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α-D-Galacturonic Acid as Natural Ligand for Selective Copper-Catalyzed *N*-Arylation of *N*-Containing Heterocycles

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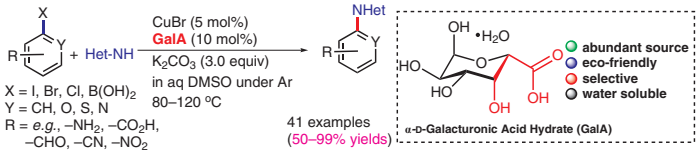

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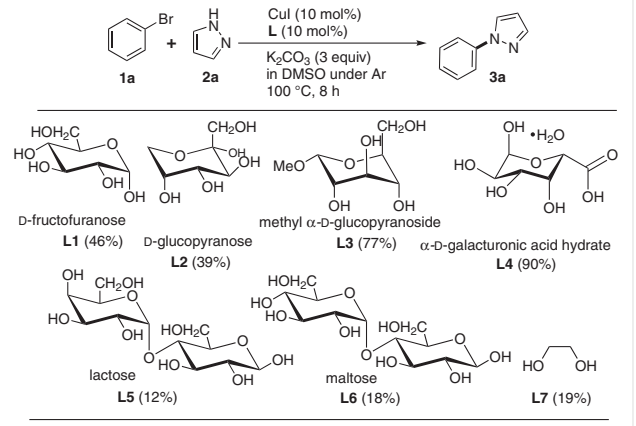
Abstract The first application of α-D-galacturonic acid hydrate (GalA) is reported here, as a potential *O*-donor ligand. The C–N couplings of *N*-heterocycles with aryl halides or arylboronic acids could be readily conducted and exhibited good functional group tolerance with characters of selectivity. These *N*-arylazoles allow rapid access to several pharmaceutical intermediates and can be easily transformed into a variety of other interesting scaffolds as well.

Key words α-D-galacturonic acid hydrate, C–N couplings, *N*-arylation, Cu catalyst, ligand

N-Arylazoles provide access to important subunits and precursors of numerous biologically active compounds, natural products, and pharmaceuticals.[1] Particularly, they account for a crucial section of the top-selling drugs including anti-inflammatory drug (celecoxib[2] and tepoxalin[3]), anticoagulant drug (apixaban[4]), antineoplastic medicine (nilotinib[5]), and psychiatric medicine (sertindole[6]). For elaboration of these synthetically challenging molecules, Ullmann-type coupling reactions[7] have becoming a practical and flexible protocol due to the low cost and less toxicity of the copper catalyst.[8,9] Copper-catalyzed couplings promoted by bidentate chelating ligands have been utilized to facilitate *N*-arylations over the succeeding two decades,[10] including β-keto ester,[11] 4,7-dimethoxy-1,10-phenanthroline,[12,13] *N*,*N*′-dimethyl-1,2-cyclohexanediamine,[14,15] amino acid,[16,17] salicylaldoxime,[18] pipecolinic acid,[19] hippuric acid,[20] 8-hydroxyquinoline and its derivatives,[21,22] and ethyl 2-oxocyclohexane-1-carboxylate.[23]

Many reported useful ligands are not commercially available in industrial scale, which might suffer from high costs in large-scale manufacture. Besides, the toxicity, sustainability, and pollution of these ligands must be taken into serious consideration for meeting the requirements of green chemistry. As results, we are devoting to develop a natural product as ligand for Cu-catalyzed C–N coupling reactions. Noteworthy is that abundant natural carbohydrates have recently attracted a great many of interest in organic synthesis due to the ability of increasing the efficiency of the co-catalyst system by coordinating the metal center as *O*,*O*-polydentate ligands.[24,25] As a result, commercially available monosaccharides and disaccharides were screened by performing the Cu-catalytic *N*-arylation reaction of bromobenzene with pyrazole under the basic conditions, as described in Scheme 1. Accordingly, α-D-galacturonic acid (GalA) ***L4*** was identified as a potent Cu chelating ligand for C–N couplings with a yield of 90% for **3a**. GalA is the monomer of polygalacturonic acid which forms the backbone of pectin in the plant cell walls.[26] GalA also exhibits various biological activities, is used in the treatment of cancer[27,28] and as coloring agent.[29] Herein, we show numer-



Scheme 1 Screening of *O*,*O*-type ligands for Cu-catalytic *N*-arylation reaction of bromobenzene with pyrazole

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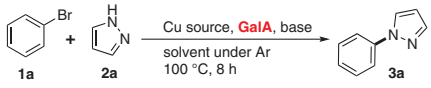
ous coupling reactions of *N*-containing heterocycles with aryl halides or arylboronic acids catalyzed by Cu/GalA and wish to disclose these results.

Optimal conditions were explored by examining the reaction of bromobenzene and pyrazole at 100 °C under argon (Table 1). Initially, Cu(I) or Cu(II) sources were screened in the presence of K_2CO_3, and GalA. The C–N coupling product **3a** was easily obtained in >80% yield using 10 mol% Cu(I) as catalyst except of Cu_2O (Table 1, entries 1–4). With the use of Cu_2SO_4, no desired product was observed (Table 1, entry 5). Considering economy and stability, CuBr was chosen, and it was also efficient with 5 mol% catalytic loading (Table 1, entry 6). Further studies revealed a significant effect of bases, with K_2CO_3 and Cs_2CO_3 proving to be optimal in terms of yield (Table 1, entries 7–10). K_2CO_3 was used for the following research as it was inexpensive. Polar solvents (DMSO, H_2O, and CH_3CN) favored this reaction, with 50% aq DMSO being the most effective (Table 1, entries 11–14). In order to investigate its effectiveness, a scale-up experiment of 5 g loading was carried out to provide **3a** in 93% yield, proving the stability of this catalyst system (Table 1, entry 15).

Table 1 Identification of Reaction Conditions[a]

