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Ruthenium-Catalyzed Direct and Selective C–H Cyanation of *N*-(Hetero)aryl-7-azaindoles

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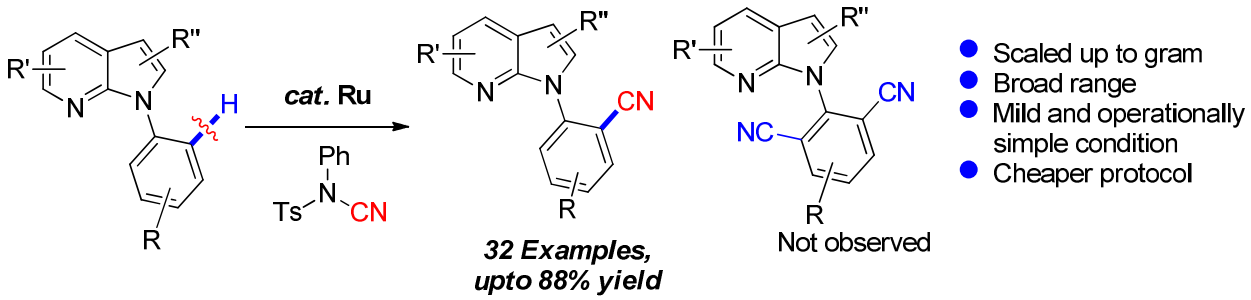
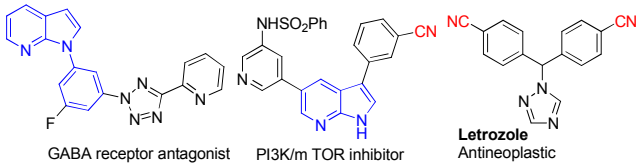


Abstract: An efficient, highly regioselective and scalable ruthenium-catalyzed ortho aryl C–H mono cyanation of *N*-aryl-7-azaindoles to form *N*-(2-cyanoaryl)-7-azaindoles has been developed through N-directed ortho C–H activation using *N*-cyano-*N*-phenyl-*p*-toluene sulfonamide as cyanating reagent in presence of AgOTf and NaOAc in DCE. A range of substrates has furnished cyanated azaindoles in good to excellent yields under the simple reaction conditions. Involvement of C–H metalation has been supported by kinetic study. This methodology provides an easy access to a class of pharmaceutically significant molecules and their precursors.

INTRODUCTION

Azaindole is a unique heterocyclic moiety present in various biologically active molecules,[1] novel synthetic materials,[2] and has been found in various marketed drugs[3] including vemurafenib. On the other hand, the nitrile group is of great research interest in the area of organic and medicinal chemistry and plays an important role in organic synthesis due to its easy conversion into many other important functional groups like amine, aldehyde, amide, ester and various heterocyclic scaffolds.[4] A large number of bioactive natural products and drug molecules such as letrozole, fadrozole and citalopram also feature cyano group(s) (Figure 1).[5]

Figure 1. Bioactive molecules

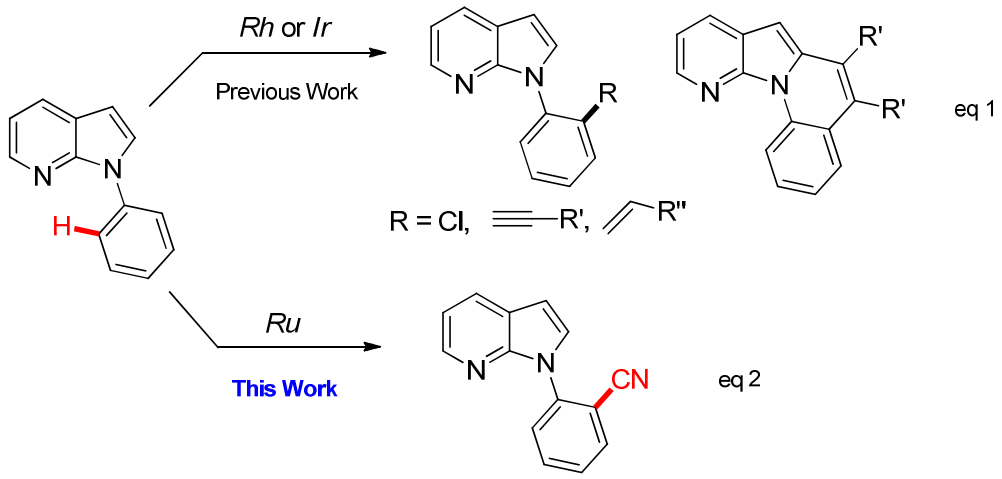


Over the past decades, direct C–H/C–X functionalization has been considered as a practical alternate catalytic approach to conventional cyanation reactions such as Rosenmund-von Braun[6] reaction and diazotization followed by Sandmeyer reaction,[7] which uses an excess amount of hazardous cyanating reagents. In this context, various methods employing transition metal catalysis have been developed.[8] Several organo-cyanating reagent including cyanohydrin, DMF-NH_3, PhTsNCN, MeCN and $MeNO_2$ have been reported for cyanation reaction.[9] During the last few years, transition metals, mainly rhodium and cobalt catalyzed chelating groups such as oxime,[10] pyridine,[11] pyrimidine,[12] amide,[13] azo,[14] nitrileoxide[15] and phosphonate[16] -assisted catalytic C–H activation has emerged as a powerful approach for C–H cyanation using NCTS. Though

ruthenium catalysis[17] is well known for C–H bond functionalization, directing group assisted C–H cyanation employing ruthenium remains less explored.[13a] In spite of the known importance of the azaindole scaffold in medicinal chemistry and in material chemistry, only a limited number of metal catalyzed functional group incorporations have been achieved. For example, palladium-catalyzed amination, C2-C3 arylation, C3-alkenylation and selective C6 arylation of azaindoles have been reported.[18]

Recently, 7-azaindole directed catalytic C–H chlorination using DCE as a chloride source, oxidative annulation with alkyne, C–C coupling with vinyl acetate and alkynylation have been reported using expensive rhodium or iridium catalysts (Scheme 1, eq 1).[19] However, to date, azaindole directed catalytic and selective C–H cyanation using transition metals has not been reported. Thus, a catalytic approach for the direct and selective C–H cyanation of azaindole appeared highly desirable. In continuation of our research interest in metal catalyzed C–H bond functionalization,[20] herein we wish to reveal N-directed selective C–H cyanation reaction of *N*-aryl-7-azaindole using the relatively less expensive $[RuCl_2(p\text{-cymene})]_2$ catalyst and the easily accessible, *N*-cyano-*N*-phenyl-*p*-toluene sulfonamide (NCTS) **2**, as the cyanating reagent in presence of additives AgOTf and NaOAc in DCE (Scheme 1, eq 2).

Scheme 1. 7-azaindole directed C–H bond functionalization

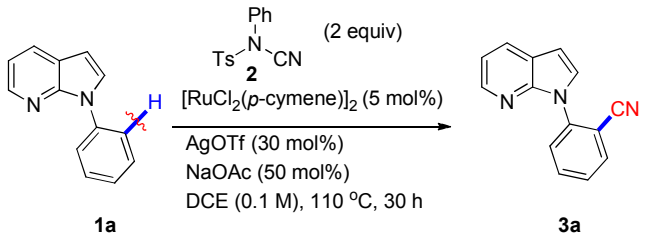


RESULTS AND DISCUSSION

We initiated our study by performing cyanation reaction of arenes using *N*-phenyl-7-azaindole **1a** as a substrate under different conditions. To our delight, screening of different nitrile sources such as benzyl cyanide, isocyanide and *N*-cyano succinimide (see SI, table S1) revealed NCTS to be an efficient cyanating reagent to provide ortho cyanated *N*-phenyl-7-azaindole **3a** in 84% yield at 110 °C (Table 1, entry 1) in presence of $[RuCl_2(p\text{-cymene})]_2$ (5 mol%) as catalyst and AgOTf (30 mol%) and NaOAc (50 mol%) as co-catalysts in DCE without the formation of any C2 or C3 cyanation product. The use of other catalytic conditions for cyanation did not give satisfactory results (see SI, table S1). No cyanation reaction occurred in absence of catalysts and silver salt (Table 1, entries 14 and 15). Screening of different solvents (chlorobenzene, toluene and 1,4-dioxane) other than DCE resulted in poor yield of the cyanated product (Table 1, entries 4 and 5). On the other hand, replacement of NaOAc with other additives (CsOAc, $Cu(OAc)_2$ and AgOAc) (see SI, table 1) proved less effective or not effective at all. Decreasing the amount of AgOTf (10 mol%) and NaOAc (30 mol%) did not improve the

yield, while increasing the proportion of NaOAc (100 mol%) also furnished less product (Table 1, entries 8, 10 and 11).

Table 1. Optimization of condition for cyanation of *N*-aryl-7-azaindoles[a]



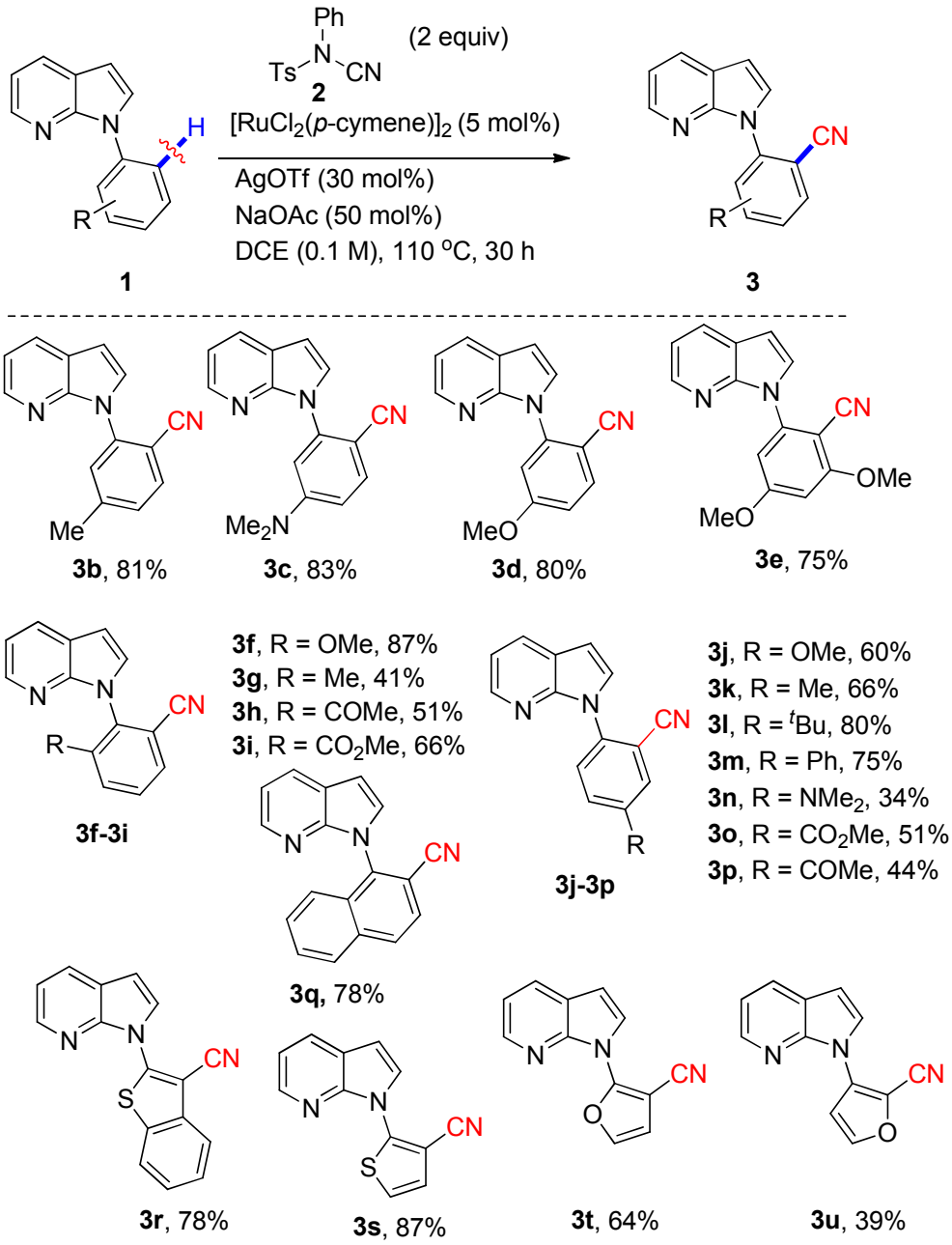
entry	deviation from standard condition	Yield (%)[b] of **3a**
1	None	84
2	$RuCl_3$ (10 mol%) instead of [$RuCl_2$(*p*-cymene)]$_2$	nr
3	[Cp(*p*-cymene)Ru (II)]PF_6 (5 mol%) instead of [$RuCl_2$(*p*-cymene)]$_2$ (5 mol%)	nr
4	Toluene or 1,4-dioxane instead of DCE	trace
5	Chlorobenzene instead of DCE	32
6	3 mol% of [$RuCl_2$(*p*-cymene)]$_2$	67
7	50 mol% of AgOTf	63
8	10 mol% of AgOTf	64
9	$AgSbF_6$ instead of AgOTf	82
10	30 mol% of NaOAc	78
11	100 mol% of NaOAc	68
12	80 °C	52
13	Omitting NaOAc	61
14	Omitting AgOTf	nr
15	Omitting [$RuCl_2$(*p* cymene)]$_2$/AgOTf/NaOAc	nr

