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Nickel(II) – N^N^O Pincer Type Complexes Catalyzed N-alkylation of Amines with Alcohols via Hydrogen Auto Transfer Reaction

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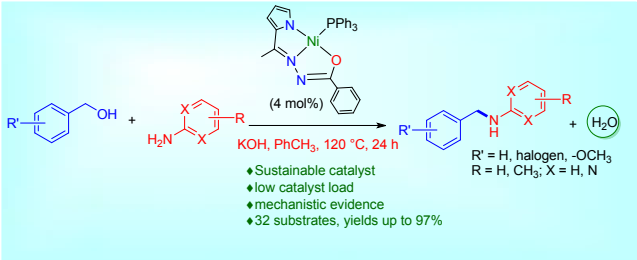
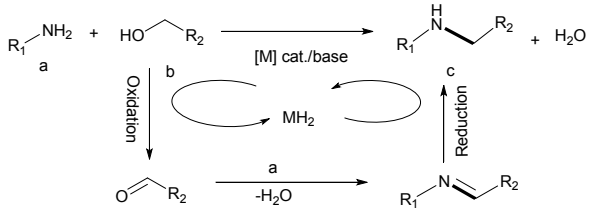


ABSTRACT: A highly sustainable catalytic protocol for the coupling of alcohols and amines to selective monoalkylated amines using Ni(II) N^N^O pincer type complexes through borrowing hydrogen methodology is described. An arrayof Ni(II) catalysts (**1-3**) was synthesized and characterized by various spectral and analytical methods. Further, the distorted square planar geometry of the complexes (**1** and **2**) was substantiated with single crystal X-ray diffraction study. The inexpensive nickel based catalytic methodology displays a broad substrate scope for the N-alkylation of aromatic and heteroaromatic amines using a diverse range of primary alcohols with excellent yields up to 97%. The present approach is environmentally benign which liberates water as the sole by-product. A short synthesis of drugs intermediate such as mepyramine and chloropyramine illustrates the utility of the present protocol.

INTRODUCTION

Production of chemical compounds or required materials from available feedstock using transition metal catalysts under environmentally benign conditions is the emerging field of catalysis chemistry.[1] particularly, the N-alkylation of amine reactions are of considerable interest due to the valuable alkylated amine products bearing carbon-nitrogen bonds which were found to be effective in the field of pharmaceuticals, material chemistry and agrochemicals (**Fig. 1**).[2] on the basis of their essentiality and utility in many fields of chemistry, a sequence of synthetic procedures have been developed to afford the amine products. In this connection, some classical synthetic routes like nucleophilic substitutions, buchwald–hartwig, ullmann reactions and hydroaminations have addressed well for the formation of a variety of amines. In fact, these methodologies were not successful to provide desired amines due to the formation of low yield, over alkylation and by-product salts.[3] There is a need by the science community in the aspect of sustainable synthetic protocol towards amination reaction with good selectivity, high yield, and atom economy without harsh reactions condition.

To achieve this goal, the direct coupling of alcohols and amines catalyzed by transition metals have been successfully exploited to synthesize selective secondary amines with greener water as a by-product through borrowing-hydrogen strategy as depicted in (**Scheme 1**).[4]



Scheme 1. Borrowing-hydrogen strategy for alcohols amination reaction.

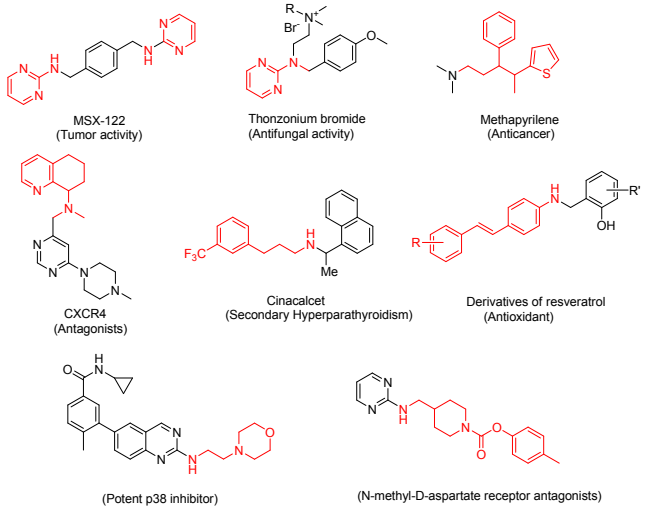
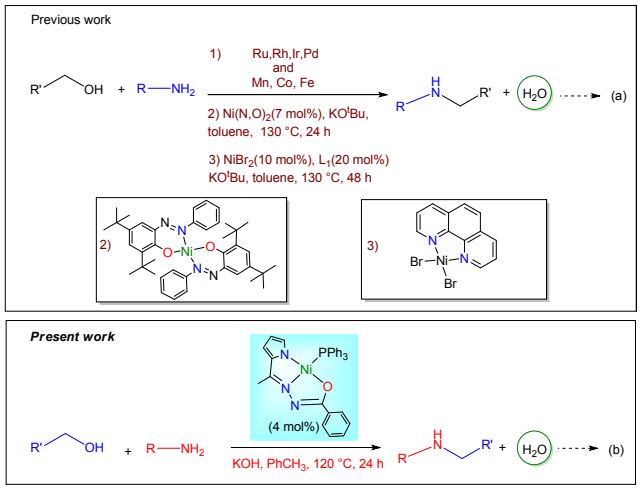


Figure 1. Representative examples of biologically active N-alkylated amines

In this connection, a huge number of reports from precious metals (Ru, Ir, Rh, and Pd) catalysed alcohol amination reactions were well documented.[5] Alternatively, non-precious metal (Fe, Co, Mn) complexes were also known as catalysts to couple the alcohols and amines to provide the desired amine product in an environmentally benign reaction condition.[6] However, the catalysts seeker showed a special interest in designing and synthesis of novel catalysts as earth-abundant based non-precious metals to achieve the same catalytic reactions with extensive substrate scope as well as the yield of the products, etc.,



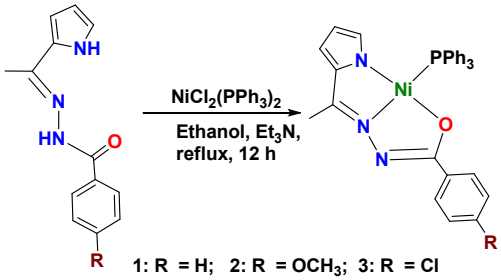
Scheme 2. Transition metal-catalyzedN-alkylation of amines (a) and (b)

Hence, low cost and high-natural-abundance nickel would serve as a sustainable alternative to noble metal complexes catalysed organic syntheses.[7] In general, most of the nickel-based catalytic reactions have gained a significant achievement in cross-coupling reaction like C-C, C-N bond formation etc.,[8-20] It has also been found that the reported literatures on nickel catalysed alkylation of amine reaction are limited. Previously, a few of them investigated the heterogeneous Raney nickel systems in alkylation of amine under borrowing-hydrogen path way.[21a-c] Yus *et al.* synthesized the nickel nanoparticle and used as heterogeneous-catalyst for alcohol amination reaction.[21d-e] In addition, Barta *et al.* have disclosed the nickel nanoparticle for monoalkylation of amines under heterogeneous catalytic condition.[21f] In contrast, to our knowledge, there are only two examples of a nickel based homogeneous catalyst to alkylation of amine reactions. Among them, Adhikari *et al.* recently accounted the azo-phenolate ligand coordinated Ni(II) catalysts for alkylation of amines with a range of primary alcohols.[22b] Banerjee *et al.* have reported in situ generated nickel complexes containing phenanthroline and phosphine co-ligands as a catalyst for the N-alkylation of amines with alcohols to selective secondary amines[22a] (**Scheme 2, a**).