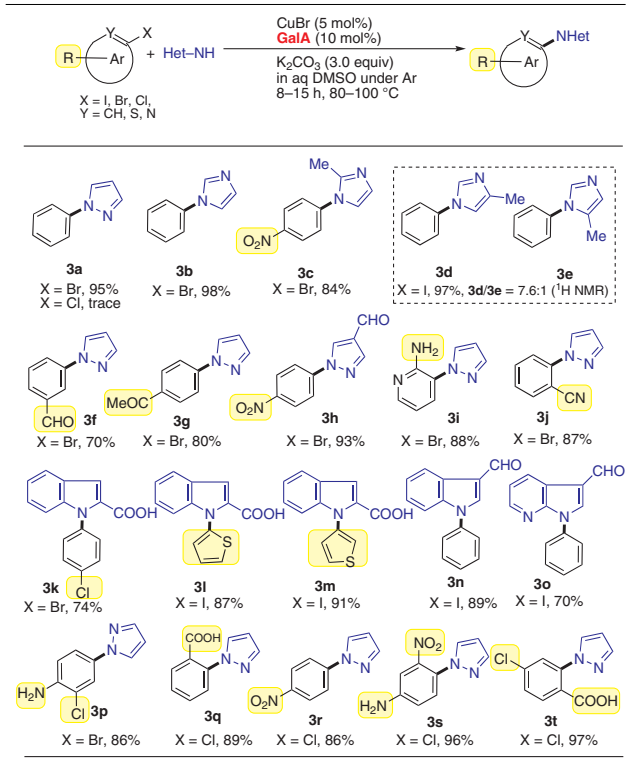


Entry	Cu (mol%)	Base	Solvent	Yield (%)[b]
1	CuI (10)	K_2CO_3	DMSO	90
2	CuBr (10)	K_2CO_3	DMSO	92
3	CuCl (10)	K_2CO_3	DMSO	84
4	Cu_2O (10)	K_2CO_3	DMSO	trace
5	$CuSO_4$ (10)	K_2CO_3	DMSO	0
6	CuBr (5)	K_2CO_3	DMSO	92
7	CuBr (5)	Cs_2CO_3	DMSO	94
8	CuBr (5)	$KHCO_3$	DMSO	0
9	CuBr (5)	$K_3PO_4{\cdot}3H_2O$	DMSO	77
10	CuBr (5)	KOH	DMSO	17
11	CuBr (5)	K_2CO_3	DMSO–H_2O	95
12	CuBr (5)	K_2CO_3	H2O	31
13	CuBr (5)	K_2CO_3	CH_3CN	70
14	CuBr (5)	K_2CO_3	toluene	trace
15[c]	CuBr (5)	K_2CO_3	DMSO–H_2O	93

[a] Standard conditions: **1a** (0.8 mmol), **2a** (1.0 mmol), 10 mol% GalA, base (2.4 mmol), aq DMSO (50%, 2.0 mL), 100 °C, 8 h, unless noted otherwise.
[b] Isolated yield.
[c] The loading of **1a** was 5 g, and the reaction time was prolonged to 24 h.

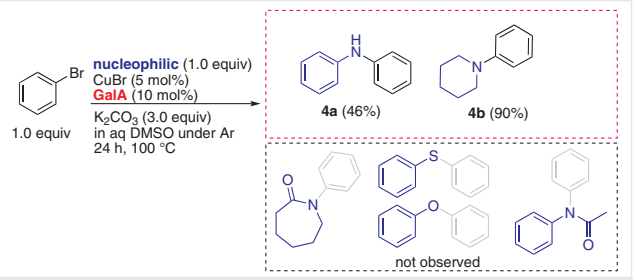
To exploit the potential of our established method, this protocol was investigated with diverse aryl halides and *N*-heterocycles, as described in Table 2. The Cu/GalA-catalyzed couplings of simple aryl bromides or aryl iodides with azoles provided *N*-arylazoles in literally quantitative yields (70–98%). It was found that the catalyst system was generally applicable to both electron-rich and electron-deficient substrates. Moreover, a range of reactive functional groups (e.g., NH_2, CHO, COOH, CN) proved to be compatible, and coupling products, such as **3–j**,**q**, were obtained in moderate to excellent yields. Noteworthy was that the coupling of asymmetric imidazole with iodobenzene could give two imidazole tautomers **3d** and **3e** with a ratio of 7.6:1 (from ^{1}H NMR analysis) in 97% yield. The sterically hindered 2-methylimidazole could also undergo *N*-arylation with 4-nitrobromobenzene to give **3c** in 84% yield. Unfortunately, chlorobenzene just resulted in trace amounts of **3a**. Attempts to use electron-deficient chlorobenzene to couple with pyrazole under standard conditions were successful, yielding related *N*-arylazoles in excellent yields (**3q–t**). Encouraged by these results, we focused on the challenging substrates with poor nucleophilicity induced by neighboring heteroatom or heteroaryl amines.[30] To our delight, the inferior nucleophiles such as indole and pyridopyrrole were found to be effective nucleophilic counterparts for the coupling process (**3k–o** in 70–91% yield).

Table 2 Scope with Respect to Aryl Halides and *N*-Heterocycles[a,b]



[a] Reaction conditions: aryl halide (0.8 mmol), *N*-heterocycle (1.0 mmol), CuBr (5 mol%), GalA (10 mol%), K_2CO_3 (2.4 mmol), aq DMSO (50%, 2.0 mL), 80–100 °C, 8–15 h.
[b] Isolated yield.

The preceding results revealed that **3p** could be exclusively obtained without formation of diaryl amine, indicating that the catalyst system may exhibit selectivity towards construction of *N*-arylazoles. Subsequently, to further investigate the application of CuBr/GalA catalyst system, a series of nucleophiles were reacted with bromobenzene under the standard conditions (Scheme 2). Only aliphatic amines and aromatic amines were able to produce C–N coupling products, with aniline and piperidine affording the desired compounds in 46% and 90% yields, respectively. However, neither phenols and thiols nor amides could perform such reactions.

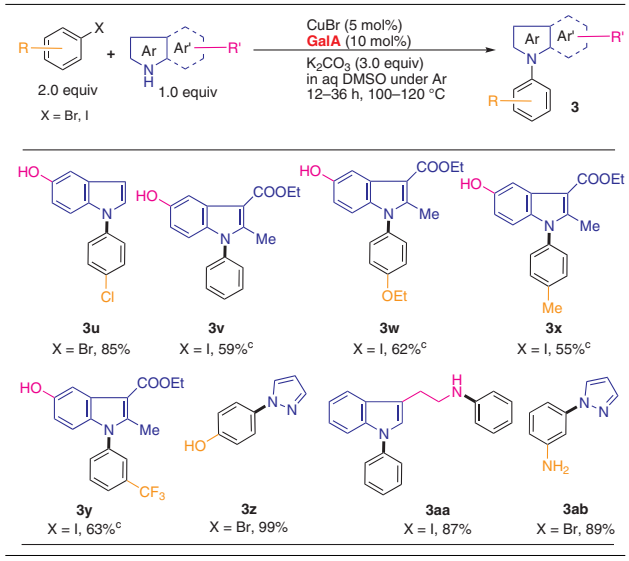


Scheme 2 Coupling reactions of bromobenzene and other nucleophiles using CuBr/GalA catalyst system

We then explored the selectivity by using bifunctional reagents and aryl halides (2.0 equiv), and the results are summarized in Table 3. Not surprisingly, most sensitive functional groups (e.g., OH and NH_2) were inferior to this catalyst system, and the selective *N*-arylation products from multifunctional substrates were obtained in moderate to excellent yields. Remarkably, the 2-methyl-5-hydroxyindolecarboxylate, of interest to us in the optimization of NorA efflux pump inhibitors,[31] is unusually resistant to hydrolysis due to the electron-donating indole. In these cases, prolonged reaction time and elevated temperature (120 °C) were required for benign conversion because of the large steric hindrance and electron-deficient indole. Interestingly, even under severe reaction conditions, the C–O coupling products were not observed, only providing the *N*-arylazoles in 55–63% yield along with unreacted starting material. However, the coupling of iodobenzene (2.0 equiv) with tryptamine provided diarylation products **3aa** in 87%, proving that CuBr /GalA catalytic system could also facilitate the C–N coupling reactions for assembly of aryl amines, which was consistent with the result of competition reactions.