[a] Reaction conditions: unless otherwise mentioned all reactions were performed with a mixture of **1a** (0.2 mmol), **2** (2 equiv), [$RuCl_2$(*p*-cymene)]$_2$ (5 mol%), AgOTf (30 mol%) and NaOAc (50 mol%) in DCE (0.1 M) at 110 °C, under N_2 for 30 h. [b] Isolated yield. nr: no reaction.

Lowering the catalyst loading (Ru(II), 3 mol%) furnished the product to the extent of 67% only (Table 1, entry 6). Although use of $AgSbF_6$ (30 mol%) gave the product in 82% yield (Table 1, entry 9), the relatively less hygroscopic AgOTf (30 mol%) was considered more economical. Decrease in the reaction temperature to 80 °C lowered the yield (Table 1, entry 12). Although, the reaction proceeds well in absence of NaOAc (Table 1, entry 13) which is common in ruthenium catalysis,[17] the presence of NaOAc is essential to obtain the cyanated product in excellent yield, it might be due the formation of relatively more active carboxylate complex of ruthenium.

Employing the optimized catalytic conditions, array of *N*-aryl-7-azaindoles were subjected to cyanation to evaluate the scope of the reaction (Scheme 2). The results showed that various substituents at different positions were tolerated and no bis-cyanated product resulted. Electron-donating groups on arenes undergoing C–H functionalization are generally favourable for this cyanation reaction, except for the 2-substituted aryl substrate **3g**. Gratifyingly, meta substituted substrates **1b-1e** yielded the cyanated products **3b-3d** in excellent yields and excellent regioselectivity, the less sterically hindered site of the substrates being favoured for functionalization. In case of para substituted substrates the desired cyanated products **3j-3p** were obtained in better yields when the group was electron-donating (except **3n**). Pleasingly, heteroarenes **1r-1t** were also efficiently cyanated using the optimized catalytic system and provided the corresponding cyanated benzothiophene **3r**, thiophene **3s**, and furans **3t** in good yields, except **3u** which was obtained in moderate yield.

Scheme 2. Scope of cyanation of *N*-aryl-7-azaindoles[a]

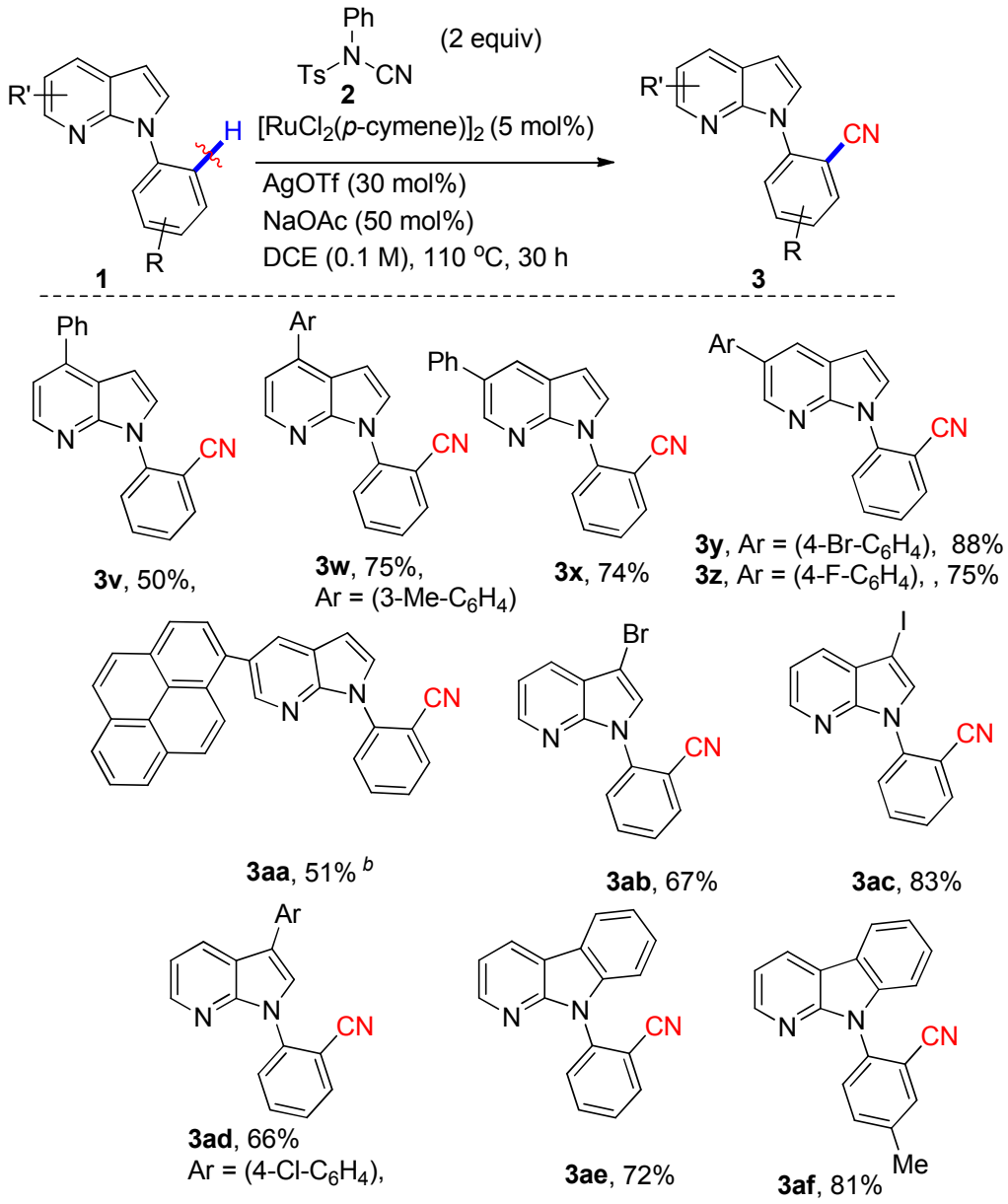


[a] Reaction condition: Mixture of **1** (0.2 mmol), **2** (2 equiv), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), AgOTf (30 mol%) and NaOAc (50 mol%) in DCE (0.1 M) at 110 °C, under N_2 for 30 h. Yields refer to isolated products.

In general, substrates bearing electron-withdrawing groups provided the cyanation products in moderate yields. Single-crystal X-ray study of **3q** confirmed the structure of the cyanated product (SI).

Next, we turned our attention to substituted 7-azaindoles. Using the optimized conditions, substrates **1v-1af** were successfully converted to cyanated products **3v-3af** in good to excellent yields (Scheme 3). Substrates possessing aryl groups reacted smoothly to afford the products **3v-3aa** and **3ad** in good yields. It should be noted that a halide such as iodo or bromo at 3 position of 7-azaindole ring exerted only a minor effect on the yields of **3ab** and **3ac**. This finding encouraged us to extend this methodology and explore whether *N*-aryl-α-carbolines **1ae-1af** could also be cyanated. Substrates **1ae-1af** indeed participated in the reaction and afforded the desired cyanated *N*-aryl-α-carboline products **3ae-3af** in 72% and 81% yields, respectively (Scheme 3).

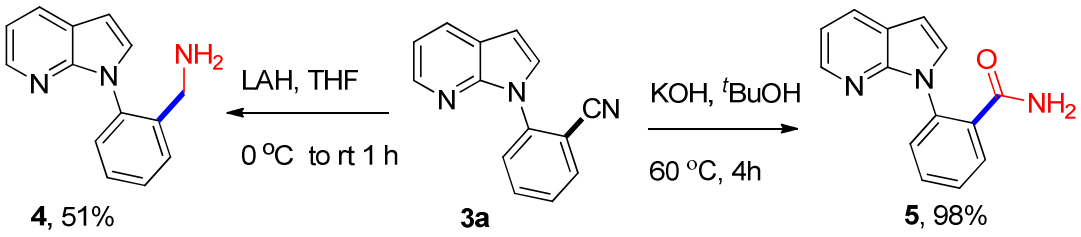
Scheme 3. Scope of cyanation of *N*-aryl-7-azaindoles[a]



[a] Reaction condition: mixture of **1** (0.2 mmol), **2** (2 equiv), $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), AgOTf (30 mol%) and NaOAc (50 mol%) in DCE (0.1 M) at 110 °C, under N_2 for 30 h. Yields refer to isolated products.