In continuation of our previous reports on the catalytic activity of metal complexes for various coupling reactions,[23] herein we report the Ni(II)-N^N^O pincer type complexes as homogeneous catalysts for alcohol amination reaction (**Scheme 2, b**). The feature of the present approach merits attention as it is eco-friendly, due to the use of readily available less toxic alcohols and elimination of water as the only by-product.

RESULTS AND DISCUSSION

Methyl-2-pyrrolyl ketone derived hydrazone ligands with N^N^O donor atoms have been prepared in accordance with previously described literature with slight modified procedure.[24] The bench-stable Ni(II)-N^N^O pincer type complexes (**1-3**) were accomplished by the reaction of $NiCl_2(PPh_3)_2$ with the prepared ligands in ethanol with an equivalent of triethylamine under refluxing condition for 12 h (**Scheme 3**). All the air and moisture stable complexes are readily soluble in organic solvents (CH_2Cl_2, $CHCl_3$, DMSO, and CH_3CN) and were analytically pure as their elemental analysis data confirmed the proposed molecular formula.



Scheme 3. Synthesis of Ni(II)-NNO pincer type complexes(**1-3**).

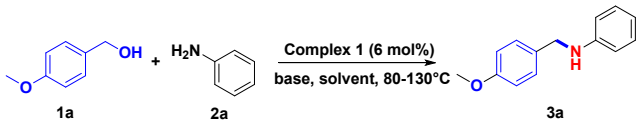
The FT-IR spectra of the free ligands showed broad bands in the regions 3218–3255 cm^{-1} correspond to N-H of pyrrole moiety. These bands were disappeared upon complexation indicate the coordination of pyrrole nitrogen to the nickel ion. The absorption bands around 1610–1642 cm^{-1} were attributed to C=N(azomethine) group of the free ligands. After the complexation, the decrease of azomethine frequency to 1520-1531 cm^{-1} revealed that azomethine nitrogen is another one of the coordinating atoms. Further, the reduction of C=O frequency from 1539–1568 cm^{-1} to 1333–1374 cm^{-1} dictated the coordination of imidolate oxygen (C-O) to nickel *via* the enolization pathway.[25] From the FT-IR spectral data, the formation of the complex as well as their N^N^O coordination pattern of ligand to nickel ion *via* pyrrole nitrogen, imine nitrogen and imidolate oxygen were confirmed.

In the ^1H NMR spectra, the absence of signals due to -NH protons of imine nitrogen and pyrrole nitrogen of free ligand around δ_H = 9.10-8.00 ppm indicated that ligand underwent deprotonation during complexation. Also, three different singlets with low intensity around δ_H = 6.30-5.00 ppm correspond to the pyrrole ring protons in the complexes. A multiplet was observed around δ_H = 7.70-6.50 ppm due to aromatic protons of triphenylphosphine and benzhydrazone ligands of the complexes (**1-3**).The position of the methyl protons signal in the complexes is slightly shifted to downfield in comparison with that of the free ligands, suggesting that the deshielding of the methyl proton after complexation. Further, the complex **2** showed a signal at δ_H = 3.80 ppm as a singlet due to methoxy proton of the ligand. The ^{13}C NMR spectra displayed signals around δ_C = 174 and 158 ppm that correspond to imine carbon and imidolate carbon of all the complexes. In addition, a signal appeared around δ_C = 11 ppm due to methyl carbon of pyrrole ketone. Thus, the NMR spectral data of all the complexes confirm the coordination mode of ligand to Ni(II) ion via the imine nitrogen, pyrrole nitrogen, and the imidolate oxygen.

Furthest, the ESI-MS was studied to determine the exact mass of all the complexes. The ESI-MS spectra showed a fragment peak of $[M+H+CH_3OH+Na]^+$ pattern for complexes **1** and **2** with the m/z = 601.1034, m/z = 631.1147 respectively. In addition, complex **3** displayed a fragment of $[M]^+$ with m/z = 579.1605.

The incredible potential of nickel catalysts in a wide spectrum of coupling reactions motivated us to carry out the N-alkylation of amines from the coupling of alcohols and amines.

Table 1. Effect of Solvent, Base and Temperature[a]



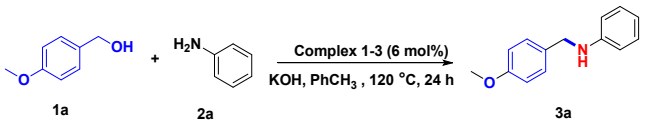
Entry	**Solvent**	**T(°C)**	**Base**	**Yield(%)[b]**
1	*t*-amyl alcohol	120	$NaOCH_3$	30
2	1,4-Dioxane	100	$NaOCH_3$	52
3	*n*-hexane	90	$NaOCH_3$	46
4	$PhCH_3$	110	$NaOCH_3$	62
5	$PhCH_3$	120	$NaOCH_3$	83
6	$PhCH_3$	120	KOH	92
7	$PhCH_3$	130	KOH	94
8	$PhCH_3$	120	NaOH	89
9	$PhCH_3$	120	KO^tBu	80
10	$PhCH_3$	120	Cs_2CO_3	50
11	$PhCH_3$	120	K_2CO_3	<32
12	$PhCH_3$	110	KOH	67
13	$PhCH_3$	80	KOH	40
14	$PhCH_3$	120	Et_3N	<10
15[c]	$PhCH_3$	120	KOH	16
16[d]	$PhCH_3$	120	-	-
17[e]	$PhCH_3$	120	KOH	5

[a]General reaction conditions: Amine (**2a**, 0.75 mmol), alcohol (**1a**, 1.5 mmol), complex **1** (6 mol%, with respect to amine), base(0. 5 mmol), solvent (2 mL), temperature(80-130 °C) for 24 h. [b]Isolatedyield. [c]Reaction performed under oxygen condition. [d]No base was used. [e]No catalyst was used.

In order to initiate the C-N bond forming reaction, the N-alkylation of 4-methoxybenzyl alcohol with aniline to respective N-(4-methoxybenzyl)aniline product using 6 mol % of catalyst 1 was preferred as a benchmark substrate (**Table 1**).The excellent yield of 92% (**Table 1**, **entry 6**) obtained in the test reaction helped us to investigate the catalytic parameters like solvent, base, and temperature. Therefore, a number of test reactions were performed by changing the catalytic parameters, which inferred that $PhCH_3$/KOH at 120 °C was preferred as the best reaction condition. On the basis of the experimental result, the bases play a key role to activate the catalyst towards the formation of alkylated amine products in an effective manner was inferred. As a whole, the activation of catalyst was found to be effective in the presence of KOH when compared to other bases (NaOH, $NaOCH_3$, KO^tBu, Cs_2CO_3, K_2CO_3, Et_3N) exploited in this catalytic reactions. Further, it has been observed a marginal change in the yield of the product on increasing the reaction temperature from 120 °C to 130 °C (**Table 1**, **entries 6** and **7**).

However, a moderate or poor yield was received when the temperature was lowered (**Table 1**, **entries 12** and **13**). The choice of solvents was also examined, which concluded that the non-polar solvent progressively enhance the alkylation process with maximum yield than other solvents employed in this reaction (**Table 1**, **entries 1–4**). Further, poor yield of the N-alkylated product was obtained under oxygen atmosphere (**Table 1**, **entries 15**). The control experiments revealed that the catalyst and base were essential for this reaction, and the reaction was ineffective in the absence of any of them (**Table 1**, **entries 16** and **17**).

