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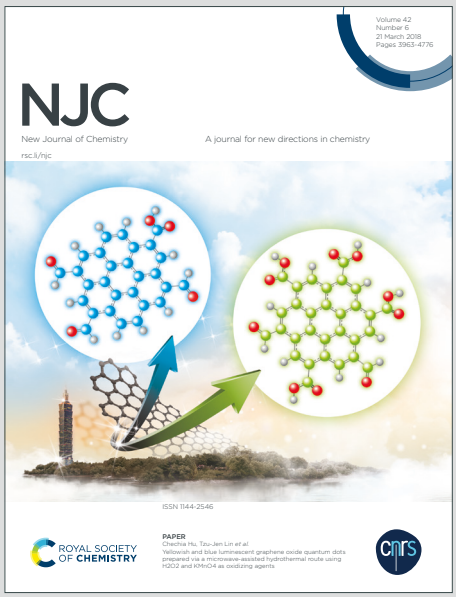

Cu(I) based catalysts derived from bidentate ligands and studies on effect of substituents for N-arylation of benzimidazoles and indoles

Received 00th January 20xx,
Accepted 00th January 20xx

DOI: 10.1039/x0xx00000x

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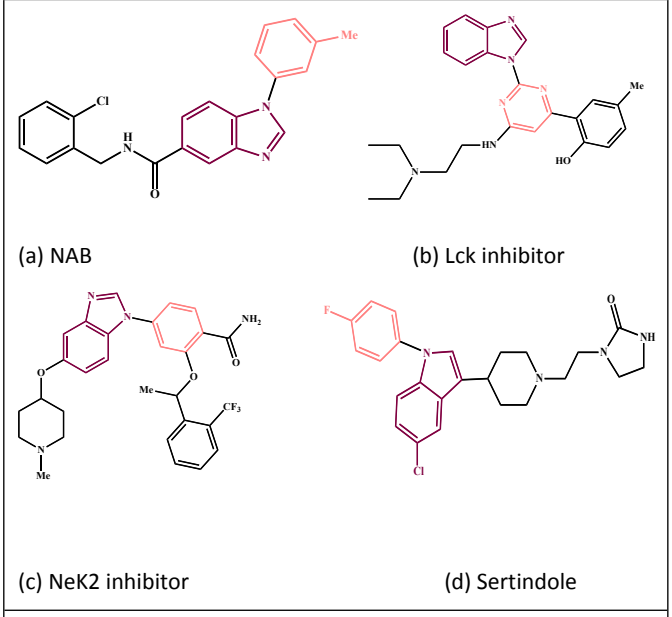
A family of Cu(I) complexes [Cu(L^{1-4})(Cl)(PPh_3)] (**C1**-**C4**) were synthesized from bidentate ligands L^1-L^4 (where L^1= (E)-2-(2-benzylidene-1-phenylhydrazinyl)pyridine, L^2= (E)-N,N-dimethyl-4-((2-phenyl-2-(pyridin-2-yl)hydrazono)methyl)aniline, L^3= (E)-2-(2-(4-chlorobenzylidene)-1-phenylhydrazinyl)pyridine and L^4= (E)-2-(2-(4-nitrobenzylidene)-1-phenylhydrazinyl)pyridine) and characterized. The structure of complex **C1** was authenticated by single-crystal X-ray diffraction. These complexes were utilised as catalysts for N-arylation of benzimidazoles and indoles. Effect of the substituents in the ligand frame of metal complexes were examined and probable reaction pathway was scrutinized.

Introduction

Transition metal complexes often act as catalyst in various organic transformations such as carbon-carbon, carbon-nitrogen, carbon-sulphur and carbon-oxygen bond formation. These reactions are extremely important for the multi-step synthesis of novel drug molecules and are often adopted in different chemical and pharmaceutical industries.[1-4] It is well known in the literature that at the beginning, carbon-nitrogen coupling reactions were carried out mainly by the reactions of amines and alkyl or aryl halides in the presence of palladium catalysts.[5-6] In recent years, 3d transition metals received considerable attention over 4d and 5d transition metal complexes because 3d transition metals are earth-abundant and the complexes derived from these metals are cost-effective.[7] There are various types of C-N coupling reactions and among them we are focussed on N-arylation of N-H heterocycles such as benzimidazoles and indoles. Here, Scheme 1 represents few important drug molecules containing N-arylated products of benzimidazoles and indoles. Among the first row 3d transition metals, copper catalysts were found to be most operative for N-arylation reaction.[7] In the literature, Cu(I) as well as Cu(II) based catalysts were utilised for N-arylation of benzimidazoles and indoles. For example, Chauhan's, Buchwald's and Collman's group utilised Cu(II) metal salts for N-arylation studies.[8-10] Investigation of mechanism suggested the occurrence of oxidative addition during catalytic reaction and flipping of oxidation state of the copper metal centre.[8,11] Keeping this in mind, several research groups utilised



Scheme 1. Models of N-arylated drugs.[1-4]