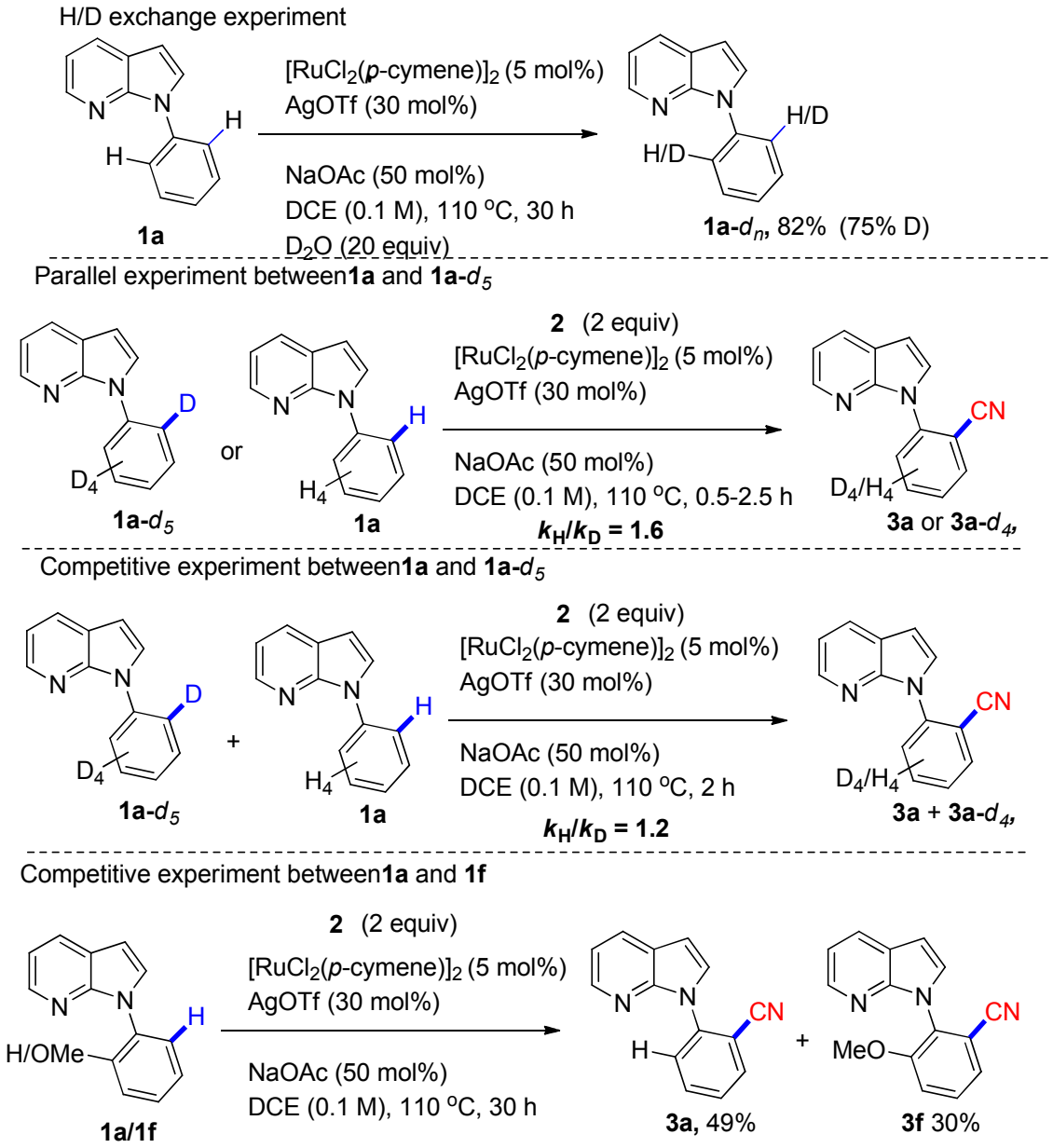
To illustrate the scalability of the cyanation, we conducted a gram scale experiment using the substrate **1a** (1 g) and obtained the cyanated product **3a** (0.79 g) in 70% yield. The nitrile bearing *N*-aryl-7-azaindole **3a** underwent smooth synthetic transformations to provide amine **4** and amide **5** in good yields (Scheme 4), underlining the utility of the cyanide product as synthetic intermediate.

Scheme 4. Synthetic transformations of cyanated *N*-phenyl-7-azaindole



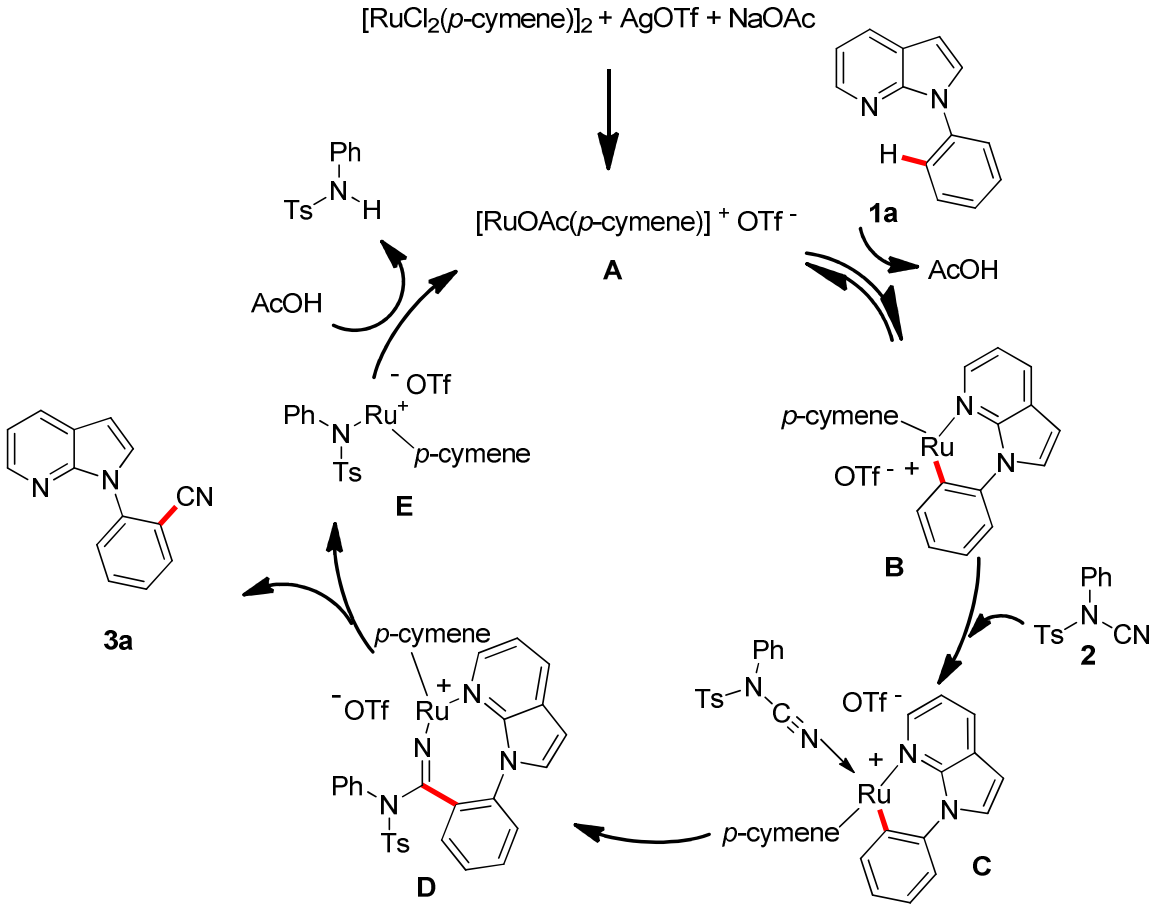
To prove the possible mechanism of the cyanation reaction, several experiments were conducted (Scheme 5). Rapid ortho H–D exchange of **1a** in presence of excess amount of D_2O clearly suggested that reversible cleavage of C–H bond may be involved in the C–H cyanation. Low kinetic isotope effect (KIE) values of 1.6 and 1.2 were found in both parallel and competitive experiment between **1a** and **1a**-d_5, implying that the cleavage of the ortho C–H bond may not be the rate–limiting step in the mechanism. No significant substituent effect was observed in competitive experiment of the substrate **1a** and **1f**.

Scheme 5. Mechanistic experiments



Based on the mechanistic studies as shown in scheme 5 and previous report,[13a] it appears that the reaction is involved in the formation of monomeric active cationic ruthenium complex **A** from $[RuCl_2(p\text{-cymene})]_2$ in presence of AgOTf and NaOAc followed by reversible C–H ruthenation of *N*-aryl-7-azaindole **1a** produces ruthenacycle **B** (Scheme 6). Co-ordination of NCTS 2 with **B** forms the intermediate **C**, which upon migratory insertion leads the formation of **D**. The intermediate **D** undergoes β-amine elimination to afford the desired cyanated product **3** and the intermediate **E**. The active catalytic species **A** is regenerated to continue the redox neutral catalytic cycle by elimination of tosylaniline from **E** via proto-demetalation.

Scheme 6. Plausible reaction mechanism



CONCLUSIONS

In summary, we have demonstrated a direct and selective C–H cyanation of *N*-aryl-7-azaindoles with a broad range of substrate scope using the relatively less expensive $[RuCl_2(p\text{-cymene})]_2$ catalyst and the easily accessible, *N*-cyano-*N*-phenyl-*p*-toluene sulfonamide (NCTS) **2**, as an electrophilic cyanating reagent in presence of additives AgOTf and NaOAc in DCE solvent.

EXPERIMENTAL SECTION

General Information:

All reactions were carried out in oven dry reaction vessel under nitrogen atmosphere unless otherwise mentioned. TLC analysis was performed on Merck 60 F_{254} silica gel TLC plates. Column chromatography was done using 230-400 mesh silica gel or neutral alumina (activity I-II) applying pressure through air pump. ^{1}H and ^{13}CNMR spectra were recorded on 300 and 600 MHz spectrometer and are reported as chemical shifts (δ) in parts per million (ppm) and multiplicities are abbreviated as s = singlet, d = doublet, t = triplet, m = multiplet, comp = complex. Internal standards or residual solvent signals were used as reference. HRMS (m/z) was recorded in Q-Tof Micro mass spectrometer (LC-MS, ESI mode) and EI mode. Melting points were determined in a capillary melting point apparatus and are uncorrected. GC analysis was done in a GC system with Flame Ionizing Detector (FID). Single crystal X-ray data was recorded in a diffractometer with MoKα radiation. The CIF is submitted into CCDC (**1472438**) and can be obtained through https://summary.ccdc.cam.ac.uk/structure-summary-form.

Preparation of starting materials:

All 7-azaindoles are commercially available. *N*-aryl-7-azaindoles were prepared by *N*-arylation of 7-azaindoles using appropriate aryl iodides (**1a**,**1b**, **1d**,**1f**, **1g**, **1h**, **1i**, **1j**, **1k**, **1l**, **1o**, **1p**, **1q**, **1s**, **1ab**, **1ae** and **1af**)[19a, 21] or aryl bromides (d_5-**1a**,**1c**, **1e**, **1n**, **1r**, **1t** and **1u**)[22] following literature procedure. **1ac** was prepared by iodination of **1a** with NIS.[19a] *N*-aryl 7-azaindoles (**1m**, **1v**, **1w**, **1x**, **1y**, **1z**, **1aa** and **1ad**) were prepared using appropriate bromo *N*-aryl-7-azaindoles and appropriate boronic acids following Suzuki cross coupling method.[19a] Characterization data of newly synthesized *N*-aryl-7-azaindoles are given below. All the reported (**1a**[19a], **1b**[19a], **1d**[19a], **1j**[19a], **1k**[19a], **1m**[19a], **1o**[19a], **1p**[19a], **1s**[23], **1v**[19a], **1x**[19a], **1ab**[19a], **1ac**[19a], **1ad**[19a], **1ae**[24] and **1af**[24]) *N*-aryl-7-azaindoles are in good agreement with literature data.

N-cyano-*N*-phenyl-*p*-toluenesulfonamide (NCTS) was prepared following literature procedure and is in good agreement with literature data.[10]

Characterization data of Starting Materials:

*N,N-dimethyl-3-(1H-pyrrolo[2,3-b]pyridin-1-yl)aniline (**1c**):* Yield: 71%; colourless solid; mp: 78 – 79 ^{o}C; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 3.03 (s, 6 H), 6.62 (d, *J* = 3.6 Hz, 1 H), 6.73 (dd, *J* = 8.1 Hz, 2.6 Hz, 1 H), 7.03 – 7.10 (comp, 2 H), 7.14 (dd, *J* = 7.8 Hz, 4.6 Hz, 1 H), 7.38 (t, *J* = 7.2 Hz, 1 H), 7.54 (d, *J* = 3.6 Hz, 1 H), 7.98 (dd, *J* = 7.8 Hz, 1.8 Hz, 1 H), 8.39 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (75 MHz, $CDCl_3$) δ 40.5, 100.9, 108.4, 110.6, 112.2, 116.3, 121.3, 128.2, 128.8, 129.7, 139.2, 143.4, 147.5, 151.2; HRMS: (EI, m/z) calcd for $C_{15}H_{15}N_3$ $[M]^+$ 237.1266, observed 237.1253.