Table 2. Effect of Substituent of Catalyst[a]

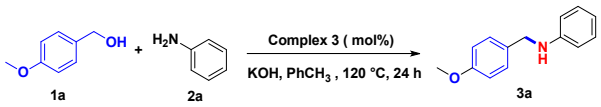


Entry	**[Ni]complex**	**Yield (%)[b]**
1	1	92
2	2	93
3	3	98

[a]General reaction conditions: Amine (**2a**, 0.75 mmol), alcohol (**1a**, 1.5 mmol), complex **1-3** (6 mol%, with respect to amine), KOH(0.5 mmol) and $PhCH_3$ (2 mL) at 120 °C for 24 h. [b]Isolated yields.

After the optimization of solvent, base and temperature in the respective catalytic reactions, next we were interested to investigate the effect of substituents (R = -H, $-OCH_3$ and -Cl) of all the catalytic complexes (**1-3**) under identical catalytic condition. Utmost all the catalysts (**1-3**) showed impressive results in the formation of N-(4-methoxybenzyl)aniline product (**Table 2**). However, the experimental results implied that the catalyst **3** exhibited a relatively higher yield of N-(4-methoxybenzyl)aniline (98%) as compared to the catalysts (**1** and **2**), which probably reflects that the presence of an electron-withdrawing group(-Cl). Hence, complex **3** opted as a model catalyst to the broad substrate scope using a different set of amines and alcohols.

Table 3. Effect of Catalyst Load[a]



Entry	Mol% of complex 3	Yield(%)[b]
1	6	98
2	**4**	**96**
3	2	63
4	1	41

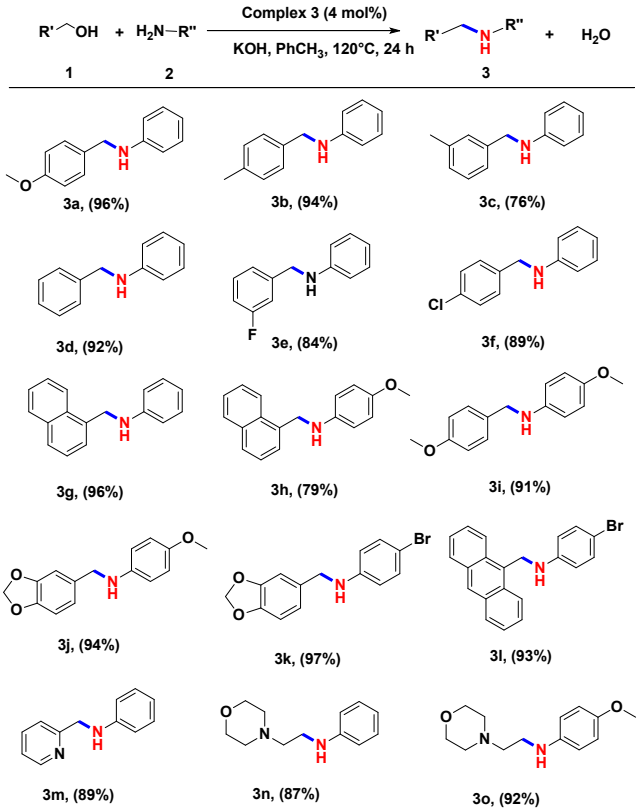
[a]General reaction conditions: Amine (**2a**, 0.75 mmol), alcohol (**1a**, 1.5 mmol), complex **3** (6.0 – 1.0 mol%), KOH(0.5 mmol) and $PhCH_3$ (2 mL) at 120 °C for 24 h. [b]Isolated yields

Performing the reactions at low catalysts loading to achieve the desired secondary amine products is the most important factor in catalysis research. Thereupon, a low catalyst load (6.0 – 1.0 mol%) has been studied under the established reaction condition (**Table 3**). Outstandingly, the complex **3** performed well with 4 mol% to give the desired amine product with 96% isolated yield. While reduce the catalyst loading from 2 to 1 mol%, there was no appreciable yield in the catalytic reactions. Based on this result, the N-alkylation of amine formation has been proceeded profoundly in 4 mol% catalyst in 24 h.

The scope of the N-alkylation reaction was examined under the optimized reaction condition for various alcohols and amines (**Table 4**). It is worth to note that the reaction of benzyl alcohols bearing the electron-releasing substituents, 4-methyl, 4-methoxy and 3-methyl with aniline increase the yield of N-alkylation process to provide the desired secondary amines **3a-3d** in **92–96%** yields. Indeed, benzyl alcohols comprising the electron-withdrawing substituents, such as 4-chloro, and 3-fluoro were found to be good coupling partners of amine and gave the selective monoalkylated products of **3e-3f** in **84–89%** yields. Further, 1-naphthalene methanol readily reacted with aniline and 4-methoxy aniline to desired **3g** and **3h** in **79%** and **96%** yields respectively. Interestingly, both of the electron-donating derivatives of 4-methoxybenzyl alcohol and 4-methoxy aniline gave the **3i** in **91%** yield. Since, piperonyl analogue is the most important building block in the drug development process.[28]

Hence, we have used the present catalyst to synthesis of piperonyl scaffolds based amines. Proficiently, we achieved the desired amines (4-methoxy aniline and 4-bromo aniline) attached with piperonyl moiety yielded **3j** and **3k** in **94%** and **97%** yields respectively. More interestingly, the catalyst performed well in the reaction of sterically hindered 9-anthracenemethanol with 4-bromo aniline gave **3i** in **93%** yield. Further, we have investigated the some of heterocyclic alcohols like 2-pyridinemethanol, 2-morpholinoethanol. The 2-pyridinemethanol smoothly alkylated with aniline and gave the product **3m** in **89%** yield.

Table 4. N-alkylation of Various Aromatic amines with Alcohols[a,b]



[a]General reaction conditions: Amine (**2**, 0.75 mmol), alcohol (**1**, 1.5 mmol), complex **3** (4 mol%, with respect to amine), KOH(0.5 mmol) and $PhCH_3$ (2 mL) at 120 °C for 24 h. [b]Isolated yields.

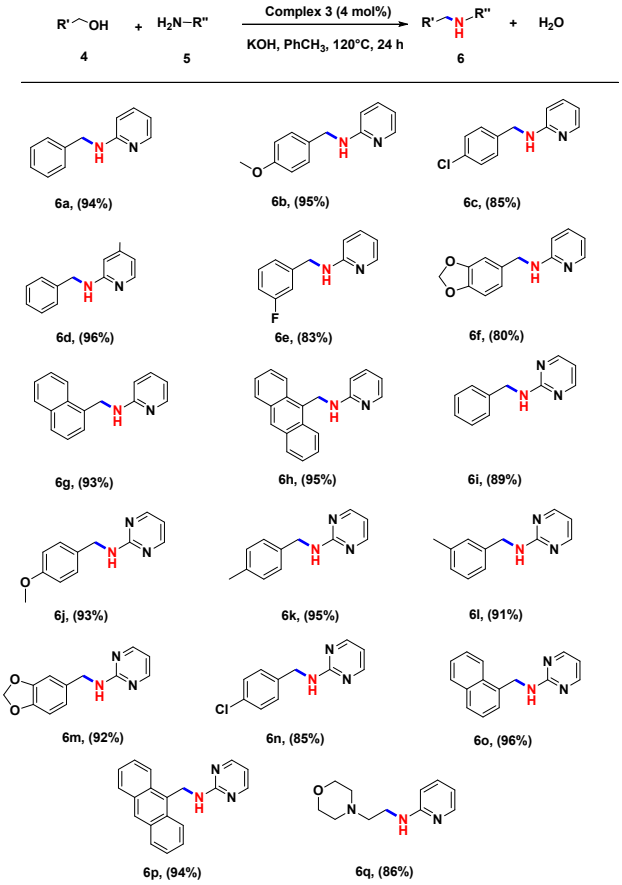
It is well known that morpholine moieties are known as potential heterocyclic building blocks and widely present in large number of drug molecules.[26b,2h] So, we have significantly tuned the current protocol in construction of the 2-morpholinoethanol with aniline and 4-methoxy aniline which gave the corresponding amines **3n** and **3o** in **87%** and **92%** yields respectively.