Ma et al. discovered that NHCOR groups in *o*-haloacetanilides could greatly promote the Ullmann-type biaryl formation reaction, which in combination with the known ligand effect led to this reaction occurred at mild condition.[19] Accordingly, several substituted *o*-haloanilides were utilized to react with pyrazole via our catalyst system (Table 4). Surprisingly, intramolecular C–O or C–N bond formation occurred more readily in most cases, and a series of benz-

Table 3 Coupling Reaction for the Synthesis of Highly Functional Azoles with Aryl Halides and N-Heterocycles[a,b]



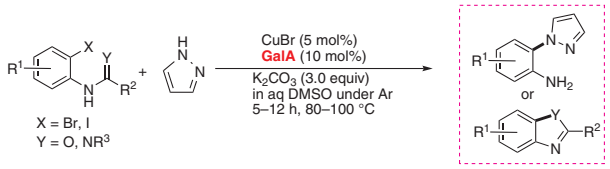
[a] Reaction conditions: aryl halide (2.0 mmol), *N*-heterocycle (1.0 mmol), CuBr (5 mol%), GalA (10 mol%), K_2CO_3 (3 mmol), aq DMSO (50%, 2.0 mL), 100 °C, 12 h, unless noted otherwise.
[b] Isolated yield.
[c] Temperature was 120 °C, reaction time was extended to 36 h.

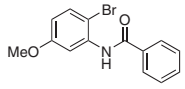
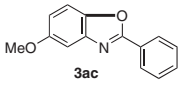
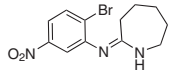
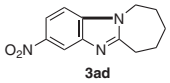
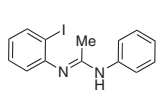
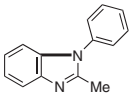
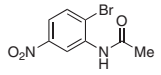
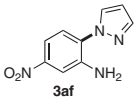
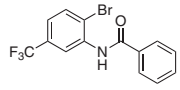
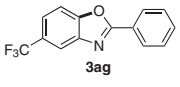
imidazoles and benzoxazoles were conveniently obtained in good yield (70–88%). Arguably, this protocol has offered a new strategy for the synthesis of benzimidazoles and benzoxazoles which are ubiquitous structural motifs in numerous biologically active compounds.[32] Exceptionally, we found that *N*-acetyl *o*-haloaniline mainly transformed to *N*-arylazole **3ak** in 50% yield along with a hydrolysis process as acetamide was more easily hydrolyzed than benzamide.

Over the past decade, Chan–Evans–Lam (CEL) couplings of arylboronic acids with nucleophiles in the presence of catalytic amounts of copper have been developed.[33] We therefore decided to explore the feasibility for the CEL reaction of arylboronic acids with azoles in aqueous solution (Table 5). We were pleased to find that arylboronic acids afforded *N*-arylazoles in excellent yield (>89%) upon heating to 40–60 °C for 3–6 hours. The Cu/GalA-catalyzed CEL reaction typically run to quantitative conversion into products, and the common side reactions such as deboration and homocoupling did not occur. In these cases, the workup procedure was convenient just through extraction with ethyl acetate.

Finally, to gain insight into the mechanism, the coupling of the radical clock 1-allyloxy-2-iodobenzene with pyrazole was performed to determine whether the aryl halide activation step proceeds via radical intermediates (Scheme 3).[34] Results showed that no conversation of ring closure product **3ap** was observed, and only the C–N coupling compound **3ao** was afforded. Thus, this catalytic reaction might run via a prototypical Cu(I)/Cu(III) catalytic cycle instead of a radi-

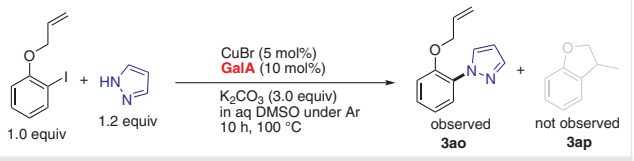
Table 4 CuBr/GalA-Catalyzed Coupling Reaction of *o*-Haloanilides with Pyrazole[a]



Entry	Substrate	Product	Temp (°C)	Time (h)	Yield (%)[b]
1		 **3ac**	100	12	72[c]
2		 **3ad**	80	12	86[c]
3		 **3ae**	80	5	70[c]
4		 **3af**	80	5	50[d]
5		 **3ag**	80	5	88[c]

[a] Reaction conditions: *o*-haloanilide (0.8 mmol), pyrazole (1.0 mmol), CuBr (5 mol%), GalA (10 mol%), K_2CO_3 (2.4 mmol), aq DMSO (50%, 2.0 mL), 80–100 °C, 5–12 h.
[b] Isolated yield.
[c] No intermolecular coupling product with pyrazole was detected.
[d] Intramolecular coupling products were not observed.

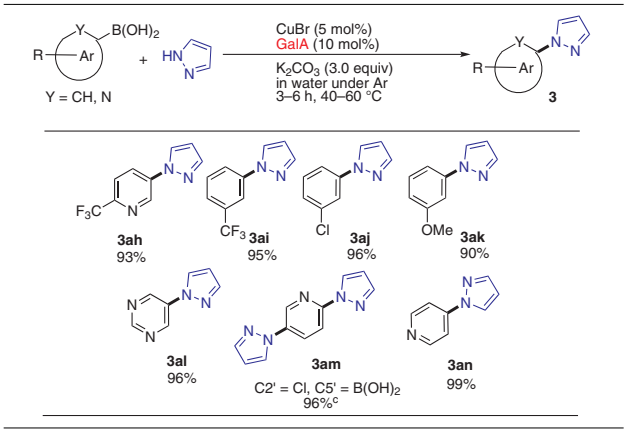
cal pathway.[35] As shown in Scheme 4, the catalytic cycle initiated from a Cu(I) complex **A**. Then, coordinated Cu(III) species **B** was produced via oxidative addition of an ArX and **A**. Subsequently, ligand exchange would occur between **A** and *N*-heterocycles to form intermediate **C**, which could be converted into **D** with assistance of base. The *N*-arylazole was afforded through final reductive elimination of **D**.