*1-(3,5-dimethoxyphenyl)-1H-pyrrolo[2,3-b]pyridine (**1e**):* Yield: 11%; colourless solid; mp: 54 – 55 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 3.88 (s, 6 H), 6.47 (t, *J* = 2.4 Hz, 1 H), 6.64 (d, *J*

= 3.6 Hz, 1 H), 6.99 (d, *J* = 1.8 Hz, 1 H), 7.16 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.53 (d, *J* = 4.2 Hz, 1 H), 7.99 (dd, *J* = 7.2 Hz, 1.8 Hz, 1 H), 8.40 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 55.5, 98.4, 101.6, 102.6, 116.6, 121.6, 127.9, 129.0, 140.0, 143.6, 147.5, 161.1; HRMS: (EI, m/z) calcd for $C_{15}H_{14}N_2O_2$ $[M]^+$ 254.1055, observed 254.1049.

*1-(2-methoxyphenyl)-1H-pyrrolo[2,3-b]pyridine (**1f**):* Yield 67%; pale brown solid; mp: 87 – 88 ^{o}C; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 3.79 (s, 3 H), 6.61 (d, *J* = 3.6 Hz, 1 H), 7.08 – 7.15 (comp, 3 H), 7.37 – 7.43 (comp, 2 H), 7.56 (dd, *J* = 7.5 Hz, 1.8 Hz, 1 H), 7.97 (dd, *J* = 7.8 Hz, 1.5 Hz, 1 H), 8.33 (dd, *J* = 4.8 Hz, 1.5 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 55.8, 100.3, 112.4, 116.2, 120.6, 120.9, 126.7, 128.7, 128.7, 128.8, 130.1, 143.4, 148.2, 154.4; HRMS: (EI, m/z) calcd for $C_{14}H_{12}N_2O$ $[M]^+$ 224.0950, observed 224.0940.

*1-(o-tolyl)-1H-pyrrolo[2,3-b]pyridine (**1g**):* Yield: 27%; yellow oil; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 2.11 (s, 3 H), 6.64 (d, *J* = 3.6 Hz, 1 H), 7.12 (dd, *J* = 7.5 Hz, 4.8 Hz, 1 H), 7.29 (d, *J* = 3.3 Hz, 1 H), 7.34 – 7.41 (comp, 4 H), 8.00 (dd, *J* = 7.8 Hz, 1.5 Hz, 1 H), 8.35 (dd, *J* = 4.8 Hz, 1.5 Hz, 1 H); ^{13}C NMR: (75 MHz, $CDCl_3$) δ 17.9, 100.6, 116.0, 120.4, 126.6, 128.1, 128.4, 128.8, 129.1, 131.1, 135.8, 137.1, 143.6, 148.0; HRMS: (ESI, m/z) calcd for $C_{14}H_{12}N_2Na$ $[M+Na]^+$ 231.0898, observed 231.0893.

*1-(2-(1H-pyrrolo[2,3-b]pyridin-1-yl)phenyl)ethanone (**1h**):* Yield: 67%; yellow solid; mp: 57 – 59 ^{o}C; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 1.97 (s, 3 H), 6.68 (d, *J* = 3.6 Hz, 1 H), 7.13 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.34 (d, *J* = 3.6 Hz, 1 H), 7.46 – 7.52 (comp, 2 H), 7.64 (td, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.76 (dd, *J* = 7.5 Hz, 2.1 Hz, 1 H), 7.98 (dd, *J* = 8.1 Hz, 1.8 Hz, 1 H), 8.31 (dd, *J* = 4.5 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (75 MHz, $CDCl_3$) δ 28.4, 102.2, 116.9, 120.9, 127.9, 128.0,

128.8, 129.1, 129.3, 132.3, 135.7, 137.5, 143.9, 148.0, 200.7; HRMS: (EI, m/z) calcd for $C_{15}H_{12}N_2O$ $[M]^+$ 236.0950, observed 236.0945.

*methyl 2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzoate (**1i**):* Yield: 57%; brown solid; mp: 60 – 63 ^oC; ^1H NMR: (300 MHz, $CDCl_3$) δ 3.46 (s, 3 H), 6.65 (d, J = 3.6 Hz, 1 H), 7.10 (dd, J = 7.8 Hz, 4.8 Hz, 1 H), 7.38 (d, J = 3.6 Hz, 1 H), 7.47 – 7.52 (comp, 2 H), 7.68 (td, J = 7.8 Hz, 1.5 Hz), 7.97 (dd, J = 7.8 Hz, 1.5 Hz), 8.03 (dd, J = 7.8 Hz, 1.5 Hz), 8.29 (dd, J = 4.8 Hz, 1.5 Hz); ^{13}C NMR:(75 MHz, $CDCl_3$) δ 52.0, 101.4, 116.4, 120.8, 127.5, 128.0, 128.6, 128.8, 129.0, 131.2, 132.8, 137.2, 143.4, 148.3, 166.7; HRMS: (EI, m/z) calcd for $C_{15}H_{12}N_2O_2$ $[M]^+$ 252.0899, observed 252.0902.

*1-(4-(tert-butyl)phenyl)-1H-pyrrolo[2,3-b]pyridine (**1l**):* Yield: 98%; colourless solid; mp: 89 – 90 ^oC; ^1H NMR: (300 MHz, $CDCl_3$) δ 1.37 (s, 9 H), 6.62 (d, J = 3.6 Hz, 1 H), 7.12 (dd, J = 7.8 Hz, 4.8 Hz, 1 H), 7.50 (d, J = 3.6 Hz, 1 H), 7.52 – 7.57 (comp, 2 H), 7.63 – 7.67 (comp, 2 H), 7.98 (dd, J = 7.8 Hz, 1.5 Hz, 1 H), 8.38 (dd, J = 4.5 Hz, 1.8 Hz, 1 H); ^{13}C NMR:(75 MHz, $CDCl_3$) δ 31.3, 34.5, 101.2, 116.4, 121.3, 123.6, 126.2, 127.9, 128.9, 135.7, 143.4, 147.4, 149.1; HRMS: (EI, m/z) calcd for $C_{17}H_{18}N_2$ $[M]^+$ 250.1470, observed 250.1476.

*N,N-dimethyl-4-(1H-pyrrolo[2,3-b]pyridin-1-yl)aniline (**1n**):* Yield: 88%; brown solid; mp: 92 – 93 ^oC; ^1H NMR: (300 MHz, $CDCl_3$) δ 3.02 (s, 6 H), 6.60 (d, J = 3.3 Hz, 1 H), 6.85 – 6.90 (comp, 2 H), 7.11 (dd, J = 7.8 Hz, 4.5 Hz, 1 H), 7.45 (d, J = 3.6 Hz, 1 H), 7.51 – 7.56 (comp, 2 H), 7.98 (dd, J = 8.1 Hz, 1.8 Hz, 1 H), 8.37 (dd, J = 4.5 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (75 MHz, $CDCl_3$) δ 40.7, 100.3, 113.0, 116.0, 121.0, 125.4, 127.8, 128.5, 128.7, 143.3, 147.6, 149.3; HRMS: (EI, m/z) calcd for $C_{15}H_{15}N_3$ $[M]^+$ 237.1266, observed 237.1264.

*1-(naphthalen-1-yl)-1H-pyrrolo[2,3-b]pyridine (**1q**):* Yield: 83%; colourless solid; mp: 98 – 99 ^{o}C; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 6.73 (d, *J* = 3.3 Hz, 1 H), 7.15 (dd, *J* = 7.8 Hz, 4.5 Hz, 1 H), 7.38 – 7.42 (comp, 2 H), 7.46 (d, *J* = 3.6 Hz, 1 H), 7.50 – 7.56 (m, 1 H), 7.61 – 7.64 (comp, 2 H), 7.59 – 7.66 (comp, 2 H), 8.06 (dd, *J* = 7.8 Hz, 1.5 Hz, 1 H), 8.31 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (75 MHz, $CDCl_3$) δ 100.9, 116.4, 120.5, 123.1, 125.4, 125.6, 126.4, 126.8, 128.2, 128.8, 129.0, 130.3, 130.7, 134.4, 134.7, 143.8, 149.0; HRMS: (ESI, m/z) calcd for $C_{17}H_{12}N_2Na$ $[M+Na]^+$ 267.0898, observed 267.0892.

*1-(benzo[b]thiophen-3-yl)-1H-pyrrolo[2,3-b]pyridine (**1r**):* Yield: 84%; yellow solid; mp: 66 – 67 ^{o}C; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 6.70 (d, *J* = 3.6 Hz, 1 H), 7.16 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.34 – 7.45 (comp, 2 H), 7.52 (d, *J* = 3.6 Hz, 1 H), 7.60 (dd, *J* = 7.2 Hz, 2.1 Hz, 1 H), 7.67 (s, 1 H), 7.92 (dd, *J* = 7.2 Hz, 1.2 Hz, 1 H), 8.02 (dd, *J* = 7.8 Hz, 1.8 Hz, 1 H), 8.36 (dd, *J* = 4.8 Hz, 1.5 Hz, 1 H); ^{13}C NMR: (75 MHz, $CDCl_3$) δ 101.4, 116.8, 120.8, 121.2, 121.9, 123.1, 124.6, 125.1, 129.0, 129.1, 130.8, 134.9, 138.8, 143.8, 148.2; HRMS: (EI, m/z) calcd for $C_{15}H_{10}N_2S$ $[M]^+$ 250.0565, observed 250.0573.

*1-(furan-2-yl)-1H-pyrrolo[2,3-b]pyridine (**1t**):* Yield: 97%; brown oil; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 6.57 (dd, *J* = 3.0 Hz, 2.1 Hz, 1 H), 6.62 (d, *J* = 3.6 Hz, 1 H), 6.72 (dd, *J* = 3.6 Hz, 0.9 Hz, 1 H), 7.16 (dd, *J* = 7.8 Hz, 4.5 Hz, 1 H), 7.33 (dd, *J* = 2.1 Hz, 1.2 Hz), 7.61 (d, *J* = 3.6 Hz, 1 H), 7.96 (dd, *J* = 7.8 Hz, 1.5 Hz, 1 H), 8.42 (dd, *J* = 4.5 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (75 MHz, $CDCl_3$) δ 97.0, 102.3, 111.6, 117.0, 121.1, 125.8, 129.0, 137.4, 143.9, 144.9, 146.6; HRMS: (ESI, m/z) calcd for $C_{11}H_8N_2ONa$ $[M+Na]^+$ 207.0534, observed 207.0527.

*1-(furan-3-yl)-1H-pyrrolo[2,3-b]pyridine (**1u**):* Yield: 98%; brown solid; mp: 61 – 62 ^{o}C; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 6.59 (d, *J* = 3.6 Hz, 1 H), 6.87 (dd, *J* = 1.8 Hz, 0.6 Hz, 1 H), 7.12

(dd, J = 7.8 Hz, 4.5 Hz, 1 H), 7.41 (d, J = 3.6 Hz, 1 H), 7.48 (t, J = 1.8 Hz, 1 H), 7.93 (dd, J = 7.8 Hz, 4.5 Hz, 1 H), 8.27 (dd, J = 1.2 Hz, 0.9 Hz, 1 H), 8.40 (dd, J = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (75 MHz, $CDCl_3$) δ 101.6, 105.6, 116.5, 121.2, 125.8, 126.5, 128.9, 133.2, 142.4, 143.6, 147.0; HRMS: (EI, m/z) calcd for $C_{11}H_8N_2O$ $[M]^+$ 184.0637, observed 184.0624.