Next, we are interested to explore the wide scope of 2-aminopyridine/2-aminopyrimidine based mono N-alkylated amines those also were primarily used as intermediate in various drug development process (**Table 5**).[26-28] Hence, we have intensely probed the utility of the catalyst in the coupling of a sort of alcohols with amines to provide a pharmaceutically active secondary amine product in excellent yield. More interestingly, the reaction of 2-aminopyridine with benzyl alcohol gave the corresponding secondary amines **6a** in **94%** of isolated yield. In addition, electron-donating substituent on amine moiety such as 2-amino-4-methylpyridine was coupled with benzyl alcohol to the respective **6d** in **96%**. Further, 2-aminopyridine with 3-fluorobenzyl alcohol underwent N-alkylation process smoothly to the desired **6e** in **83%** yield. Also, the present catalyst worked well in the coupling of piperonyl alcohol with amine afforded the **6f** in **80%** yield. Furthere, sterically hindered 1-naphthalenemethanol and 9-anthracenemethanol were reacted with 2-aminopyridine to provide the respective **6g** and **6h** in **93%** and **95%** yields.

It is worth to mention that the current catalytic strategy is more useful to the synthesis of drug intermediates such as mepyramine **6b** and chloropyramine **6c** with the yield of **95%**

and **85%** respectively from the coupling of 4-methoxybenzyl alcohol and 4-chlorobenzyl alcohol with the 2-aminopyridine.[29a-b]

Table 5. N-alkylation of Various Heteroaromatic Amines with Alcohols[a,b]

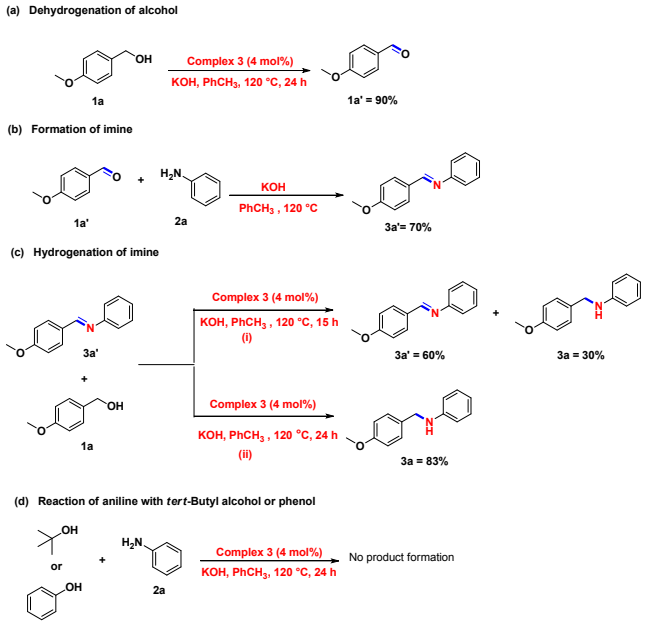


[a]General reaction conditions: Amine (**5**, 0.75 mmol), alcohol (**4**, 1.5 mmol), complex **3** (4 mol%, with respect to amine), KOH(0.5 mmol) and $PhCH_3$ (2 mL) at 120°C for 24 h. [b]Isolated yields.

Pyrimidine based amines are considered to be a privileged scaffold and have given a significant contribution in the fields of bioorganic and medicinal chemistry.[2g-h,29] But, only few reports were investigated on the synthesis of pyrimidine based N-alkylated amine moieties under the borrowing-hydrogen catalytic condition.[30] Furthest, we continued our investigation and tuned the Ni(II)-N^N^O complex **3** to catalyse the 2-aminopyrimidine with a range of benzyl alcohol derivatives led to selective mono alkylated amine products in appreciable yields (**Table 5**). More impressively, the benzyl alcohols comprising electron-donating substituents, such as 4-methylbenzyl alcohol, 3-methylbenzyl alcohol, 4-methoxybenzyl alcohol and unsubstituted benzyl alcohol were readily alkylated with 2-aminopyrimidine to the selective mono-alkylated products **6i-6l** with the isolated yields of **89–95%**. Further, reducible 4-chlorobenzyl alcohol also readily underwent N-alkylation with aminopyrimidine to the desired **6n** of **85%** yield. In addition, sterically hindered 1-naphthalenemethanol and 9-anthracenemethanol were alkylated with 2-aminopyrimidine to give the respective **6o** and **6p** in **96%** and **94%** yields. More interestingly, 2-morpholinoethanol easily alkylated with 2-aminopyridine to provide the desired **6q** in **86%** yield. Attempts were also taken for secondary alcohols in the catalytic reactions and are not successful.

At this point, we are very much interested to compare the efficiency of present Ni(II)-N^N^O catalyst with structurally related Ni(II) catalysts. In this regard, Adhikari *et al.* recently accounted the azo-phenolate ligand coordinated Ni(II) catalysts in N-alkylation of amines with a range of primary alcohols using 7 mol% of catalyst in 24 h at 130°C.[22b] Similarly, Banerjee *et al.* reported the alcohol amination reaction using 10 mol% of in situ generated Ni(II) catalyst in 48 h at 130°C.[22a] Therefore, the present Ni(II) pincer type complexes worked well with 4 mol% of catalyst load at 120°C in 24 h for effectively couple the alcohol and amine to produce the monoalkylated amine product with an excellent yield of 97% than the existing methodology.

Further,wehave carried out a sequence of controlexperiments under different conditions **(Scheme 4)** in order to get more insight into the reaction mechanism.