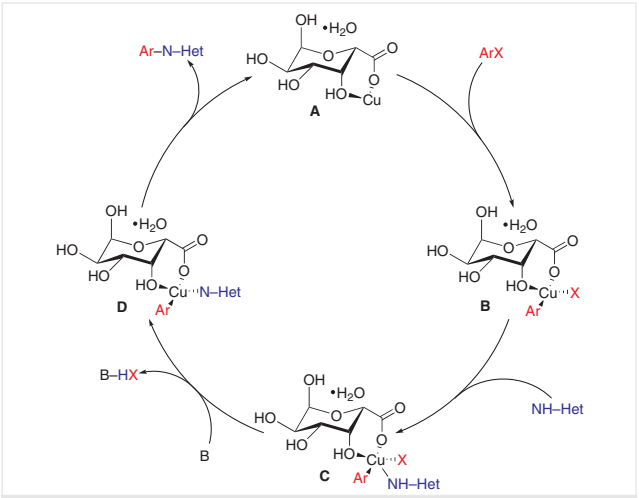
Scheme 3 Reaction of 2-(allyloxy)iodobenzene with pyrazole to determine if the aryl halide activation step proceeds via radical intermediates

In summary, we have developed an efficient and environmentally friendly catalyst system for the assembly of *N*-arylazoles with aryl halides or arylboronic acids and related

Table 5 CuBr/GalA-Catalyzed Couplings of Arylboronic Acids with Pyrazole[a,b]



[a] Reaction conditions: arylboronic acid (1.0 mmol), pyrazole (1.0 mmol), CuBr (5 mol%), GalA (10 mol%), K_2CO_3 (3.0 mmol), H_2O (2.0 mL), 40–60 °C, 3–6 h.
[b] Isolated yield.
[c] Pyrazole (2.0 mmol).



Scheme 4 Proposed mechanism for cross-coupling reactions of (hetero)aryl halides with *N*-containing heterocycles

N-heterocycles, where a natural monosaccharide GalA was first employed.[59,60] This novel catalyst system has shown high selectivity towards *N*-arylazole formation against many other competitive nucleophiles, and enjoyed a large scope with respect to *N*-containing heterocycles and aryl halides or arylboronic acids. On the other hand, GalA contains multiple chiral centers, which may open a new scope for enantiopure synthesis of various important optically active *N*-arylazoles in a cheap and environmentally friendly way. Applications of GalA to other coupling reactions, along with detailed mechanistic studies, are in progress.

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Supporting Information

Supporting information for this article is available online at https://doi.org/10.1055/s-0039-1690226.

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(59) **General Procedure**
All of the starting materials, reagents, and solvents are commercially available and used without further purification. Melting points were determined with a X-4 apparatus and were uncorrected. The nuclear magnetic resonance (NMR) spectra were recorded on a Bruker 400 MHz spectrometer in $CDCl_3$ or DMSO-d_6 using tetramethylsilane (TMS) as an internal standard. Electrospray ionization mass spectrometry (MS (ESI)) analyses were recorded in an Agilent 1100 Series MSD Trap SL (Santa Clara, CA, USA). The reactions were monitored by thin-layer chromatography (TLC: HG/T2354-92, GF254), and compounds were visualized on TLC with UV light.
(60) **General Procedure for Catalytic Experiments**
To a 10 mL vial was charged with aryl halide (0.8 mmol), *N*-containing heterocycle (1.0 mmol), CuBr (0.04 mmol), GalA (0.08 mmol), K_2CO_3 (2.4 mmol), and 50% aq DMSO. The flask was evacuated and backfilled with argon three times, and the reaction mixture was stirred at appropriate temperature under oil bath for the indicated time. After the complete consumption of aryl halide monitored by TLC, the mixture was then cooled to ambient temperature (if the product was acidic, the mixture was acidified), diluted with ethyl acetate (5 mL), filtered via a Celite pad, and washed with ethyl acetate (10–20 mL). The organic layer was separated by the separating funnel, which was washed successively with water (2 × 10 mL) and brine (2 × 10 mL). The organic layer was dried over anhydrous $MgSO_4$ and concentrated by reduced pressure in a rotary evaporator, which was then purified by column chromatography on silica gel to provide the desired products.

1-Phenyl-1*H*-pyrazole (3a)[36]
Yield: 0.109 g (95%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.93–7.92 (d, *J* = 2.4 Hz, 1 H), 7.73–7.68 (m, 3 H), 7.47–7.43 (m, 2 H), 7.30–7.25 (m, 1 H), 6.46 (t, *J* = 2.3 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 141.0, 129.3, 126.7, 126.4, 119.1, 107.5 ppm. MS (ESI$^+$): *m/z* = 145.04 [M + H]$^+$.

1-Phenyl-1*H*-imidazole (3b)[37]
Yield: 0.113 g (98%), colorless oil. ^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.28 (s, 1 H), 7.77 (s, 1 H), 7.67–7.64 (m, 2 H), 7.54–7.50 (m, 2 H), 7.37 (t, *J* = 7.4 Hz, 1 H), 7.14 (s, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 137.3, 135.5, 130.3, 129.8, 127.4, 121.4, 118.2 ppm. MS (ESI$^+$): *m/z* = 145.04 [M + H]$^+$.

2-Methyl-1-(4-nitrophenyl)-1*H*-imidazole (3c)[38]
Yield: 0.136 g (84%), light yellow solid; mp 128–130 °C (lit. mp 140–142 °C). ^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.38 (d, *J* = 9.0 Hz, 2 H), 7.78 (d, *J* = 9.0 Hz, 2 H), 7.45 (d, *J* = 1.3 Hz, 2 H), 7.0 (d, *J* = 1.2 Hz, 1 H), 2.38 (s, 3 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 146.8, 144.4, 143.1, 128.7, 125.7, 125.1, 120.1, 14.1 ppm. MS (ESI$^+$): *m/z* = 204.05 [M + H]$^+$.

4-Methyl-1-phenyl-1*H*-imidazole (3d)[39] and 5-Methyl-1-phenyl-1*H*-imidazole (3e)[40]
Yield: 0.123 g (97%), yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$, **3d**/**3e** = 7.6:1): δ = 7.76 (d, *J* = 1.3 Hz, 1 H), 7.57 (br, 0.13 H), 7.50–7.49 (m, 0.2 H), 7.48–7.43 (m, 2 H), 7.37–7.33 (m, 3 H), 7.32–7.28 (m, 0.5 H), 7.01 (t, *J* = 1.0 Hz, 1 H), 6.91 (br, 0.13 H), 2.31 (d, *J* = 1.0 Hz, 3 H), 2.18 (d, *J* = 1.0 Hz, 0.42 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 139.5, 137.5, 134.6, 129.8, 129.5, 128.3, 127.1, 125.6, 121.1, 114.6, 13.7 ppm. MS (ESI$^+$): *m/z* = 159.09 [M + H]$^+$.

3-(1*H*-Pyrazol-1-yl)benzaldehyde (3f)[41]
Yield: 0.096 g (70%), off-white solid; mp 28–30 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.08 (s, 1 H), 8.19 (t, *J* = 1.8 Hz, 1 H), 8.05–8.02 (m, 2 H), 7.81–7.76 (m, 2 H), 7.64 (t, *J* = 7.9 Hz, 1 H), 6.52 (t, *J* = 2.1 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 191.4, 141.6, 136.5, 135.8, 130.2, 127.6, 125.9, 124.6, 119.0, 108.3 ppm. MS (ESI$^+$): *m/z* = 173.08 [M + H]$^+$.