*1-phenyl-4-(m-tolyl)-1H-pyrrolo[2,3-b]pyridine (**1w**):* Yield: 98%; colourless solid; mp: 143 – 145^{o}C; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 2.49 (s, 3 H), 6.84 (d, J = 3.6 Hz, 1 H), 7.22 (app d, J = 4.8 Hz, 1 H), 7.29 (app d, J = 7.5 Hz, 1 H), 7.37 (app t, J = 7.2 Hz, 1 H), 7.44 (app t, J = 7.8 Hz, 1 H), 7.53 – 7.59 (comp, 5 H), 7.77 – 7.80 (comp, 2 H), 8.43 (app d, J = 5.1 Hz, 1 H); ^{13}C NMR: (75 MHz, $CDCl_3$) δ 21.6, 101.2, 116.0, 119.6, 124.2, 125.8, 126.4, 128.1, 128.8, 129.2, 129.3, 129.4, 138.6 (2 C), 138.7, 142.6, 143.9, 148.1; HRMS: (EI, m/z) calcd for $C_{20}H_{16}N_2$ $[M]^+$ 284.1313, observed 284.1317.

*5-(4-bromophenyl)-1-phenyl-1H-pyrrolo[2,3-b]pyridine (**1y**):* Yield: 29%; colorless solid; mp: 172 – 173 ^{o}C; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 6.71 (d, J = 3.6 Hz, 1 H), 7.36 – 7.41 (m, 1 H), 7.51 – 7.64 (comp, 7 H), 7.78 – 7.82 (comp, 2 H), 8.14 (d, J = 2.1 Hz, 1 H), 8.59 (d, J = 2.1 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 101.9, 121.4, 121.6, 123.9, 126.4, 127.2, 128.8, 128.9, 129.2, 129.4, 132.0, 138.3 (2 C), 142.5, 147.1; HRMS: (ESI, m/z) calcd for $C_{19}H_{13}BrN_2Na$ $[M+Na]^+$ 371.0160, observed 371.0164.

*5-(4-fluorophenyl)-1-phenyl-1H-pyrrolo[2,3-b]pyridine (**1z**):* Yield: 92%; colourless solid; mp: 121 – 123 ^{o}C; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 6.70 (d, J = 3.6 Hz, 1 H), 7.16 – 7.22 (comp, 2 H), 7.38 (app t, J = 7.2 Hz, 1 H), 7.54 – 7.63 (comp, 6 H), 7.79 – 7.82 (comp, 2 H), 8.12 (d, J = 2.1 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 101.8, 115.8 (d, $^2J_{F-C}$ = 21.3 Hz), 121.5, 123.9, 126.4, 127.3, 128.7, 128.9 (d, $^3J_{F-C}$ = 8.0 Hz), 129.5 (d, $^3J_{F-C}$ = 12.9 Hz), 129.4,

135.5, 138.3, 142.7, 146.9, 162.4 (d, $^{1}J_{F-C}$ = 245.1 Hz); HRMS: (ESI, m/z) calcd for $C_{19}H_{13}FN_2Na$ $[M+Na]^+$ 311.0960, observed 311.0956.

*1-phenyl-5-(pyren-1-yl)-1H-pyrrolo[2,3-b]pyridine (**1aa**):* Yield: 91%; green solid; mp: 130 – 132°C; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 6.76 (d, *J* = 3.6 Hz, 1 H), 7.39 (app t, *J* = 7.5 Hz, 1 H), 7.56 – 7.62 (comp, 2 H), 7.65 (d, *J* = 3.6 Hz, 1 H), 7.86 – 7.89 (comp, 2 H), 8.00 – 8.06 (comp, 3 H), 8.13 (comp, 2 H), 8.17 – 8.28 (comp, 5 H), 8.65 (d, *J* = 2.1 Hz, 1 H); ^{13}C NMR: (75 MHz, $CDCl_3$) δ 101.8, 121.3, 123.9, 124.6, 124.8 (2 C), 124.9, 125.0, 125.1, 126.0, 126.4, 127.3, 127.4, 127.6, 128.1, 128.6, 129.0, 129.4, 129.9, 130.6 (2 C), 130.9, 131.4, 135.1, 138.4, 145.3, 146.7; HRMS: (ESI, m/z) calcd for $C_{29}H_{19}N_2$ $[M+H]^+$ 395.1548, observed 395.1545.

General procedure for cyanation:

(0.2 mmol scale):

To an oven dried 10 mL schlenk tube 38.8 mg (0.2 mmol) of 1-phenyl-1*H*-pyrrolo[2,3-*b*]pyridine (**1a**) was taken. To that NCTS (109 mg, 0.4 mmol), NaOAc (8.2 mg, 50 mol%), AgOTf (15.4 mg, 30 mol%) and $[RuCl_2(p\text{-cymene})]_2$ (6.1 mg, 5 mol%) were added. Next it was degassed and backfilled with nitrogen. 2.0 mL of anhydrous DCE was added as solvent. Then the tube was degassed and backfilled with nitrogen (3 times). The tube was closed with a teflon-lined cap and heated at 110 °C (oil bath temperature). After 30 h, the reaction was stopped and cooled to room temperature. The reaction mixture was filtered through a short pad of celite and concentrated under vacuo. The crude reaction mixture was directly purified by column chromatography on silica gel using pet ether/ethyl acetate as eluent and isolated the product **3a** in 84 % yield (36.8 mg).

(Gram scale):

1 gram (5.1 mmol) of 1-phenyl-1*H*-pyrrolo[2,3-*b*]pyridine (**1a**) was taken in an oven dried 100 mL round bottom flask equipped with a reflux condenser. To that NCTS (2.8 g, 10.3 mmol), NaOAc (205 mg, 50 mol%), AgOTf (385 mg, 30 mol%) and $[RuCl_2(p\text{-cymene})]_2$ (154 mg, 5 mol%) were added. Next it was degassed and backfilled with nitrogen. 50 mL of anhydrous DCE was added. Then it was degassed and backfilled with nitrogen (3 times) and heated at 110 ^oC (oil bath temperature). After 30 h, the reaction was stopped and cooled to room temperature. The reaction mixture was filtered through a short pad of celite and concentrated under vacuo. The crude reaction mixture was directly purified by column chromatography on silica gel using pet ether/ethyl acetate as eluent to give 2-(1*H*-pyrrolo[2,3-*b*]pyridin-1-yl)benzonitrile (**2a**) (0.79 g, 70% yield).

Characterization data of cyanated products:

*2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3a**):* Yield: 84% (36.8 mg); colourless solid; mp: 132 – 133 ^oC; ^1H NMR: (600 MHz, $CDCl_3$) δ 6.75 (d, J = 3.6 Hz, 1 H), 7.21 (dd, J = 7.8 Hz, 4.8 Hz, 1 H), 7.53 (td, J = 7.2 Hz, J = 1.2 Hz, 1 H), 7.58 (d, J = 3.6 Hz, 1 H), 7.78 – 7.83 (comp, 2 H), 7.87 (dd, J = 7.8 Hz, 1.2 Hz), 8.03 (dd, J = 7.8 Hz, 1.2 Hz, 1 H), 8.39 (dd, J = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 102.8, 110.0, 116.7, 117.5, 121.3, 127.5, 128.1, 128.3, 129.5, 133.7, 134.2, 140.4, 143.9, 147.8; HRMS: (ESI, m/z) calcd for $C_{14}H_9N_3Na$ $[M+Na]^+$ 242.0694, observed 242.0687.

*4-methyl-2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3b**):* Yield: 81% (37.7 mg); pale orange solid; mp: 88 – 89 ^oC; ^1H NMR: (300 MHz, $CDCl_3$) δ 2.51 (s, 3 H), 6.70 (d, J = 3.6 Hz, 1 H), 7.18 (dd, J = 7.8 Hz, 4.8 Hz, 1 H), 7.30 (dd, J = 8.4 Hz, 1.5 Hz, 1 H), 7.52 (d, J = 3.6 Hz, 1

H), 7.58 (d, *J* = 1.8 Hz, 1 H), 7.72 (d, *J* = 7.8 Hz, 1 H), 8.00 (dd, *J* = 7.8 Hz, 1.8 Hz, 1 H), 8.36 (dd, *J* = 4.8 Hz, 1.5 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 21.9, 102.6, 107.1, 116.9, 117.3, 121.2, 128.4, 128.5, 128.8, 129.4, 113.8, 140.3, 143.8, 145.1, 147.8; HRMS: (EI, m/z) calcd for $C_{15}H_{11}N_3$ $[M]^+$ 233.0953, observed 233.0948.

*4-(dimethylamino)-2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3c**):* Yield: 83% (43.5 mg); colourless solid; mp: 179 – 180 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 3.10 (s, 6 H), 6.70 – 6.72 (comp, 2 H), 6.95 (d, *J* = 3.0 Hz, 1 H), 7.18 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.57 (d, *J* = 3.6 Hz, 1 H), 7.62 (d, *J* = 9.0 Hz, 1 H), 8.01 (dd, *J* = 8.4 Hz, 1.8 Hz, 1 H), 8.38 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 40.0, 95.1, 102.0, 110.4, 110.5, 117.0, 118.4, 121.2, 128.7, 129.2, 134.8, 141.6, 143.7, 147.9, 153.1; HRMS: (EI, m/z) calcd for $C_{16}H_{14}N_4$ $[M]^+$ 262.1218, observed 262.1212.

*4-methoxy-2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3d**):* Yield: 80% (39.9 mg); pale yellow solid; mp: 132 – 135 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 3.93 (s, 3 H), 6.73 (d, *J* = 3.6 Hz, 1 H), 7.02 (dd, *J* = 9.0 Hz, 2.4 Hz, 1 H), 7.21 (dd, *J* = 9.0 Hz, 2.4 Hz, 1 H), 7.21 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.34 (d, *J* = 2.4 Hz, 1 H), 7.58 (d, *J* = 4.2 Hz, 1 H), 7.76 (d, *J* = 9.0 Hz, 1 H), 8.02 (dd, *J* = 8.4 Hz, 1.8 Hz, 1 H), 8.39 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 55.9, 101.4, 102.7, 113.6, 113.8, 117.1, 117.4, 121.3, 128.3, 129.4, 135.3, 142.1, 143.9, 147.7, 163.4; HRMS: (EI, m/z) calcd for $C_{15}H_{11}N_3O$ $[M]^+$ 249.0902, observed 249.0908.

*2,4-dimethoxy-6-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3e**):* Yield: 75% (41.9 mg); colourless solid; mp: 141 – 143 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 3.92 (s, 3 H), 3.98 (s, 3 H), 6.52 (d, *J* = 1.8 Hz, 1 H), 6.70 (d, *J* = 3.6 Hz, 1 H), 6.92 (dd, *J* = 1.8 Hz, 1 H), 7.19 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.57 (d, *J* = 4.2 Hz, 1 H), 8.00 (dd, *J* = 8.4 Hz, 1.8 Hz, 1 H), 8.38 (dd, *J* = 4.8

Hz, 1.2 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 55.9, 56.4, 92.2, 97.3, 102.5, 105.2, 114.6, 117.3, 121.4, 128.4, 129.4, 143.0, 143.8, 147.8, 163.7, 164.4; HRMS: (ESI, m/z) calcd for $C_{16}H_{13}O_2N_3Na$ $[M+Na]^+$ 302.0905, observed 302.0901.