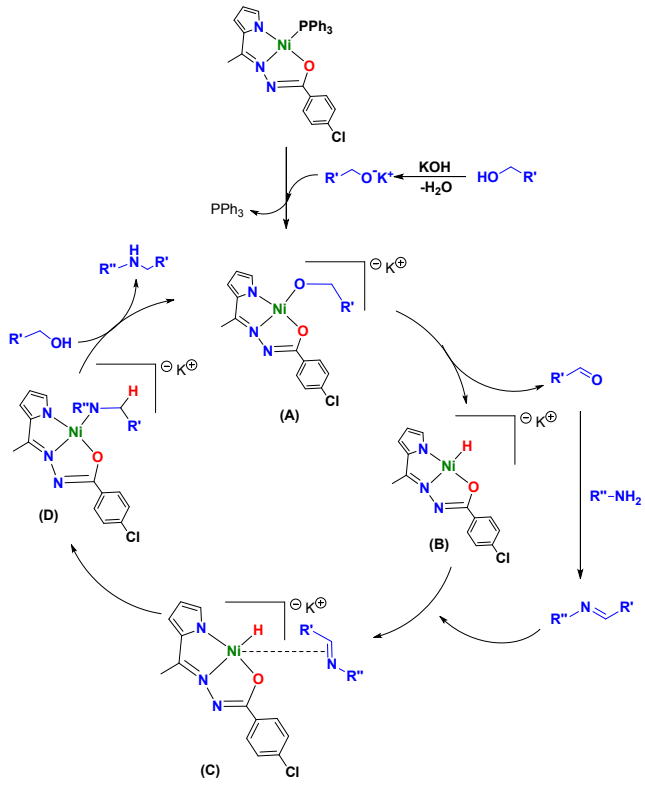


Scheme 4. Control experiments

The reaction of 4-methoxybenzyl alcohol **1a** in absence of amine **2a** under standard reaction condition yielded the corresponding aldehyde **1a'** (**1a' Fig. S76**, page no. **S44**, **Supporting Information**) which dictated that the formation of 4-methoxybenzaldehyde **1a'** occurs through dehydrogenation of alcohol pathway. Further, the reaction of 4-methoxybenzaldehyde **1a'** and amine **2a** yielded imine intermediate **3a'** (**Fig. S77**, page no. **S44**, **Supporting Information**). In addition, the reaction of 4-methoxybenzyl alcohol **1a** with imine **3a'** under standard condition in 15 h afforded N-alkylated product **3a** in **30%** yield and **60%** of unreactive imine **3a'** was observed in the reaction mixture (**Fig. S78**, page no. **S45**, **Supporting Information**). Significantly, the excellent yield of N-alkylated product **3a** achieved when the reaction time extended to 24 h. Hence that, the formed imine intermediate underwent hydrogen autotransfer reaction yielded to desired N-alkylated product was proved.

A plausible catalytic mechanism has been proposed for the C-N bond forming reaction based on our experimental observation which is further supported by literature reports[22]

(**Scheme 5**). Initially, alcohol is coordinated to nickel in presence of KOH base to form Ni-alkoxide **(A)** with the release of PPh_3. This active species **(A)** subsequently underwent β-hydride elimination to release aldehyde with the formation of Ni-hydride **(B)**. Then the aldehyde coupled with amine to form an imine which is inserted to nickel to form **(C)**. The reduction of imine with metal hydride leads to the formation of **(D)**.This species **(D)** further reacts with alcohol and delivered the alkylated amine product, thereby regeneration of Ni-alkoxide **(A)** for next catalytic cycle. Further, we have deeply probed the reaction mechanism to isolate the Ni-hydride intermediate and that was not successful. Indeed, the most of the literatures reported that isolation of Ni-hydride species from the reaction mixture was unsuccessful due to its unstable nature.[22] To further establish the N-alkylation process via borrowing hydrogen stategy, we conducted a control experiment involving the alkylation of aniline with *tert*-butyl alcohol or phenol under the optimized condition (**Scheme 4d**). It has been observed that no coupled products were obtained, which supports the borrowing hydrogen mechanism for the present nickel-catalyzed N-alkylation via alcohol dehydrogenation reaction using benzylalcohol. Hence, we believe the formation of amine products via borrowing hydrogen strategy as evidenced from our control experiments[31] and the previous reports.[22,32]



Scheme 5. Plausible mechanism for N-alkylation of amine reaction

CONCLUSIONS

In conclusion, three Ni(II)-N^N^O pincer type complexes were demonstrated as effective catalysts for synthesis of biologically important monoalkylated amines. A diverse range of primary alcohols was coupled with different sets of amines to selective monoalkylated products by using nickel complexeswith 85-97% isolated yields. Further, the greener hydrogen auto transfer path way of the catalytic reaction was evidenced by mechanistic investigation.

EXPERIMENTAL SECTION

Materials and Methods

$NiCl_2(PPh_3)_2$, Methyl-2-pyrrolyl ketone, benzhydrazide derivatives, and $CDCl_3$ were purchased from Aldrich and were used as received. Solvents were freshly distilled before use following the standard procedures.[33] The benzhydrazone ligands were prepared as described in the literature.[24] Melting points were recorded in the Boetius micro heating table and are uncorrected. The C, H and N analyses were performed on a Vario EL III CHNS elemental analyser at the Sophisticated Test and Instrumentation Centre (STIC), Cochin University, Cochin. The FT-IR spectra of the complexes were recorded with KBr pellets using a Perkin-Elmer 597 spectrophotometer in the range 4000–400 cm^{-1}. The NMR spectra were recorded on a Bruker 400 MHz spectrometer in $CDCl_3$ solvent using TMS as an internal standard. The HRMS(ESI) was recorded for all the complexes in methanol solution with Micro mass Thermo scientific LTQ XL mass spectrometer.

X-ray crystallography

The single crystals have been grown for complexes **1** and **2** by slow evaporation of ethanol solvent at room temperature. The molecular structures of the complex **1** and **2** were resolved by single crystal X-ray diffraction. The thermal ellipsoid view of complexes,selected bond lengths, bond angles and detailed description of crystal structures are provided (**S8-S9**, **Table 1** and **2**, see **Supporting Information**). Hence, the observed bond lengths and bond angles of the present complex are consistent with the reported nickel complexes.[25] Bruker SMART APEX II four-circle diffractometer with monochromated Mo-Kα radiation (λ = 0.71073 Å) was used to collect the X-ray intensity data at room temperature. The absorption corrections were performed by a multi-scan method using SADABS software. The unit cell parameters were determined by the method of difference vectors using reflections scanned from three different zones of the reciprocal lattice. The intensity data were measured using ω and ϕ scan with a frame width of 0.5o. Frame integration and data reduction were performed using the Bruker SAINT-Plus (Version 7.06a)[34] software Corrections were made for Lorentz and polarization effects. The crystal structures were solved and refined using Olex2,[35] SHELXS and SHELXL[36] programs.

Synthetic procedure for Ni(II) complexes(1-3)

$NiCl_2(PPh_3)_2$ (65.41 mg, 0.1 mmol), Methyl-2-pyrrolyl ketone derived benzhydrazone ligands (R = H, OCH_3 and Cl) (22-30 mg, 0.1mmol) and triethylamine(1 equiv.) as a base were dissolved in 15 ml of ethanol and taken in a round neck flask(50 ml) and stirred at refluxing condition for 12 h. Further, the formation of complex was identified with thin layer chromatographic technique. Then, the solvent volume was reduced to 5 ml under reduced pressure and the addition

of 10 ml pet. ether in the reaction mixture to form a brown precipitate and filtered and dried in a vacuum.

Characterization of the complexes (1-3)

Complex 1. Yield: 40 mg, 73.23%. Mp:293°C (with decomposition). Anal.Calcd. For $C_{31}H_{26}N_3OPNi$ (546.2248 g mol^{-1}): C, 68.16; H, 4.80; N, 7.69. Found: C, 68.20; H, 4.71; N, 7.61. FT-IR (KBr, cm^{-1}): 1539 (s), 1337 (m), 1573 (s). ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.75-7.20(m, 20H, aromatic), 6.31(s, 1H, pyrrole-H), 5.57(s, 1H, pyrrole-H), 5.09(s, 1H, pyrrole-H), 2.42(s, 3H, pyrrole-CH_3), $^{13}C\{1H\}$NMR (100 MHz, $CDCl_3$): δ (ppm)=11.85,109.2,114.0,127.6,128.2,128.6,129.8,130.8,131.4,134.7,136.7,144.4,158.8,174.8. HRMS (ESI) m/z: [M + H + CH_3OH + Na]+ Calcd. for $C_{31}H_{26}N_3NiOPNa,CH_4O,H$ 601.1405; Found 601.1034.

