h) Seo, S. Y.; Marks, T. J. *Org. Lett.* **2008**, *10*, 317.

(4) Ghosh, S.; Jana, C. K. *Org. Lett.* **2016**, *18*, 5788.

(5) (a) Yang, S.; Yan, H.; Ren, X.; Shi, X.; Li, J.; Wang Y.; Huang, G. *Tetrahedron* **2013**, *69*, 6431. (b) Patel, O. P. S.; Anand, D.; Maurya, R. K.; Yadav, P. P. *Green Chem.* **2015**, *17*, 3728. (c) Sankari Devi, E.; Alanthadka, A.; Tamilselvi, A.; Nagarajan, S.; Sridharan, V.; Maheswari, C. U. *Org. Biomol. Chem.* **2016**, *14*, 8228.

(6) (a) Wang, Y.; Yamaguchi, K.; Mizuno, N. *Angew. Chem. Int. Ed.* **2012**, *51*, 7250. (b) Vanjari, R.; Guntreddi, T.; Singh, K. N. *Org. Lett.* **2013**, *15*, 4908. (c) Feng, J. B.; Wei, D.; Gong, J. L.; Qi, X.; Wu, X. F. *Tetrahedron Lett.* **2014**, *55*, 5082. (d) Du, B.; Sun, P. *Sci. China: Chem.* **2014**, *57*, 1176. (e) Kim, Y. R.; Cho, S.; Lee, P. H. *Org. Lett.* **2014**, *16*, 3098. (f) Wang, T.; Yuan, L.; Zhao, Z. G.; Shao, A. L.; Gao, M.; Huang, Y. F.; Xiong, F.; Zhang H. L.; Zhao, J. F. *Green Chem.* **2015**, *17*, 2741.

(7) Huang, X. Q.; Li, X. Y.; Zou, M. C.; Song, S.; Tang, C. H.; Yuan, Y. Z.; Jiao, N. J. *Am. Chem. Soc.* **2014**, *136*, 14858.

(8) (a) Cao, L. P.; Ding, J. Y.; Gao, M.; Wang, Z. H.; Li, J.; Wu, A. X. *Org. Lett.* **2009**, *11*, 3810. (b) Sharif, M.; Chen, J.; Langer, P.; Beller, M.; Wu, X. F. *Org. Biomol. Chem.* **2014**, *12*, 6359.

(9) (a) Zhu, C. Y.; Wei, W.; Du, P.; Wan, X. B. *Tetrahedron* **2014**, *70*, 9615. (b) Rajendar, K.; Kant, R.; Narender, T. *Adv. Synth. Catal.* **2013**, *355*, 3591. (c) Angeles, N. A.; Villavicencio, F.; Guadarrama, C.; Corona, D.; Cuevas-Yañez, E. *J. Braz. Chem. Soc.* **2010**, *21*, 905.

(10) Tang, C.; Jiao, N. *Angew. Chem. Int. Ed.* **2014**, *53*, 6528.

(11) Subramanian, P.; Indu, S.; Kaliappan, K. P. *Org. Lett.* **2014**, *16*, 6212.

(12) Ragupathi, A.; Sagadevan, A.; Lin, C. C.; Hwu, J. R.; Hwang, K. C. *Chem. Commun.* **2016**, *52*, 11756.

(13) Luo, W. K.; Shi, X.; Zhou, W.; Yang, L. *Org. Lett.* **2016**, *18*, 2036.

(14) (a) Effenberger, F.; Keill, M.; Bessey, u. E. *Chem. Ber.* **1980**, *113*, 2110. (b) Suchy, M.; Elmehriki, A. A. H.; Hudson, R. H. E. *Org. Lett.* **2011**, *13*, 3952.