*3-methoxy-2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3f**):* Yield: 87% (43.3 mg); grey solid; mp: 140 – 143 °C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 3.79 (s, 3 H), 6.73 (d, *J* = 3.6 Hz, 1 H), 7.17 (dd, *J* = 8.4 Hz, 4.2 Hz, 1 H), 7.32 – 7.34 (comp, 2 H), 7.44 (dd, *J* = 8.4 Hz, 1.8 Hz, 1 H), 7.54 (t, *J* = 8.4 Hz, 1 H), 8.01 (dd, *J* = 8.4 Hz, 1.8 Hz, 1 H), 8.36 (dd, *J* = 4.2 Hz, 1.2 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 56.2, 102.2, 114.0, 116.0, 116.8, 116.9, 120.6, 124.9, 129.0, 129.2, 129.3, 129.9, 143.7, 148.3, 156.1; HRMS: (EI, m/z) calcd for $C_{15}H_{11}N_3O$ $[M]^+$ 249.0902, observed 249.0896.

*3-methyl-2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3g**):* Yield: 41% (19.1 mg); yellow solid; mp: 86 – 89 °C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 2.11 (s, 3 H), 6.77 (d, *J* = 4.2 Hz, 1 H), 7.18 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.31 (d, *J* = 3.6 Hz, 1 H), 7.50 (t, *J* = 7.8 Hz, 1 H), 7.65 (app d, *J* = 7.2 Hz, 1 H), 7.69 (app d, *J* = 7.8 Hz, 1 H), 8.04 (dd, *J* = 7.8 Hz, 1.2 Hz, 1 H), 8.35 (dd, *J* = 4.2 Hz, 1.2 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 18.0, 102.6, 113.3, 116.3, 116.9, 120.6, 128.1, 129.0, 129.5, 131.3, 135.6, 138.9, 139.4, 144.0, 148.0; HRMS: (EI, m/z) calcd for $C_{15}H_{11}N_3$ $[M]^+$ 233.0953, observed 233.0944.

*3-acetyl-2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3h**):* Yield: 51% (26.6 mg); brown solid; mp: 86 – 88 °C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 1.92 (s, 3 H), 6.50 (d, *J* = 3.6 Hz, 1 H), 7.21 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.44 (d, *J* = 3.6 Hz, 1 H), 7.67 (t, *J* = 7.8 Hz, 1 H), 7.98 (dd, *J* = 7.2 Hz, 1.8 Hz, 1 H), 8.00 (dd, *J* = 8.4 Hz, 1.8 Hz, 1 H), 8.04 (dd,*J* = 7.2 Hz, 1.2 Hz, 1 H), 8.34 (dd, *J* = 4.8 Hz, 1.2 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 28.1, 103.7, 113.3, 115.7,

117.6, 120.8, 128.3, 128.8, 129.8, 133.2, 136.3, 138.1, 139.7, 144.2, 148.3, 198.4; HRMS: (EI, m/z) calcd for $C_{16}H_{11}N_3O$ $[M]^+$ 261.0902, observed 261.0902.

*methyl 3-cyano-2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzoate (**3i**):* Yield: 66% (36.6 mg); colourless solid; mp: 92 – 94 ^oC; ^1H NMR: (300 MHz, $CDCl_3$) δ 3.41 (s, 3 H), 6.76 (d, J = 3.6 Hz, 1 H), 7.15 (dd, J = 7.8 Hz, 1.8 Hz, 1 H), 7.45 (d, J = 3.6 Hz, 1 H), 7.64 (t, J = 7.8 Hz, 1 H), 7.98 (app t, J = 2.1 Hz, 1 H), 8.01 (app t, J = 2.1 Hz, 1 H), 8.23 – 8.29 (comp, 2 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 52.5, 102.9, 113.5, 115.7, 117.2, 120.9, 128.5 (2 C), 131.2, 135.4, 136.9, 139.8, 143.7, 148.7, 164.9; HRMS: (EI, m/z) calcd for $C_{16}H_{11}N_3O_2$ $[M]^+$ 277.0859, observed 277.0852.

*5-methoxy-2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3j**):* Yield: 60% (29.9 mg); colourless solid; mp: 130 – 133 ^oC; ^1H NMR: (600 MHz, $CDCl_3$) δ 3.92 (s, 3 H), 6.71 (d, J = 3.6 Hz, 1 H), 7.19 (dd, J = 8.4 Hz, 4.8 Hz, 1 H), 7.29 – 7.32 (comp, 2 H), 7.49 (d, J = 3.6 Hz, 1 H), 7.65 (d, J = 8.4 Hz, 1 H), 8.02 (dd, J = 7.8 Hz, 1.2 Hz, 1 H), 8.37 (dd, J = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 56.0, 102.3, 111.2, 116.4, 117.1, 118.0, 120.1, 121.0, 128.5, 129.3, 129.6, 133.4, 143.8, 148.1, 158.5; HRMS: (ESI, m/z) calcd for $C_{15}H_{11}N_3ONa$ $[M+Na]^+$ 272.0800, observed 272.0811.

*5-methyl-2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3k**):* Yield: 66% (30.7 mg); colourless solid; mp: 143 – 146 ^oC; ^1H NMR: (600 MHz, $CDCl_3$) δ 2.49 (s, 3 H), 6.72 (d, J = 4.2 Hz, 1 H), 7.19 (dd, J = 7.8 Hz, 4.8 Hz, 1 H), 7.54 (d, J = 3.6 Hz, 1 H), 7.58 (dd, J = 8.4 Hz, 1.8 Hz, 1 H), 7.66 – 7.68 (comp, 2 H), 8.02 (dd, J = 7.8 Hz, 1.2 Hz, 1 H), 8.38 (dd, J = 4.2 Hz, 1.2 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 20.8, 102.5, 109.9, 116.8, 117.3, 121.1, 128.0, 128.3,

129.4, 134.2, 134.6, 138.0, 138.1, 143.8, 147.9; HRMS: (EI, m/z) calcd for $C_{15}H_{11}N_3$ $[M]^+$ 233.0953, observed 233.0948.

*5-(tert-butyl)-2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3l**):* Yield: 80% (44.0 mg); colourless gummy; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 1.38 (s, 9 H), 6.70 (d, *J* = 3.6 Hz, 1 H), 7.17 (dd, *J* = 8.1 Hz, 4.8 Hz, 1 H), 7.52 (d, *J* = 3.6 Hz, 1 H), 7.69 (d, *J* = 8.4 Hz, 1 H), 7.76 – 7.83 (comp, 2 H), 8.00 (dd, *J* = 7.8 Hz, 1.8 Hz, 1 H), 8.36 (dd, *J* = 4.8 Hz, 1.5 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 31.0, 34.8, 102.5, 109.5, 117.2, 117.3, 121.2, 127.6, 128.4, 129.4, 131.1, 131.2, 137.8, 143.8, 147.8, 151.0; HRMS: (ESI, m/z) calcd for $C_{18}H_{17}N_3Na$ $[M+Na]^+$ 298.1320, observed 298.1308.

*4-(1H-pyrrolo[2,3-b]pyridin-1-yl)-[1,1'-biphenyl]-3-carbonitrile (**3m**):* Yield: 75% (44.3 mg); colourless solid; mp: 150 – 153 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 6.77 (d, *J* = 3.6 Hz, 1 H), 7.23 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.48 (app t, *J* = 7.2 Hz, 1 H), 7.53 – 7.55 (comp, 2 H), 7.62 – 7.65 (comp, 3 H), 7.89 (d, *J* = 8.4 Hz, 1 H), 7.99 (dd, *J* = 8.4 Hz, 2.4 Hz, 1 H), 8.04 – 8.06 (comp, 2 H), 8.42 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 102.9, 110.2, 116.7, 117.5, 121.3, 127.1, 128.2, 128.4, 128.5, 129.2, 129.5, 132.3, 132.5, 138.2, 139.2, 140.9, 143.9, 147.9; HRMS: (EI, m/z) calcd for $C_{20}H_{13}N_3$ $[M]^+$ 295.1109, observed 295.1104.

*5-(dimethylamino)-2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3n**):* Yield: 34% (17.8 mg); brown solid; mp: 189 – 191 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 3.07 (s, 6 H), 6.68 (d, *J* = 3.6 Hz, 1 H), 7.02 – 7.04 (comp, 2 H), 7.16 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.46 (d, *J* = 3.6 Hz, 1 H), 7.52 (dd, *J* = 7.2 Hz, 2.4 Hz, 1 H), 8.00 (dd, *J* = 7.8 Hz, 1.2 Hz, 1 H), 8.37 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 40.3, 101.6, 111.2, 115.7, 116.7, 116.8, 117.2,

120.8, 128.6, 128.9, 129.1, 129.2, 143.7, 148.3, 149.4; HRMS: (EI, m/z) calcd for $C_{16}H_{14}N_4$ $[M]^+$ 262.1218, observed 262.1213.

*methyl 3-cyano-4-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzoate (**3o**):* Yield: 51% (28.3 mg); colourless solid; mp: 156 – 158 ^oC; ^1H NMR: (600 MHz, $CDCl_3$) δ 4.02 (s, 3 H), 6.79 (d, J = 3.6 Hz, 1 H), 7.25 (dd, J = 7.8 Hz, 4.8 Hz, 1 H), 7.66 (d, J = 4.2 Hz, 1 H), 8.02 (d, J = 8.4 Hz, 1 H), 8.04 (dd, J = 8.4 Hz, 1.8 Hz, 1 H), 8.40 (dd, J = 4.8 Hz, 1.8 Hz, 1 H), 8.42 (dd, J = 8.4 Hz, 1.8 Hz, 1 H), 8.54 (d, J = 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 52.8, 103.8, 109.2, 116.2, 118.0, 121.6, 127.7 (2 C), 128.9, 129.6, 134.5, 135.7, 143.6, 144.0, 147.7, 164.6; HRMS: (EI, m/z) calcd for $C_{16}H_{11}N_3O_2$ $[M]^+$ 277.0851, observed 277.0847.

*5-acetyl-2-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3p**):* Yield: 44% (23 mg); pale orange solid; mp: 145 – 145 ^oC; ^1H NMR: (600 MHz, $CDCl_3$) δ 2.70 (s, 3 H), 6.79 (d, J = 3.6 Hz, 1 H), 7.25 (dd, J = 7.8 Hz, 4.8 Hz, 1 H), 7.66 (d, J = 4.2 Hz, 1 H), 8.03 – 8.06 (comp, 2 H), 8.34 (dd, J = 8.4 Hz, 1.8 Hz, 1 H), 8.40 (dd, J = 4.2 Hz, 1.2 Hz, 1 H), 8.44 (d, J = 2.4 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 26.6, 103.9, 109.3, 116.2, 118.0, 121.6, 127.7, 127.9, 129.7, 133.1, 134.6, 135.2, 143.6, 144.0, 147.7, 194.9; HRMS: (EI, m/z) calcd for $C_{16}H_{11}N_3O$ $[M]^+$ 261.0902, observed 261.0908.

*1-(1H-pyrrolo[2,3-b]pyridin-1-yl)-2-naphthonitrile (**3q**):* Yield: 78% (42 mg); colourless solid; mp 151 – 152 ^oC (crystallization from diethyl ether and pet ether); ^1H NMR: (600 MHz, $CDCl_3$) δ 6.87 (d, J = 3.6 Hz, 1 H), 7.22 (dd, J = 8.4 Hz, 4.8 Hz, 1 H), 7.39 (dd, J = 8.4 Hz, 1.2 Hz, 1 H), 7.47 (d, J = 3.6 Hz, 1 H), 7.54 (ddd, J = 8.4 Hz, 7.2 Hz, 1.2 Hz, 1 H), 7.69 (ddd, J = 8.4 Hz, 7.2 Hz, 1.2 Hz, 1 H), 7.80 (d, J = 8.4 Hz, 1 H), 8.02 (d, J = 8.4 Hz, 1 H), 8.08 (d, J = 8.4 Hz, 1 H), 8.10 (dd, J = 7.8 Hz, 1.2 Hz, 1 H), 8.33 (dd, J = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150

MHz, $CDCl_3$) δ 102.9, 110.4, 116.6, 117.2, 120.6, 124.2, 126.7, 128.4, 128.6, 129.3, 129.5, 129.6, 129.7, 130.8, 135.8, 139.8, 144.2, 149.1; HRMS: (ESI, m/z) calcd for $C_{18}H_{11}N_3Na$ $[M+Na]^+$ 292.0851, observed 292.0837.