Complex 2. Yield: 50 mg, 79.11%. Mp:301°C (with decomposition). Anal.Calcd. For $C_{32}H_{28}N_3NiO_2P$ (576.2508 g mol^{-1}): C, 66.70; H, 4.90; N, 7.29. Found: C, 66.62; H, 4.64; N, 7.32. FT-IR (KBr, cm^{-1}): 1535 (s), 1338 (m), 1577 (s). ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.78 (s, 6H, aromatic), 7.73-7.53 (m, 11H, aromatic), 6.70(d, 2H, J = 8.8 Hz, aromatic), 6.32(d, 1H, J = 3.2 Hz, pyrrole-H), 5.57(t,1H, J = 2.2 Hz, pyrrole-H), 5.09(s,1H, pyrrole-H), 3.77(s, 3H, -OCH_3), 2.41(s, 3H, pyrrole-CH_3). $^{13}C\{^1H\}$NMR (100 MHz, $CDCl_3$): δ (ppm) = 11.8, 55.2, 109.0, 113.0, 113.6, 124.0, 128.6, 129.9, 130.9, 134.7, 136.5, 144.5, 158.1, 161.0, 174.8. HRMS (ESI) m/z: [M + H + CH_3OH + Na]$^+$ Calcd.for $C_{32}H_{28}N_3NiO_2PNa,CH_4O,H$ 631.1511; Found 631.1134.

Complex 3. Yield: 45 mg, 77.50%. Mp:315°C (with decomposition). Anal.Calcd. For $C_{31}H_{25}N_3ClNiOP$ (580.6699 g mol^{-1}): C, 64.12; H, 4.34; N, 7.24. Found: C, 64.01; H, 4.10; N, 7.30. FT-IR (KBr, cm^{-1}): 1538 (s), 1347 (m), 1598 (s). ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.79 (d, 6H, J = 8 Hz, aromatic), 7.53-7.45 (m, 11H, aromatic), 7.15(d, 2H, J = 8 Hz, aromatic) 6.35(s, 1H, pyrrole-H), 5.58(s, 1H, pyrrole-H), 5.11(s, 1H, pyrrole-H), 2.40(s, 3H, pyrrole-CH_3).$^{13}C\{^1H\}$NMR (100 MHz, $CDCl_3$): δ (ppm) = 11.7, 109.4, 114.3, 127.8, 128.6, 129.5, 130.0, 130.9, 134.6, 135.7, 136.9, 144.4, 159.1, 173.3. HRMS (ESI) m/z: [M]$^+$ Calcd. for $C_{31}H_{25}N_3ClNiOP$ 579.0777; Found 579.1605).

Catalytic procedure for N-alkylation of amine reactions

Alcohols (1.5 mmol), amines (0.75 mmol), catalyst 3 (4 mol% with respect to amine), KOH (0.5 mmol) and $PhCH_3$ (2 ml) were transferred into a 10 mL oven dried schlenk tube under an atmosphere of N_2 and was heated at 120 °C (oil bath) for 24 h. The progress of N-alkylation was monitored with thin layer chromatography. After the reaction was completed, the reaction mixture was cooled to room temperature and 4 ml of ethyl acetate was added and dried under vacuum and resulting residue purified with column chromatography over silica gel (60–120 mesh) with pet.ether/EtOAc (80:20) mixture as eluent.

Catalytic procedure for large-scale reaction

4-methoxybenzyl alcohol (**1a**, 3.1g, 22.5 mmol), aniline (**2a**, 1.0 g, 11.2 mmol), catalyst **3** (60 mol% with respect to amine), KOH (0.4 g, 7.5 mmol) and $PhCH_3$ (30 ml) were transferred into a 100 mL oven dried schlenk tube under an atmosphere of N_2 and was heated at 120 °C (oil bath) for 24 h. The progress of N-alkylation was monitored with thin layer chromatography. After the reaction was completed, the reaction mixture was cooled to room temperature. Then, 60 ml of ethyl acetate was added and dried under vacuum and resulting residue purified with column chromatography over silica gel (60–120 mesh) with pet.ether/EtOAc (80:20) mixture as eluent to give **3a** (1.9 g, 80%).

Characterization of the catalyzed products

N-(4-methoxybenzyl)aniline (**3a**):[22a] yellow oil, yield 96% (153 mg); ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.24(d, 2H, J = 8.8 Hz), 7.13(t, 2H, J = 9.2 Hz), 6.84(d, 2H, J = 8.8 Hz), 6.68(s, 1H), 6.59(d, 2H, J = 7.6 Hz), 4.19(s, 2H), 3.92(s, 1H), 3.74(s, 3H). $^{13}C\{^1H\}$NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.9,148.3, 131.5, 129.3, 128.9, 117.5, 114.1, 112.9, 55.4, 47.9.

N-(4-methylbenzyl)aniline (**3b**):[22a] yellow oil, yield 94% (139 mg); ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) =7.24(t, 2H, J = 8 Hz), 7.19-7.14(m, 4H), 6.71(s, 1H), 6.63(d, 2H, J = 8 Hz), 4.27(s, 2H), 3.99(s, 1H), 2.34(s, 3H).$^{13}C\{^1H\}$NMR (100 MHz, $CDCl_3$): δ (ppm) = 148.3, 136.9, 136.4, 129.4, 127.6, 117.5, 112.9, 48.1, 21.2.

N-(3-methylbenzyl)aniline (**3c**): yellow oil, yield 76% (112 mg); ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.36-7.07(m, 6H), 6.73-6.62(m, 3H), 4.27(s, 2H), 3.99(s, 1H), 2.34(s, 3H). $^{13}C\{^1H\}$NMR (100 MHz, $CDCl_3$): δ (ppm) = 148.3, 139.4, 138.4, 129.3, 129.1, 128.6, 128.4, 128.1, 124.7, 117.6, 112.9, 48.4, 21.5.

N-benzylaniline (**3d**):[22a] yellow oil, yield 92% (126 mg); ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.37-7.15(m, 7H), 6.73-6.62(m, 3H), 4.31(s, 2H), 4.02(s, 1H). $^{13}C\{^1H\}$NMR (100 MHz, $CDCl_3$): δ (ppm) = 148.2, 139.5, 129.3, 128.7, 127.6, 127.3, 117.6, 112.9, 48.4.

N-(3-fluorobenzyl)aniline (**3e**): yellow oil, yield 84% (125 mg); ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.67-6.99(m, 7H), 6.97-6.60(m, 2H), 4.34(s, 2H), 4.12(s, 1H). $^{13}C\{^1H\}$NMR (100 MHz, $CDCl_3$): δ (ppm) = 147.8, 130.2, 129.3, 122.8, 117.8, 114.3, 114.2,114.1, 114.0, 113.9, 112.9, 47.8.

N-(4-chlorobenzyl)aniline (**3f**):[22a] yellow oil, yield 89% (145 mg); ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.33-7.23(m, 5H), 7.15(t, 2H, J = 8 Hz), 6.70(t, 1H, J = 6.8Hz), 6.61-6.55(m, 2H), 4.25(s, 2H), 4.01(s, 1H). $^{13}C\{^1H\}$NMR (100 MHz, $CDCl_3$): δ (ppm) = 147.9, 138.1, 132.9, 129.4, 129.4, 128.8, 128.8, 128.7, 127.6, 117.9, 113.0, 112.9, 47.7.