1-(4-(1*H*-Pyrazol-1-yl)phenyl)ethan-1-one (3g)[42]
Yield: 0.119 g (80%), white solid; mp 101–104 °C (lit. mp 108 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.08–8.05 (m, 2 H), 8.02 (d, *J* = 2.5 Hz, 1 H), 7.83–7.81 (m, 2 H), 7.78 (d, *J* = 1.5 Hz, 1 H), 6.52 (t, *J* = 2.0 Hz, 1 H), 2.63 (s, 3 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 196.7, 143.2, 142.0, 134.7, 129.9, 126.8, 118.3, 108.5, 26.5 ppm. MS (ESI$^+$): *m/z* = 187.09 [M + H]$^+$.

1-(4-Nitrophenyl)-1*H*-pyrazole-4-carbaldehyde (3h)[43]
Yield: 0.162 g (93%), yellow solid; mp 158–160 °C (lit. mp 84 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.02 (s, 1 H), 8.55 (s, 1 H), 8.41–8.38 (m, 2 H), 8.23 (s, 1 H), 7.97–7.94 (m, 2 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 183.7, 146.6, 143.3, 142.6, 130.3, 126.6, 125.5, 119.7 ppm. MS (ESI$^+$): *m/z* = 218.34 [M + H]$^+$.

3-(1*H*-Pyrazol-1-yl)pyridin-2-amine (3i)[44]
Yield: 0.112 g (88%), brown oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.68 (br, 1 H), 8.08–8.06 (dd, *J* = 5.0 Hz, 1.6 Hz, 1 H), 7.77–7.75 (m, 2 H), 7.48–7.46 (dd, *J* = 7.7 Hz, 1.6 Hz, 1 H), 6.74–6.71 (q, *J* = 7.7 Hz, 5.0 Hz, 1 H), 6.48 (t, *J* = 2.1 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 152.7, 146.6, 140.9, 143.3, 130.4, 129.6, 121.6, 113.2, 107.1 ppm. MS (ESI$^+$): *m/z* = 161.03 [M + H]$^+$.

2-(1*H*-Pyrazol-1-yl)benzonitrile (3j)[45]
Yield: 0.118 g (87%), yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.15 (d, *J* = 2.5 Hz, 1 H), 7.81–7.70 (m, 3 H), 7.73–7.69 (dt, *J* = 7.6 Hz, 1.5 Hz, 1 H), 7.45–7.41 (dt, *J* = 7.6 Hz, 1.0 Hz, 1 H), 6.55 (t, *J* = 2.1 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 142.3, 142.1, 134.5, 134.0, 129.5, 127.2, 124.3, 117.0, 108.5, 105.4 ppm. MS (ESI$^+$): *m/z* = 170.07 [M + H]$^+$.

1-(4-Chlorophenyl)-1*H*-indole-2-carboxylic Acid (3k)
Yield: 0.160 g (74%), white to pale grey solid; mp 227–230 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.75–7.73 (dt, *J* = 8.4 Hz, 0.9 Hz, 1 H), 7.57 (d, *J* = 0.7 Hz, 1 H), 7.50–7.47 (m, 2 H), 7.33–7.26 (m, 3 H), 7.23–7.19 (m, 1 H), 7.09–7.06 (m, 1 H) ppm. ^{13}C NMR (150 MHz, DMSO-d_6): δ = 162.2, 140.4, 137.5, 132.7, 130.1, 129.4, 126.6, 125.9, 121.7, 111.6 ppm. MS (ESI$^-$): *m/z* = 270.02 [M – H]$^-$.

1-(Thiophen-2-yl)-1*H*-indole-2-carboxylic Acid (3l)
Yield: 0.169 g (87%), white solid; mp 175–176 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.02 (s, 1 H), 8.55 (s, 1 H), 8.41–8.38 (m, 2 H), 8.23 (s, 1 H), 7.97–7.94 (m, 2 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 165.8, 142.4, 138.9, 128.9, 126.5, 126.0, 125.9,125.5, 125.0, 122.6, 121.9, 114.6, 111.8 ppm. MS (ESI$^-$): *m/z* = 241.99 [M – H]$^-$.

1-(Thiophen-3-yl)-1*H*-indole-2-carboxylic Acid (3m)
Yield: 0.177 g (91%), white to a pale grey solid; mp 190–192 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.74–7.71 (dt, *J* = 7.9 Hz, 1.0 Hz, 1 H), 7.55 (d, *J* = 0.6 Hz, 1 H), 7.43–7.41 (m, 1 H), 7.34–7.30 (m, 2 H), 7.22–7.17 (m, 2 H), 7.09–7.07 (q, *J* = 5.2 Hz, 1.4 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 165.8, 141.2, 135.8, 127.8, 126.8, 126.2, 125.9, 124.9, 122.6, 121.5, 121.2, 113.7, 111.7 ppm. MS (ESI$^-$): *m/z* = 242.02 [M – H]$^-$.

1-Phenyl-1*H*-indole-3-carbaldehyde (3n)[46]
Yield: 0.157 g (89%), brown oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.12 (s, 1 H), 8.40–8.38 (m, 1 H), 7.92 (s, 1 H), 7.61–7.57 (m, 2 H), 7.54–7.47 (m, 4 H), 7.39–7.32 (m, 2 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 184.9, 138.2, 138.1, 137.5, 130.0, 128.3, 125.6,

124.9, 124.6, 123.5, 122.3, 119.7, 111.1 ppm. MS (ESI$^+$): *m/z* = 222.07 [M + H]$^+$.

Phenyl-1*H*-pyrrolo[2,3-*b*]pyridine-3-carbaldehyde (3o)

Yield: 0.124 g (70%), yellow solid; mp 238–240 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.10 (s, 1 H), 8.69–8.66 (dd, *J* = 7.8 Hz, 1.6 Hz, 1 H), 8.49-8.48 (dd, *J* = 4.8 Hz, 1.6 Hz, 1 H), 8.12 (s, 1 H), 7.76–7.74 (m, 2 H), 7.62–7.57 (m, 2 H), 7.49–7.45 (m, 1 H), 7.36–7.33 (q, *J* = 7.8 Hz, 4.8 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 184.8, 148.5, 145.7, 137.5, 137.0, 130.8, 129.6, 128.0, 124.5, 119.5, 118.2, 117.6 ppm. MS (ESI$^+$): *m/z* = 223.12 [M + H]$^+$.

2-Chloro-4-(1*H*-pyrazol-1-yl)aniline (3p)

Yield: 0.133 g (86%), light yellow solid; mp 70–73 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.77 (d, *J* = 2.4 Hz, 1 H), 7.70 (d, *J* = 1.5 Hz, 1 H), 7.61 (d, *J* = 2.5 Hz, 1 H), 7.39–7.36 (dd, *J* = 8.6 Hz, 2.5 Hz, 1 H), 6.81 (d, *J* = 8.6 Hz, 1 H), 6.42 (t, *J* = 2.1 Hz, 1 H), 4.09 (br, 2 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 144.5, 141.2, 131.4, 128.4, 120.7, 119.9, 118.2, 116.7, 108.3 ppm. MS (ESI$^+$): *m/z* = 194.05 [M + H]$^+$.