*3-(1H-pyrrolo[2,3-b]pyridin-1-yl)benzo[b]thiophene-2-carbonitrile (**3r**):* Yield: 78% (43 mg); yellow solid; mp: 136 – 137 ^oC; ^1H NMR: (300 MHz, $CDCl_3$) δ 6.81 (d, *J* = 3.6 Hz, 1 H), 7.22 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.46 (app t, *J* = 7.5 Hz, 1 H), 7.54 (d, *J* = 3.6 Hz, 1 H), 7.60 (m, 1 H), 7.67 (app d, *J* = 8.4 Hz, 1 H), 7.90 (app d, *J* = 8.1 Hz, 1 H), 8.05 (dd, *J* = 7.8 Hz, 1.5 Hz, 1 H), 8.37 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 103.7, 104.3, 113.0, 117.7, 121.1, 123.0, 124.3, 125.9, 128.2, 128.7, 129.6, 133.3, 139.6, 140.1, 144.1, 147.8; HRMS: (EI, m/z) calcd for $C_{16}H_9N_3S$ $[M]^+$ 275.0517, observed 275.0520.

*2-(1H-pyrrolo[2,3-b]pyridin-1-yl)thiophene-3-carbonitrile (**3s**):* Yield: 87% (39.2 mg); colourless solid; mp: 90 – 92 ^oC; ^1H NMR: (600 MHz, $CDCl_3$) δ 6.75 (d, *J* = 3.6 Hz, 1 H), 7.19 – 7.21 (comp, 2 H), 7.24 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 8.00 (dd, *J* = 7.2 Hz, 1.8 Hz, 1 H), 8.02 (d, *J* = 4.2 Hz, 1 H), 8.44 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 99.4, 104.4, 115.1, 118.2, 121.4, 121.5, 126.7, 127.1, 129.6, 143.9, 147.1, 147.8; HRMS: (ESI, m/z) calcd for $C_{12}H_8N_3S$ $[M+H]^+$ 226.0439, observed 226.0435.

*2-(1H-pyrrolo[2,3-b]pyridin-1-yl)furan-3-carbonitrile (**3t**):* Yield: 64% (26.7 mg); brown solid; mp: 62 – 64 ^oC; ^1H NMR: (600 MHz, $CDCl_3$) δ 6.76 – 6.78 (comp, 2 H), 7.26 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.44 (d, *J* = 2.4 Hz, 1 H), 7.58 (d, *J* = 3.6 Hz, 1 H), 8.00 (dd, *J* = 8.4 Hz, 1.2 Hz, 1 H), 8.49 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 86.1, 105.2, 112.8, 112.9, 118.5, 121.3, 126.0, 129.7, 139.4, 144.7, 147.3, 150.4; HRMS: (EI, m/z) calcd for $C_{12}H_7N_3O$ $[M]^+$ 209.0589, observed 209.0583.

*3-(1H-pyrrolo[2,3-b]pyridin-1-yl)furan-2-carbonitrile (**3u**):* Yield: 39% (16.4 mg); pale yellow solid; mp: 133 – 135 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 6.75 (d, *J* = 3.6 Hz, 1 H), 7.23 (dd, *J* = 8.4 Hz, 4.2 Hz, 1 H), 7.65 (d, *J* = 1.8 Hz, 1 H), 7.77 (d, *J* = 2.4 Hz, 1 H), 7.82 (d, *J* = 4.2 Hz, 1 H), 8.00 (dd, *J* = 7.2 Hz, 1.8 Hz, 1 H), 8.43 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 104.6, 108.5, 112.0, 115.5, 117.9, 121.4, 125.6, 129.5, 136.0, 144.1, 147.2, 147.6; HRMS: (ESI, m/z) calcd for $C_{12}H_8N_3O$ $[M+H]^+$ 210.0667, observed 210.0663.

*2-(4-phenyl-1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3v**):* Yield: 50% (29.5 mg); yellow solid; mp: 223 – 225 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 6.94 (d, *J* = 3.6 Hz, 1 H), 7.30 (d, *J* = 4.8 Hz, 1 H), 7.49 – 7.59 (comp, 4 H), 7.62 (d, *J* = 4.2 Hz, 1 H), 7.78 – 7.85 (comp, 4 H), 7.89 (dd, *J* = 7.8 Hz, 1.2 Hz, 1 H), 8.45 (d, *J* = 4.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 102.3, 110.1, 116.6, 116.7, 119.3, 127.6, 128.2, 128.4, 128.5, 128.6, 128.9, 133.7, 134.2, 138.4, 140.5, 142.9, 144.2, 148.4; HRMS: (EI, m/z) calcd for $C_{20}H_{13}N_3$ $[M]^+$ 295.1109, observed 295.1112.

*2-(4-(m-tolyl)-1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3w**):* Yield: 75% (46.4 mg); colourless solid; mp: 143 – 145 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 2.51 (s, 3 H), 6.94 (d, *J* = 3.6 Hz, 1 H), 7.29 (t, *J* = 2.4 Hz, 1 H), 7.32 (app d, *J* = 7.2 Hz, 1 H), 7.47 (app t, *J* = 7.2 Hz, 1 H), 7.54 (td, *J* = 7.2 Hz, 1.2 Hz, 1 H), 7.58 – 7.60 (comp, 2 H), 7.61 (d, *J* = 3.6 Hz, 1 H), 7.80 – 7.86 (comp, 2 H), 7.89 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H), 8.43 (d, *J* = 4.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 21.5, 102.4, 110.1, 116.6, 116.7, 119.3, 125.7, 127.6, 128.2, 128.3, 128.8, 129.2, 129.3, 133.7, 134.2, 138.3, 138.6, 140.6, 143.1, 144.2, 148.4; HRMS: (EI, m/z) calcd for $C_{21}H_{15}N_3$ $[M]^+$ 309.1266, observed 309.1251.

*2-(5-phenyl-1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3x**):* Yield: 79% (43.6 mg); colourless solid; mp: 142 – 143 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 6.80 (d, J = 4.2 Hz, 1 H), 7.42 (app t, J = 7.2 Hz, 1 H), 7.51 – 7.56 (comp, 3 H), 7.62 (d, J = 3.6 Hz, 1 H), 7.66 – 7.67 (comp, 2 H), 7.82 (td, J = 7.8 Hz, 1.8 Hz, 1 H), 7.86 (dd, J = 7.8 Hz, 1.2 Hz, 1 H), 7.89 (dd, J = 7.2 Hz, 1.8 Hz, 1 H), 8.21 (d, J = 2.4 Hz, 1 H), 8.62 (d, J = 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 103.1, 109.9, 116.7, 121.3, 127.2, 127.4, 127.6, 127.9, 128.1, 129.0 (2 C), 131.3, 133.8, 134.2, 139.1, 140.4, 143.2, 147.3; HRMS: (EI, m/z) calcd for $C_{20}H_{13}N_3$ $[M]^+$ 295.1109, observed 295.1110.

*2-(5-(4-bromophenyl)-1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3y**):* Yield: 88% (65.9 mg); colourless solid; mp: 208 – 210 ^{o}C; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 6.78 (d, J = 3.6 Hz, 1 H), 7.48 – 7.56 (comp, 3 H), 7.59 – 7.63 (comp, 3 H), 7.79 – 7.81 (comp, 2 H), 7.87 (dd, J = 7.2 Hz, 1.8 Hz, 1 H), 8.14 (d, J = 2.1 Hz, 1 H), 8.54 (d, J = 2.1 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 103.1, 110.0, 116.6, 121.3, 121.6, 127.7 (2 C), 128.1, 129.0, 129.2, 130.1, 133.8, 134.2, 138.0, 140.2, 142.9, 147.4; HRMS: (EI, m/z) calcd for $C_{20}H_{12}N_3Br$ $[M]^+$ 373.0215, observed 373.0216.

*2-(5-(4-fluorophenyl)-1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3z**):* Yield: 75% (47 mg); colourless solid; mp: 181 – 183 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 6.79 (d, J = 3.6 Hz, 1 H), 7.19 – 7.22 (comp, 2 H), 7.55 (td, J = 7.2 Hz, 1.8 Hz, 1 H), 7.59 – 7.62 (comp, 3 H), 7.89 (dd, J = 7.2 Hz, 1.8 Hz, 1 H), 8.15 (d, J = 2.4 Hz, 1 H), 8.56 (d, J = 2.4 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 103.0, 110.0, 115.9 (d, $^{2}J_{F-C}$ = 21.3 Hz), 116.7, 121.2, 127.7 (2 C), 128.1, 129.0 (d, $^{3}J_{F-C}$ = 8.0 Hz), 129.1, 130.4, 133.7, 134.0, 135.2 (d, $^{4}J_{F-C}$ = 3.4 Hz), 140.3, 143.0, 147.3, 162.4 (d, $^{1}J_{F-C}$ = 245.0 Hz); HRMS: (EI, m/z) calcd for $C_{20}H_{12}N_3F$ $[M]^+$ 313.1015, observed 313.1014.

*2-(5-(pyren-1-yl)-1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3aa**):* Yield: 51% (42.8 mg); yellow solid; mp: 225 – 227 ^{o}C; ^{1}H NMR: (300 MHz, $CDCl_3$) δ 6.86 (d, *J* = 3.6 Hz, 1 H), 7.56 (td, *J* = 7.5 Hz, 1.5 Hz, 1 H), 7.69 (d, *J* = 3.9 Hz, 1 H), 7.84 (td, *J* = 7.8 Hz, 1.5 Hz, 1 H), 7.90 – 7.95 (comp, 2 H), 8.01 – 8.07 (comp, 3 H), 8.13 (comp, 2 H), 8.18 – 8.29 (comp, 5 H), 8.63 (d, *J* = 2.1 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 103.0, 110.0, 116.8, 121.0, 124.7, 124.8, 124.9, 125.2, 126.1, 127.4, 127.6, 127.7, 127.8, 128.2 (2 C), 129.1 (2 C), 130.8, 130.9 (2 C), 131.1, 131.4, 133.8, 134.2, 134.8, 140.4, 145.6, 147.2; HRMS: (EI, m/z) calcd for $C_{30}H_{17}N_3$ $[M]^+$ 419.1422, observed 419.1424.

*2-(3-bromo-1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3ab**):* Yield: 67% (40 mg); colourless solid; mp: 214 – 215 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 7.30 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.56 (td, *J* = 7.2 Hz, 1.2 Hz, 1 H), 7.60 (s, 1H), 9.73 (dd, *J* = 7.8 Hz, 1.2 Hz, 1 H), 7.80 (td, *J* = 7.8 Hz, 1.2 Hz, 1 H), 7.88 (dd, *J* = 8.4 Hz, 1.8 Hz, 1 H), 8.00 (dd, *J* = 8.4 Hz, 1.8 Hz, 1 H), 8.43 (dd, *J* = 4.8 Hz, 1.2 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 92.3, 110.3, 116.3, 118.1, 120.7, 127.0, 128.1 (2 C), 128.3, 133.8, 134.2, 139.4, 145.1, 146.8; HRMS: (EI, m/z) calcd for $C_{14}H_8BrN_3$ $[M]^+$ 296.9902, observed 296.9889.