N-(naphthalene-1-ylmethyl)aniline (**3g**):[22a] white solid, yield 96% (168 mg); ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.06(t, 1H, J = 4.6 Hz), 7.90-7.87(m, 1H), 7.80(d, 1H, J = 8 Hz), 7.54-7.49(m, 3H),7.41(t, 1H, J = 8 Hz), 7.22-7.18(m, 2H), 6.74 (t, 1H, J = 7.6 Hz), 6.68(d, 2H, J = 8 Hz), 4.72(s, 2H), 3.98(s, 1H). $^{13}C\{^1H\}$NMR (100 MHz, $CDCl_3$): δ (ppm) = 148.3, 134.4, 133.9, 131.6, 129.4, 128.8, 128.2, 126.4, 126.1, 125.9, 125.6, 123.7, 117.6, 112.8, 46.5.

4-methoxy-N-(naphthalene-1-ylmethyl)aniline (**3h**):[37] white solid, yield 79% (155 mg); ^1H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.09-8.06(m, 1H), 7.90-7.88(m, 2H), 7.80(d, 1H, J = 8.4 Hz), 7.53-7.50(m, 3H), 7.42(t, 1H, J = 7.6 Hz), 6.80(d, 2H, J = 8.8 Hz), 6.67(d, 2H, J = 9.2 Hz), 4.68(s, 2H), 3.75(s, 4H). $^{13}C\{^1H\}$NMR (100 MHz, $CDCl_3$): δ (ppm) = 152.2, 142.7, 134.7, 133.9, 131.6,

128.8, 128.2, 126.3, 126.1, 125.9, 125.6, 123.7, 115.0, 114.0, 55.9, 47.3.

4-methoxy-N-(4-methoxybenzyl)aniline (**3i**):[38] white solid, yield 91% (165 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.28(t, 2H, J = 8.8 Hz), 6.87(d, 2H, J = 8.4 Hz), 6.77(d, 2H, J = 8.8 Hz), 6.60(d, 2H, J = 8.8 Hz), 4.20(s, 2H), 3.80(s, 4H), 3.74(s, 3H). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.8, 152.2, 142.6, 131.7, 128.9, 114.9, 114.2, 114.0, 55.8, 55.3, 48.8.

N-(benzo[d][dioxal-5-ylmethyl)-4-methoxyaniline (3**j**):[38] white solid, yield 94% (181 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 6.86-6.75(m,5H), 6.60-6.57(m, 2H), 5.93(s, 2H), 4.18(s, 2H), 3.74(s, 4H). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 152.2, 147.9, 146.7, 142.4, 133.7, 120.6, 114.9, 114.2, 108.3, 108.1, 101.0, 55.8, 49.1.

N-(benzo[d][1,3]dioxol-5-ylmethyl)-4-bromoaniline (**3k**):[39] white solid, yield 97% (222 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.24(t, 2H, J = 7 Hz), 6.82-6.76(m, 3H), 6.48(d, 2H, J = 8.8 Hz), 5.94(s, 2H), 4.19(s, 2H), 4.04(s, 1H). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 148.0, 147.0, 146.9, 132.8, 132.0, 120.6, 114.5, 109.2, 108.4, 107.9, 101.1, 48.1.

N-(anthracen-9-ylmethyl)-4-bromoaniline (**3l**): white solid, yield 93% (252 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.44(s, 1H), 8.38(d, 3H, J = 8.4 Hz), 8.01(d, 3H, J = 8.4 Hz), 7.56-7.52(m, 3H), 7.47(t, 3H, J = 7.6 Hz), 5.63(s, 3H). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 131.6, 131.0, 130.2, 129.1, 128.4, 126.5, 125.1, 123.9, 57.4.

N-(pyridine-2-ylmethyl)aniline (**3m**):[22a] yellow oil, yield 89% (123 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.49(d, 1H, J = 4.4 Hz), 7.55-7.51(m, 1H), 7.23(d, 1H, J = 7.6 Hz), 7.12-7.06(m, 3H), 6.65-6.56(m, 3H), 4.70(s, 1H), 4.36(s, 2H). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.6, 149.2, 147.9, 136.7, 129.3, 122.1, 121.6, 117.6, 113.1, 49.3.

N-(2-morpholinoethyl)aniline (**3n**):[40] yellow oil, yield 87% (134 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.12(t, 2H, J = 7.2 Hz), 6.65-6.55(m, 3H), 4.23(s, 1H), 3.64(t, 4H, J = 4.8 Hz), 3.08(t, 2H, J = 5.6 Hz), 2.54 (t, 2H, J = 6Hz), 2.39(d, 4H, J = 3.6 Hz). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 148.5, 129.3, 117.4, 112.9, 67.0, 57.2, 53.4, 39.9.

4-methoxy-N-(2-morpholinoethyl)aniline (**3o**):[41] yellow oil, yield 92% (162 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 6.79(d, 2H, J = 8.8 Hz), 6.61(d, 2H, J = 8.8 Hz), 3.74(s, 3H), 3.71(t, 4H, J = 4.4 Hz), 3.12(t, 2H, J = 6 Hz), 2.62(t, 2H, J = 6 Hz), 2.46(t, 4H,J = 4.4 Hz). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 152.2, 142.8, 114.9, 114.3, 67.0, 57.3, 55.9, 53.4,41.0.

N-benzylpyridin-2-amine (**6a**):[22b] white solid, yield 94% (129 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.11(s, 1H), 7.43-7.26(m, 6H), 6.60(t, 1H, J = 5.6 Hz), 6.35(d, 1H, J = 8.4 Hz), 4.90(s, 1H), 4.49(d, 2H, J = 5.6 Hz). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.4, 148.1, 137.8, 137.6, 132.9, 128.8, 128.6, 113.5, 106.9, 45.6.

N-(4-methoxybenzyl)pyridin-2-amine (**6b**):[22a] white solid, yield 95% (153 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.11(s, 1H), 7.39(t, 1H, J = 7.6 Hz), 7.27(d, 2H, J = 8.4 Hz), 6.86(d, 2H, J = 8.4 Hz), 6.58(s, 1H), 6.38(s, 1H), 4.90(s, 1H), 4.41(s, 2H), 3.79(s, 3H) . ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.8, 158.7, 148.0, 137.4, 131.1, 128.7, 144.0, 113.2, 106.9, 55.3, 45.8.

N-(4-chlorobenzyl)pyridin-2-amine (**6c**):[22a] white solid, yield 85% (140 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.11(s, 1H), 7.42-7.29(m, 4H), 6.60(t, 1H, J = 5.2 Hz), 6.35(d, 1H, J = 8.4 Hz), 4.91(s, 1H), 4.49(d, 2H, J = 5.6 Hz). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.4, 148.2, 137.8, 137.5, 132.9, 128.7, 128.6, 127.4, 113.4, 106.9, 45.5.

N-benzyl-4-methylpyridin-2-amine (**6d**):[42] white solid, yield 96% (142 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 7.96(d,1H, J = 4.8 Hz), 7.36-7.25(m, 5H), 6.44(d, 1H, J = 4.8 Hz), 6.20(s,1H), 4.89(s,1H), 4.49(s, 2H), 2.21(s, 3H). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.8, 148.6, 147.7, 139.3, 128.6, 127.4, 127.2, 114.8, 107.0, 46.3, 21.2.