2-(1*H*-Pyrazol-1-yl)benzoic Acid (3q)[47]

Yield: 0.134 g (89%), white solid; mp 128–129 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.41 (br, 1 H), 8.06–8.04 (dd, *J* = 7.8 Hz, 1.1 Hz, 1 H), 7.77–7.75 (m, 2 H), 7.63–7.59 (m, 1 H), 7.50–7.46 (t, *J* = 7.5 Hz, 1 H), 7.43 (d, *J* = 7.8 Hz, 1 H), 6.49–6.48 (t, *J* = 2.1 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 168.8, 141.0, 138.6, 132.7, 132.3, 131.0, 128.2, 127.1, 125.7, 107.6 ppm. MS (ESI$^-$): *m/z* = 187.06 [M – H]$^-$.

1-(4-Nitrophenyl)-1*H*-pyrazole (3r)[36]

Yield: 0.130 g (86%), yellow solid; mp 167–168 °C (lit. mp 168.5–169 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.37–8.33 (m, 2 H), 8.04 (d, *J* = 2.6 Hz, 1 H), 7.91–7.87 (m, 2 H), 7.81 (d, *J* = 1.5 Hz, 1 H), 6.57–5.56 (q, *J* = 2.4 Hz, 1.9 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 140.8, 129.6, 125.6, 120.6, 119.3, 110.4 ppm. MS (ESI$^+$): *m/z* = 190.08 [M + H]$^+$.

3-Nitro-4-(1*H*-pyrazol-1-yl)aniline (3s)

Yield: 0.156 g (96%), yellow solid; mp 135–136 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.69 (d, *J* = 1.0 Hz, 1 H), 7.60 (d, *J* = 2.4 Hz, 1 H), 7.31 (d, *J* = 8.6 Hz, 1 H), 7.13 (d, *J* = 2.6 Hz, 1 H), 6.88–6.85 (dd, *J* = 8.6 Hz, 2.6 Hz, 1 H), 6.44 (t, *J* = 2.0 Hz, 1 H), 3.85 (br, 2 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 147.0, 145.7, 141.3, 130.3, 128.4, 124.3, 118.1, 109.9, 107.1 ppm. MS (ESI$^+$): *m/z* = 205.06 [M + H]$^+$.

4-Chloro-2-(1*H*-pyrazol-1-yl)benzoic Acid (3t)

Yield: 0.172 g (97%), pale grey solid; mp 237–240 °C. ^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.20 (d, *J* = 2.4 Hz, 1 H), 7.73–7.71 (m, 3 H), 7.57–7.54 (dd, *J* = 8.3 Hz, 2.0 Hz, 1 H), 6.51–6.50 (q, *J* = 2.4 Hz, 1.9 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, DMSO-d_6): δ = 168.5, 142.3, 140.4, 136.7, 132.5, 131.8, 128.5, 128.4, 125.4, 108.8 ppm. MS (ESI$^+$): *m/z* = 220.94 [M + H]$^+$, 222.93 [M + H]$^+$.

1-(4-Nitrophenyl)-1*H*-indol-5-ol (3u)

Yield: 0.216 g (85%), yellow solid; mp 188–191 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.40 (d, *J* = 9.0 Hz, 2 H), 7.67 (d, *J* = 9.0 Hz, 2 H), 7.53 (d, *J* = 8.8 Hz, 1 H), 7.36 (d, *J* = 3.3 Hz, 1 H), 7.09 (d, *J* = 2.4 Hz, 1 H), 6.87–6.84 (dd, *J* = 8.8 Hz, 2.4 Hz, 1 H), 6.66 (d, *J* = 3.2 Hz, 1 H), 4.60 (br, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 152.8, 145.2, 144.2, 131.5, 129.2, 128.6, 125.9, 122.8, 113.2, 111.9, 105.8, 105.7 ppm. MS (ESI$^-$): *m/z* = 253.06 [M – H]$^-$.

Ethyl 5-Hydroxy-2-methyl-1-phenyl-1*H*-indole-3-carboxylate (3v)[48]

Yield: 0.174 g (59%), brown solid; mp 203–205 °C (lit. mp 203–204 °C). ^{1}H NMR (600 MHz, DMSO-d_6): δ = 9.06 (s, 3 H), 7.63 (t, *J* = 7.4 Hz, 2 H), 7.57 (t, *J* = 7.3 Hz, 1 H), 7.47 (d, *J* = 2.3 Hz, 1 H), 7.45 (d, *J* = 7.3 Hz, 2 H), 6.78 (d, *J* = 8.7 Hz, 1 H), 6.65–6.63 (dd, *J* = 8.8 Hz, 2.4 Hz, 1 H), 4.33–4.30 (q, *J* = 14.2 Hz, 7.1 Hz, 2 H), 2.49 (s, 3 H), 1.38 (t, *J* = 7.1 Hz, 3 H) ppm. ^{13}C NMR (150 MHz, DMSO-d_6): δ = 165.6, 153.6, 145.3, 136.5, 131.9, 130.3, 129.3, 128.4, 127.5, 112.5, 111.2, 105.9, 104.0, 59.4, 15.0, 13.3 ppm. MS (ESI$^+$): *m/z* = 296.12 [M + H]$^+$.

Ethyl 1-(4-Ethoxyphenyl)-5-hydroxy-2-methyl-1*H*-indole-3-carboxylate (3w)

Yield: 0.210 g (62%), brown solid; mp 225–226 °C. ^{1}H NMR (600 MHz, DMSO-d_6): δ = 9.02 (s, 1 H), 7.45 (d, *J* = 2.2 Hz, 1 H), 7.33 (d, *J* = 8.8 Hz, 2 H), 7.13 (d, *J* = 8.8 Hz, 2 H), 6.75 (d, *J* = 8.6 Hz, 1 H), 6.63–6.61 (dd, *J* = 8.7 Hz, 2.3 Hz, 1 H), 4.32–4.29 (q, *J* = 14.2 Hz, 7.1 Hz, 2 H), 4.13–4.10 (q, *J* = 13.7 Hz, 6.9 Hz, 2 H), 2.46 (s, 3 H), 1.39–1.36 (q, *J* = 14.1 Hz, 7.0 Hz, 6 H) ppm. ^{13}C NMR (150 MHz, DMSO-d_6): δ = 165.6, 159.0, 153.5, 145.6, 132.3, 129.6, 128.8, 127.4, 115.8, 112.4, 111.2, 105.9, 103.6, 63.9, 59.3, 15.1, 15.0, 13.3 ppm. MS (ESI$^+$): *m/z* = 340.16 [M + H]$^+$.

Ethyl 5-Hydroxy-2-methyl-1-(*p*-tolyl)-1*H*-indole-3-carboxylate (3x)[49]

Yield: 0.170 g (55%), yellow solid; mp 190–192 °C. ^{1}H NMR (600 MHz, DMSO-d_6): δ = 9.03 (s, 1 H), 7.45–7.41 (m, 3 H), 7.31 (d, *J* = 7.5 Hz, 2 H), 6.77 (d, *J* = 8.5 Hz, 1 H), 6.63 (d, *J* = 8.1 Hz, 1 H), 4.32–4.29 (q, *J* = 14.0 Hz, 7.1 Hz, 2 H), 2.47 (s, 3 H), 2.43 (s, 3 H), 1.37 (t, *J* = 6.8 Hz, 3 H) ppm. ^{13}C NMR (150 MHz, DMSO-d_6): δ = 165.6, 153.5, 145.4, 138.9, 133.9, 132.0, 130.8, 128.2, 127.5, 112.4, 111.2, 105.9, 103.8, 59.4, 21.2, 15.0, 13.3 ppm. MS (ESI$^+$): *m/z* = 310.13 [M + H]$^+$.