*2-(3-iodo-1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3ac**):* Yield: 83% (57.3 mg); colourless solid; mp: 219 – 221 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 7.30 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.55 – 7.58 (m, 1 H), 7.73 (dd, *J* = 8.4 Hz, 1.2 Hz, 1 H), 7.78 – 7.81 (m, 1 H), 7.86 (dd, *J* = 8.4 Hz, 1.2 Hz, 1 H), 7.88 (dd, *J* = 8.4 Hz, 1.8 Hz, 1 H), 8.40 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 58.1, 110.3, 116.3, 118.2, 123.7, 128.1 (2 C), 130.0, 131.9, 133.8,

134.2, 139.4, 145.0, 147.4; HRMS: (EI, m/z) calcd for $C_{14}H_8IN_3$ $[M]^+$ 344.9763, observed 344.9756.

*2-(3-(4-chlorophenyl)-1H-pyrrolo[2,3-b]pyridin-1-yl)benzonitrile (**3ad**):* Yield: 66% (43.5 mg); colourless solid; mp: 209 – 210 ^oC; ^1H NMR: (600 MHz, $CDCl_3$) δ 7.30 (dd, *J* = 7.2 Hz, 4.8 Hz, 1 H), 7.47 – 7.50 (comp, 2 H), 7.56 (td, *J* = 7.2 Hz, 1.2 Hz, 1 H), 7.64 – 7.66 (comp, 2 H), 7.74 (s, 1 H), 7.82 (td, *J* = 7.8 Hz, 1.8 Hz, 1 H), 7.87 (dd, *J* = 7.8 Hz, 1.2 Hz, 1 H), 7.90 (dd, *J* = 7.2 Hz, 1.2 Hz, 1 H), 8.26 (dd, *J* = 7.8 Hz, 1.2 Hz, 1 H), 8.45 (dd, *J* = 4.8 Hz, 1.2 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 109.9, 116.7, 117.1, 118.0, 119.4, 125.1, 127.7, 128.1, 128.5, 128.6, 129.2, 132.2, 132.7, 133.8, 134.2, 140.0, 144.4, 148.2; HRMS: (EI, m/z) calcd for $C_{20}H_{12}ClN_3$ $[M]^+$ 329.0720, observed 329.0722.

*2-(9H-pyrido[2,3-b]indol-9-yl)benzonitrile (**3ae**):* Yield: 72% (38.7 mg); colourless solid; mp: 139 – 140 ^oC; ^1H NMR: (600 MHz, $CDCl_3$) δ 7.29 – 7.32 (comp, 2 H), 7.41 (app t, *J* = 7.2 Hz, 1 H), 7.52 (app t, *J* = 7.8 Hz, 1 H), 7.64 (app t, *J* = 7.8 Hz, 1 H), 7.70 (app d, *J* = 7.8 Hz, 1 H), 7.86 (dt, *J* = 7.8 Hz, 1.8 Hz, 1 H), 7.97 (dd, *J* = 7.2 Hz, 1.8 Hz, 1 H), 8.17 (app d, *J* = 7.8 Hz, 1 H), 8.43 (dd, *J* = 7.8 Hz, 1.2 Hz, 1 H), 8.52 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 110.1, 123.2, 116.3, 116.7, 116.9, 121.3 (2 C), 121.5, 127.2, 128.6, 128.7, 129.7, 134.1, 134.3, 139.0, 139.6, 146.5, 151.9; HRMS: (ESI, m/z) calcd for $C_{18}H_{11}N_3Na$ $[M+Na]^+$ 292.0851, observed 292.0858.

*5-methyl-2-(9H-pyrido[2,3-b]indol-9-yl)benzonitrile (**3af**):* Yield: 81% (46 mg); colourless solid; mp: 166 – 168 ^oC; ^1H NMR: (600 MHz, $CDCl_3$) δ 2.54 (s, 3 H), 7.29 – 7.31 (comp, 2 H), 7.39 (app t, *J* = 7.2 Hz, 1 H), 7.52 (app t, *J* = 7.8 Hz, 1 H), 7.57 (app d, *J* = 7.8 Hz, 1 H), 7.66 (app d, *J* = 8.4 Hz, 1 H), 7.76 (d, *J* = 1.8 Hz, 1 H), 8.16 (app d, *J* = 7.8 Hz, 1 H), 8.42

(app d, J = 7.8 Hz, 1 H), 8.50 (dd, J = 4.8 Hz, 1.2 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 21.0, 110.1, 113.0, 116.4, 116.6, 116.7, 121.2 (2 C), 121.3, 127.2, 128.6, 129.5, 134.5, 134.9, 136.4, 139.2, 139.8, 146.5, 152.0; HRMS: (EI, m/z) calcd for $C_{19}H_{13}N_3$ $[M]^+$ 283.1109, observed 283.1110.

Synthetic transformation of cyanated products 3a:

Synthesis of (2-(1*H*-pyrrolo[2,3-*b*]pyridin-1-yl)phenyl)methanamine (4):

Following literature procedure,[11a] to a solution of **3a** (43.8 mg, 0.2 mmol) in THF (2 mL) $LiAlH_4$ (15.2 mg, 0.4 mmol) was added portion wise at 0 °C. Then the reaction mixture was allowed to come at room temperature and stirred for 1 h. The reaction mixture was diluted with Et_2O, cooled to 0 °C and quenched with 15% aq. NaOH followed by $MgSO_4$. It was stirred for another 15 min and filtered to remove the salts. After regular extraction with ethyl acetate the combined organic layers were dried over Na_2SO_4 and concentrated in vacuo. The crude residue was purified by column chromatography on basic alumina using dichloromethane/methanol as eluent to obtain **4** (22.7 mg, 51% yield).

Yield: 51% (22.7 mg); Brown gummy; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 3.62 (s, 2 H), 6.67 (d, J = 3.6 Hz, 1 H), 7.14 (dd, J = 7.8 Hz, 4.8 Hz, 1 H), 7.33 – 7.34 (comp, 2 H), 7.42 (app t, J = 7.8 Hz, 1 H), 7.50 (app t, J = 7.8 Hz, 1 H), 7.61 (app d, J = 7.8 Hz, 1 H), 8.01 (app d, J = 7.8 Hz, 1 H), 8.32 (app d, J = 4.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 42.5, 101.2, 116.4, 120.5, 127.9, 128.4, 129.0, 129.1, 129.2, 129.5, 136.2, 140.9, 143.7, 148.5; HRMS**:** (ESI, m/z) calcd for $C_{14}H_{14}N_3$ $[M+H]^+$ 224.1188, observed 224.1174.

Synthesis of 2-(1*H*-pyrrolo[2,3-*b*]pyridin-1-yl)benzamide (5):

Following literature procedure,[11a] To a solution of **3a** (43.8 mg, 0.2 mmol) in ^{t}BuOH (1 mL) solid KOH (210 mg, 3.7mmol) was added and the reaction mixture was heated at 60 °C for 4 h. After cooling to room temperature ^{t}BuOH was removed in vacuo. After regular extraction with ethyl acetate the combined organic layers were dried over Na_2SO_4 and concentrated in vacuo to obtain **5** (46.5 mg, 98%).

Yield: 98% (46.5 mg); Colourless solid; mp: 160 – 161 ^{o}C; ^{1}H NMR: (600 MHz, $CDCl_3$) δ 5.69 (br s, 1 H), 6.04 (br s, 1 H), 6.67 (d, *J* = 3.6 Hz, 1 H), 7.15 (dd, *J* = 7.8 Hz, 4.8 Hz, 1 H), 7.38 (d, *J* = 3.6 Hz, 1 H), 7.44 (app d, *J* = 7.8 Hz, 1 H), 7.53 (app t, *J* = 7.2 Hz, 1 H), 7.60 (td, *J* = 7.2 Hz, 1.8 Hz, 1 H), 7.84 (dd, *J* = 8.4 Hz, 1.8 Hz, 1 H), 8.01 (dd, *J* = 7.8 Hz, 1.2 Hz, 1 H), 8.29 (dd, *J* = 4.8 Hz, 1.8 Hz, 1 H); ^{13}C NMR: (150 MHz, $CDCl_3$) δ 102.0, 116.8, 120.9, 128.5, 128.7, 129.5, 129.7 (2 C), 131.4, 133.9, 135.0, 143.6, 148.6, 169.1; HRMS: (ESI, m/z) calcd for $C_{14}H_{11}N_3ONa$ $[M+Na]^+$ 260.0800, observed 260.0795.

Mechanistic experiments:

(a) Procedure for H/D exchange experiment:

To an oven dried 10 mL schlenk tube 150 mg (0.8 mmol) of **1a** was weighed. To that NaOAc (31mg, 50 mol%), AgOTf (58 mg, 30 mol%) and $[RuCl_2(p\text{-cymene})]_2$ (23 mg, 5 mol%) were added. Next it was degassed and backfilled with nitrogen. Under nitrogen 3.8 mL D_2O and 7.7 mL of anhydrous DCE was added. Then it was degassed and backfilled with nitrogen (3 times). The tube was closed with a teflon-lined cap and kept on stirring in an oil bath. The bath temperature was slowly increased to 110 ^{o}C. After 30 h, the reaction was stopped and cooled to

room temperature. The reaction mixture was filtered through a short pad of celite and concentrated under vacuo. The crude reaction mixture was directly purified by column chromatography on silica gel using pet ether/ethyl acetate as eluent to recover the starting material (123 mg, 82%). The deuterium incorporation (75%) was determined by ^{1}H NMR spectroscopy (see SI for details).

(b) Procedure for parallel experiment between 1a and 1a-d_5:

Two sets of parallel reactions (four each) of **1a** (19.4 mg, 0.1 mmol) and **1a-d_5** (20 mg, 0.1 mmol) were subjected under standard condition in 10 mL oven dried schlenk tubes. The reactions were quenched with ethyl acetate at four different time intervals. 48 μL (0.2 mmol) of tridecane (internal standard) was added in each reaction mixture and the percentage conversion was monitored by GC analysis. Primary Kinetic Isotopic Effect (KIE) was found to be 1.6 (see SI for details).

(c) Procedure for competitive experiment between 1a and 1a-d_5:

To an oven dried 10 mL schlenk tube a mixture of **1a** (19.4 mg, 0.1 mmol) and **1a-d_5** (20 mg, 0.1 mmol) were subjected under standard condition. After 2 h, the reaction was stopped and cooled to room temperature. The reaction mixture was filtered through a short pad of celite and concentrated under vacuo. The crude reaction mixture was directly purified by column chromatography on silica gel using pet ether/ethyl acetate as eluent. The ratio of **3a** and **3a-d_4** was determined by ^{1}H NMR spectroscopy. Primary Kinetic Isotopic Effect (KIE) was found to be 1.2 (see SI for details).

(d) Procedure for competitive experiment between 1a and 1f:

To an oven dried 10 mL schlenk tube a mixture of **1a** (19.4 mg, 0.1 mmol) and **1f** (20 mg mg, 0.1 mmol) were subjected under standard condition. After 30 h, the reaction was stopped and cooled to room temperature. The reaction mixture was filtered through a short pad of celite and concentrated under vacuo. The crude reaction mixture was directly purified by column chromatography on silica gel using pet ether/ethyl acetate as eluent to obtain pure **3a** (10.7 mg) and **3f** (7.6 mg) in 49% and 30% yields respectively.

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ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website. http://pubs.acs.org.

Experimental procedures, characterization data, ^{1}H and ^{13}C NMR spectra of all new compounds (PDF)

Single crystal X-ray diffraction data for compounds **3q** (CIF)

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Notes

The authors declare no competing financial interest.

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