N-(3-fluorobenzyl)pyridin-2-amine (**6e**) : white solid, yield 83% (126 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.09(s, 1H), 7.42-7.37(m,1H), 7.30-7.24(m, 1H), 7.10(dd,2H, J = 7.6, 9.6 Hz), 6.96-6.91(m,1H), 6.60(dd,1H, J = 5.2, 5.2 Hz), 6.36(d, 1H, J = 8.4 Hz), 5.14(s, 1H), 4.50(d, J = 4.8 Hz). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 164.3, 161.8, 158.4, 148.0, 142.1, 142.0, 137.6, 130.1, 130.0, 122.7, 114.2, 114.1, 114.0, 113.9, 113.4, 106.9, 45.7.

N-(benzo[d][1,3]dioxol-5-ylmethyl)pyridin-2-amine (**6f**) : white solid, yield 80% (137 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.09(d, 1H, J = 4 Hz), 7.42-7.38(m, 1H), 6.85-6.75(m,3H), 6.58(t, 1H, J = 5.2 Hz), 6.36(d, 1H, J = 8.4 Hz), 5.93(s, 2H), 4.96(s, 1H), 4.39(d, 2H, J = 5.2 Hz). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.5, 148.1, 147.9, 146.7, 137.5, 133.3, 120.5, 113.2, 108.3, 108.0, 106.8, 101.0, 46.1.

N-(naphthalene-1-ylmethyl)pyridin-2-amine (**6g**):[43] white solid, yield 93% (164 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.14(s, 1H), 8.06(d, 1H, J = 8.8 Hz),7.87(t, 1H, J = 6 Hz), 7.79(d, 1H, J = 8 Hz), 7.50 (q, 3H, J = 3.2 Hz), 7.40(q, 2H, J = 7.6 Hz), 6.60(t, 1H, J = 5.6 Hz), 6.38(d, 1H, J = 8.4 Hz), 4.93(s, 3H). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.5, 148.1, 137.5, 134.2, 133.9, 131.5, 128.8, 128.2, 126.4, 125.9, 125.8, 125.5, 123.5, 113.1, 107.2, 44.3 .

N-(anthracen-9-ylmethyl)pyridin-2-amine (**6h**) : white solid, yield 95% (203 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.48(s, 1H), 8.33(d, 2H, J = 8.8 Hz), 8.25(d, 1H, J = 4.4 Hz), 8.04(d, 2H, J = 8 Hz), 7.54-7.43(m, 5H), 6.66(t, 1H, J = 5.6 Hz), 6.45(d, 1H, J = 8 Hz), 5.44(d, 2H, J = 4.4 Hz), 4.52(s, 1H).^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.4, 148.2, 137.3, 131.5, 130.4, 129.5, 129.1, 127.9, 126.4, 125.1, 124.2, 113.1, 107.9, 38.7.

N-benzylpyrimidin-2-amine (**6i**):[30b] white solid, yield 89% (123 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.27(s, 2H), 7.37-7.26(m, 5H), 6.55(t, 1H, J = 4.8 Hz), 5.69(s, 1H), 4.65(d, 2H, J = 5.6 Hz). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 162.3, 158.1, 139.0, 128.6, 127.4, 127.2, 110.9, 45.4.

N-(4-methoxybenzyl)pyrimidin-2-amine (**6j**):[30b] white solid, yield 93% (149 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.25(d, 2H, J = 4Hz), 7.27(t, 2H, J = 8.8 Hz), 6.86(d,2H, J = 8.4 Hz), 6.53(t, 1H, J = 4.8 Hz), 5.67(s, 1H), 4.56(d, 2H, J = 6 Hz), 3.80(s, 3H).^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 162.2, 158.8, 158.0, 131.0, 128.8, 114.0, 110.7, 55.3, 44.9.

N-(4-methylbenzyl)pyrimidin-2-amine (**6k**):[30b] white solid, yield 95% (141 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.27(d, 2H, J = 4 Hz), 7.25(d, 2H, J = 8.8 Hz), 7.14(d, 2H, J = 7.6 Hz), 6.54(s, 1H), 5.53(s, 1H), 4.59(d, 2H, J = 5.6 Hz), 2.34(s, 3H).^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 162.3, 158.1, 136.9, 135.9, 129.3, 127.4, 110.8, 45.2, 21.1.

N-(3-methylbenzyl)pyrimidin-2-amine (**6l**) : white solid, yield 91% (134 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.28(s, 2H), 7.26-7.08(m, 4H),6.55(t, 1H, J = 4.4 Hz),5.60(s, 1H),4.61(d, 2H, J = 5.2 Hz),2.34(s, 3H).^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.1, 138.9, 138.3, 128.5, 128.2, 128.0, 124.5, 110.8, 45.4, 21.4.

N-(benzo[d][1,3]dioxol-5-ylmethyl)pyrimidin-2-amine (**6m**) : white solid, yield 92% (157 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) =8.28(s, 2H), 6.86-6.75(m, 3H), 6.56(d, 1H, J = 4.4 Hz), 5.94(s, 2H), 5.58(s, 1H), 4.54(d, 2H, J = 5.6 Hz).^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.1, 147.9, 146.7, 133.0, 120.6, 108.3, 108.1, 101.0, 45.2.

N-(4-chlorobenzyl)pyrimidin-2-amine (**6n**):[30b] white solid, yield 85% (139 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.26(s, 2H), 7.35-7.26(m, 4H), 6.54(t, 1H, J = 4.8 Hz), 5.71(s, 1H), 4.64(d, 2H, J = 6 Hz).^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 162.3, 158.1, 139.0, 128.6, 127.5, 127.2, 110.8, 45.4.

N-(naphthalen-1-ylmethyl)pyrimidin-2-amine (**6o**):[44] white solid, yield 96% (168 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.21(s, 2H), 8.07(d, 1H, J = 8.8 Hz), 7.88-7.79(m, 2H), 7.69-7.40(m, 4H), 6.51(s, 1H), 5.89(s, 1H), 5.06(d, 2H, J = 3.6 Hz) . ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 162.2, 158.1, 134.2, 133.8, 131.5, 128.7, 128.2, 126.4, 125.8, 125.4, 123.5, 110.8, 43.6.

N-(anthracen-9-ylmethyl)pyrimidin-2-amine (**6p**): white solid, yield 94% (200 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.47(s, 1H), 8.33(t, 4H, J = 8.8 Hz), 8.04(d, 2H, J = 8 Hz), 7.55-7.47(m, 4H), 6.54(t, 1H, J = 4.8 Hz), 5.53(s, 3H). ^{13}C{^{1}H}NMR(100 MHz, $CDCl_3$): δ (ppm) = 162.0, 158.1, 131.5, 130.4, 129.1, 128.0, 126.5, 125.1, 124.1, 110.8, 38.1.

N-(2-morpholinoethyl)pyridin-2-amine (**6q**):[45] yellow oil, yield 86% (134 mg); ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 8.08(d, 1H, J = 4.4 Hz), 7.43-7.39(m, 1H), 6.57-6.55(m, 1H), 6.40(d, 1H, J = 8.4 Hz), 5.14(s, 1H), 3.72(t, 4H, J = 4.4 Hz), 3.35(q, 2H, J = 5.2 Hz), 2.62(t, 2H, J = 6 Hz), 2.49(s, 4H). ^{13}C{^{1}H}NMR (100 MHz, $CDCl_3$): δ (ppm) = 158.7, 148.0, 137.4, 112.7, 107.1, 66.9, 57.1, 53.3, 38.1.

ASSOCIATED CONTENT

Supporting Information

characterization data and figures illustrating HRMS and NMR spectra

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