Ethyl 5-Hydroxy-2-methyl-1-[3-(trifluoromethyl)phenyl]-1*H*-indole-3-carboxylate (3y)

Yield: 0.229 g (63%), white solid; mp 199–201 °C. ^{1}H NMR (600 MHz, DMSO-d_6): δ = 9.09 (s, 1 H), 7.96 (d, *J* = 7.8 Hz, 1 H), 7.92 (s, 1 H), 7.87 (t, *J* = 7.9 Hz, 1 H), 7.82 (d, *J* = 7.9 Hz, 1 H), 7.47 (d, *J* = 2.1 Hz, 1 H), 6.80 (d, *J* = 8.7 Hz, 1 H), 6.67–6.65 (dd, *J* = 8.7 Hz, 2.2 Hz, 1 H), 4.34–4.31 (q, *J* = 14.2 Hz, 7.1 Hz, 2 H), 1.38 (t, *J* = 7.1 Hz, 3 H) ppm. ^{13}C NMR (150 MHz, DMSO-d_6): δ = 165.5, 153.7, 145.4, 137.3, 132.9, 131.7, 131.6, 131.1 (*J* = 31.9 Hz), 127.6, 126.1 (*J* = 3.5 Hz), 125.4 (*J* = 3.8 Hz), 125.0, 123.2, 112.7, 111.0, 106.0, 104.5, 59.5, 15.0, 13.3 ppm. MS (ESI$^+$): *m/z* = 364.15 [M + H]$^+$.

4-(1*H*-Pyrazol-1-yl)phenol (3z)[50]

Yield: 0.158 g (99%), white solid; mp 99–101 °C (lit. mp 94–96 °C) ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.77–7.72 (m, 2 H), 7.41–7.37 (m, 2 H), 6.82–6.78 (m, 2 H), 6.45 (t, *J* = 2.1 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 155.6, 140.3, 132.9, 127.8, 121.9, 116.2, 107.1 ppm. MS (ESI$^+$): *m/z* = 161.02 [M + H]$^+$.

N-[2-(1-phenyl-1*H*-indol-3-yl)ethyl]aniline (3aa)

Yield: 0.271 g (87%), yellow solid; mp 85–87 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.67–7.65 (m, 1 H), 7.58–7.56 (m, 1 H), 7.53–7.46 (m, 1 H), 7.35–7.30 (m, 1 H), 7.26–7.16 (m, 5 H), 6.73–6.69 (m, 1 H), 6.66–6.63 (m, 2 H), 3.98 (br, 1 H), 3.53 (t, *J* = 6.9 Hz, 2 H), 3.16–3.12 (m, 2 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 148.0, 139.7, 136.1, 129.6, 128.8, 126.2, 125.7, 124.1, 122.6, 120.0, 119.1, 117.4, 114.4, 113.0, 110.6, 43.9, 25.0 ppm. MS (ESI$^+$): *m/z* = 313.18 [M + H]$^+$.

3-(1*H*-Pyrazol-1-yl)aniline (3ab)[51]

Yield: 0.141 g (89%), brown oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.89 (d, *J* = 2.3 Hz, 1 H), 7.70 (d, *J* = 1.5 Hz, 1 H), 7.20 (t, *J* = 8.0 Hz, 1 H), 7.10 (t, *J* = 2.2 Hz, 1 H), 7.01–6.99 (m, 1 H), 6.61–6.58 (m, 1 H), 6.44 (t, *J* = 2.0 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 147.6, 140.8, 130.2, 126.8, 113.1, 109.0, 107.3, 106.1 ppm. MS (ESI$^+$): *m/z* = 160.07 [M + H]$^+$.

5-Methoxy-2-phenylbenzo[*d*]oxazole (3ac)[52]

Yield: 0.129 g (72%), white solid; mp 66–69 °C (lit. mp 60–61 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.24–8.22 (m, 2 H), 7.52–7.51 (m, 3 H), 7.45 (d, *J* = 8.8 Hz, 1 H), 7.27 (d, *J* = 2.5 Hz, 1 H),

6.96–6.93 (dd, *J* = 2.6 Hz, 8.9 Hz, 1 H), 3.87 (s, 3 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 163.7, 157.3, 145.3, 142.8, 131.3, 128.8, 128.7, 127.4, 127.2, 113.7, 110.6, 102.8, 55.9 ppm. MS (ESI$^+$): *m/z* = 226.10 [M + H]$^+$.

3-Nitro-5a,6,7,8,9,10-hexahydro-5*H*-benzo[4,5]imidazo[1,2-*a*]azepine (3ad)

Yield: 0.160 g (86%), yellow solid; mp 171 °C (lit. mp 170–171 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.58 (d, *J* = 2.1 Hz, 1 H), 8.18 (dd, *J* = 9.0, 2.2 Hz, 1 H), 7.32 (d, *J* = 9.0 Hz, 1 H), 4.24–4.21 (m, 2 H), 3.17–3.14 (m, 2 H), 2.02–1.96 (m, 2 H), 1.92–1.82 (m, 4 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 161.2, 143.1, 141.6, 117.9, 115.8, 108.5, 45.1, 30.5, 30.1, 28.5, 25.1 ppm. MS (ESI$^+$): *m/z* = 232.14 [M + H]$^+$.

2-Methyl-1-phenyl-1*H*-benzo[*d*]imidazole (3ae)[53]

Yield: 0.116 g (70%), white solid; mp 62–65 °C (lit. mp 68 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.76 (d, *J* = 7.9 Hz, 1 H), 7.60–7.56 (m, 2 H), 7.54–7.49 (m, 1 H), 7.38–7.35 (m, 2 H), 7.29–7.24 (m, 1 H), 7.21–7.17 (m, 1 H), 7.14–7.12 (m, 1 H), 2.51 (s, 3 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 151.6, 142.7, 136.5, 136.1, 129.9, 128.8, 127.1, 122.6, 122.4, 119.0, 109.9, 14.5 ppm. MS (ESI$^+$): *m/z* = 209.11 [M + H]$^+$.

5-Nitro-2-(1*H*-pyrazol-1-yl)aniline (3af)

Yield: 0.081 g (50%), red solid; mp 100 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.83–7.80 (m, 2 H), 7.69 (d, *J* = 2.4 Hz, 1 H), 7.63–7.60 (dd, *J* = 8.7 Hz, 2.5 Hz, 1 H), 7.33 (d, *J* = 8.7 Hz, 1 H), 6.52 (t, *J* = 2.3 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 147.0, 141.3, 141.2, 129.9, 129.7, 123.1, 112.5, 111.9, 107.5 ppm. MS (ESI$^+$): *m/z* = 205.10 [M + H]$^+$.

2-Phenyl-5-(trifluoromethyl)benzo[*d*]oxazole (3ag)[52]

Yield: 0.185 g (88%), white solid; mp 83 °C (lit. mp 86–87 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.95 (d, *J* = 1.9 Hz, 1 H), 8.56 (br, 1 H), 7.96–7.93 (m, 2 H), 7.73–7.70 (m, 1 H), 7.64–7.60 (m, 1 H), 7.57–7.51 (m, 2 H), 7.29–7.26 (m, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 136.4, 133.9, 132.6, 132.5, 131.0 (*J* = 33.0 Hz), 129.0, 128.8, 127.0, 123.5 (*J* = 271.0 Hz), 121.5 (*J* = 3.5 Hz), 118.3 (*J* = 3.7 Hz), 116.8 ppm. MS (ESI$^+$): *m/z* = 264.05 [M + H]$^+$.

5-(1*H*-Pyrazol-1-yl)-2-(trifluoromethyl)pyridine (3ah)

Yield: 0.198 g (93%), white solid; mp 115–117 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.10 (d, *J* = 2.4 Hz, 1 H), 8.26–8.23 (dd, *J* = 8.5 Hz, 2.2 Hz, 1 H), 8.04 (d, *J* = 2.6 Hz, 1 H), 7.82 (d, *J* = 1.6 Hz, 1 H), 7.80 (d, *J* = 8.5 Hz, 1 H), 6.58–6.57 (q, *J* = 2.4 Hz, 1.8 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 145.4 (*J* = 36.0 Hz), 142.8, 140.1, 138.2, 126.8, 126.7, 121.3 (*J* = 273.1 Hz), 121.2 (*J* = 2.3 Hz), 109.3 ppm. MS (ESI$^+$): *m/z* = 214.08 [M + H]$^+$.

1-[3-(Trifluoromethyl)phenyl]-1*H*-pyrazole (3ai)[54]

Yield: 0.201 g (95%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.00 (br, 1 H), 7.98 (d, *J* = 1.9 Hz, 1 H), 7.90–7.88 (dt, *J* = 7.8 Hz, 0.9 Hz, 1 H), 7.76 (d, *J* = 1.4 Hz, 1 H), 7.60–7.53 (m, 2 H), 6.51 (t, *J* = 1.9 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 141.7, 140.4, 131.9 (*J* = 32.7 Hz), 130.0, 126.7, 123.6 (*J* = 271.2 Hz), 122.8 (*J* = 3.4 Hz), 121.9, 115.9 (*J* = 3.6 Hz), 108.3 ppm. MS (ESI$^+$): *m/z* = 213.05 [M + H]$^+$.

1-(3-Chlorophenyl)-1*H*-pyrazole (3aj)[55]

Yield: 0.171 g (96%), white solid; mp 27–29 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.93 (br, 1 H), 7.75 (t, *J* = 1.9 Hz, 1 H), 7.74 (br, 1 H), 7.60–7.57 (m, 1 H), 7.37 (t, *J* = 8.0 Hz, 1 H), 7.27–7.24 (m, 1 H), 6.49 (br, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 141.4, 141.0, 135.2, 130.4, 126.7, 126.3, 119.3, 116.9, 108.1 ppm. MS (ESI$^+$): *m/z* = 179.02 [M + H]$^+$, 181.03 [M + H]$^+$.

1-(3-Methoxyphenyl)-1*H*-pyrazole (3ak)[36]

Yield: 0.156 g (90%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.92–791 (dd, *J* = 2.4 Hz, 0.4 Hz, 1 H), 7.72 (d, *J* = 1.5 Hz, 1 H), 7.36–7.31 (m, 2 H), 7.24–7.21 (m, 1 H), 6.85–6.82 (m, 1 H), 6.46–6.45 (q, *J* = 2.4 Hz, 1.9 Hz, 1 H), 3.87 (s, 3 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 160.5, 141.3, 140.9, 130.1, 126.9, 112.3, 111.1, 107.5, 105.0, 55.4 ppm. MS (ESI$^+$): *m/z* = 175.10 [M + H]$^+$.

5-(1*H*-Pyrazol-1-yl)pyrimidine (3al)[56]

Yield: 0.140 g (96%), white solid; mp 88–90 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.16 (s, 1 H), 8.00 (d, *J* = 2.5 Hz, 1 H), 7.83 (d, *J* = 1.6 Hz, 1 H), 6.59 (t, *J* = 1.9 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 156.1, 147.0, 142.8, 134.6, 126.6, 109.2 ppm. MS (ESI$^+$): *m/z* = 147.05 [M + H]$^+$.

2,5-Di(1*H*-pyrazol-1-yl)pyridine (3am)[57]

Yield: 0.202 g (96%), white solid; mp 160–161 °C (lit. mp 162 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.78 (d, *J* = 1.5 Hz, 1 H), 8.59 (d, *J* = 2.4 Hz, 1 H), 8.19–8.10 (m, 2 H), 7.96 (d, *J* = 2.4 Hz, 1 H), 7.79 (d, *J* = 1.6 Hz, 1 H), 7.77 (s, 1 H), 6.54 (t, *J* = 2.1 Hz, 1 H), 6.50 (t, *J* = 2.0 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 149.6, 142.2, 141.8, 138.5, 134.8, 129.5, 127.1, 126.7, 112.8, 108.3, 108.0 ppm. MS (ESI$^+$): *m/z* = 212.10 [M + H]$^+$.

4-(1*H*-Pyrazol-1-yl)pyridine (3an)[55]

Yield: 0.143 g (99%), white solid; mp 72–74 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.71 (br, 2 H), 8.05 (d, *J* = 2.4 Hz, 1 H), 7.79 (d, *J* = 1.5 Hz, 1 H), 7.67 (d, *J* = 4.0 Hz, 2 H), 6.55–6.54 (q, *J* = 2.6 Hz, 1.8 Hz, 1 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 151.1, 145.9, 142.5, 126.5, 112.5, 109.0 ppm. MS (ESI$^+$): *m/z* = 146.02 [M + H]$^+$.

1-(2-(Allyloxy)phenyl)-1*H*-pyrazole (3ao)[58]

Yield: 0.160 g (84%), colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.09 (s, 1 H), 7.77–7.74 (dd, *J* = 7.9 Hz, 1.4 Hz, 1 H), 7.73 (s, 1 H), 7.30–7.25 (m, 1 H), 7.10–7.03 (m, 2 H), 6.44 (s, 1 H), 6.06–5.96 (m, 1 H), 5.39–5.33 (m, 1 H), 5.29–5.25 (m, 1 H), 4.61–4.59 (dt, *J* = 5.1 Hz, 1.5 Hz, 2 H) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 148.6, 140.6, 140.2, 131.4, 128.8, 127.6, 125.0, 123.1, 116.4, 108.4, 106.5, 69.7 ppm. MS (ESI$^+$): *m/z* = 201.12 [M + H]$^+$.