Cu(I) metal salts with different ligands such as transcyclohexanediamine[12], 4,7-dimethoxy-1,10-phenanthroline[13], salicylaldoxime,[14] amino acid,[15,16] 1,2-dimethylethylenediamine[17], 4,7-dichloro-1,10-phenanthroline[18], 8-quinolinol[19], aminoarenethiol[20], phosphine oxime oxides[21], phosphoramidites[22], 2-aminopyrimidinediols[23], phenanthroline[24], calcium fluorophosphate[25], N-(4-thiazolylmethyl)morpholine N-Oxide[26] and 2-(2′-pyridyl)benzimidazole[27] to carry out N-arylation activity. To the best of our knowledge, there is only one report available where copper(I) complex was utilized for N-arylation of benzimidazoles and indoles.[28]

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† Electronic supplementary information (ESI) available: X-ray crystal structure data have been deposited in the Cambridge Crystallographic Data Centre and the deposition number for complex **C1** is CCDC 2005016. For. See DOI: 10.1039/x0xx00000x

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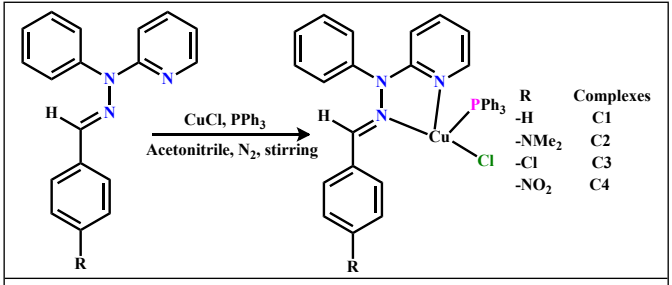
The design of ligand as well as metal complex are very essential to study the catalytic reaction. To carry out N-arylation reaction, catalyst should have free site or labile groups at the metal centre so that nucleophile can easily attack to the metal centre. In the catalytic cycle, the stabilization of Cu(III) intermediate species formed during the reaction is an essential factor. The presence of π-acid ligands like PPh_3 and electron-donating groups in the ligand frame could impart significant effect in the catalytic process.[11]

Considering these facts, recently we have communicated our results on the effect of substituents in Sonogashira coupling reaction.[29] In this communication, we have synthesized all the four complexes $[Cu(L^{1-4})(Cl)(PPh_3]$ (**C1-C4**) reported. [29] These complexes were characterized by different spectroscopic studies. The structure of complex **C1** was authenticated by single-crystal X-ray study. These complexes were utilised as catalysts for N-arylation reactions of benzimidazoles and indoles with iodo and bromo arenes. A total of 13 substrates were examined for the study and the formation of isolated products were characterized using ^1H and ^{13}C NMR spectral techniques. On the basis of literature reports, a reaction pathway of C-N coupling reaction will be scrutinized.[11]



Scheme 2: Schematic drawing of complexes $[Cu(L^{1-4})(Cl)(PPh_3)]$ **(C1-C4)**.

Results and discussion

Synthesis of catalysts

Ligands (L^{1-4}) were synthesized by the reported methods and Scheme 2 was followed to synthesize Cu(I) complexes (**C1-C4**).[29] The UV-Vis spectral change and IR data indicated the formation of Cu(I) complexes (**C1-C4**).[29]

Description of crystal structure

The single crystal of complex **C1** was obtained by slow evaporation of acetonitrile and dichloromethane solvent. Molecular structure of the complex **C1** was authenticated using single-crystal X-ray technique and the ORTEP view is depicted in Figure 1. The matrix parameters and bond distances and bond angles related to complex **C1** were described in the Table S1 and S2 of supporting file.

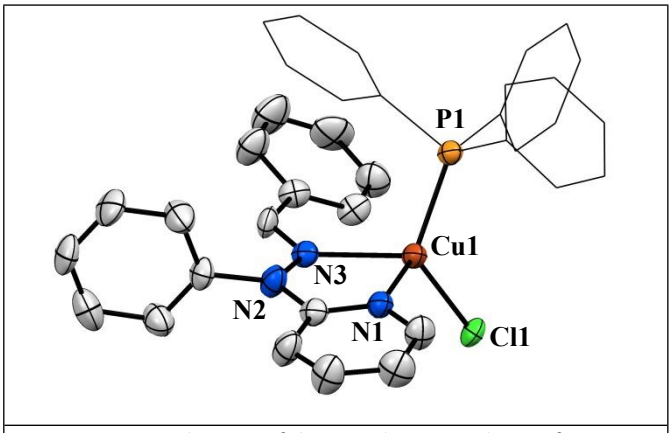
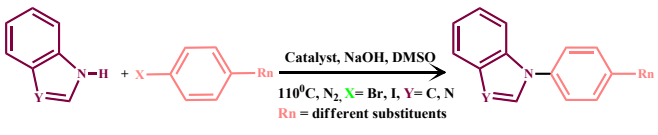


Figure 1: ORTEP diagram of the complex **C1**. Hydrogen fragments were removed for the soberness.

The metal centre of the complex was found to be coordinated to bidentate ligands having –NN donor atoms, one phosphorus atom from phosphine group and one chlorine atom. This tetra coordination imparted a distorted tetrahedral geometry around the metal centre. The Cu1-Cl1 bond distance is 2.2787(19)A° which is lower than the values reported by Facchin and co-workers and our previous report.[29-30] Cu1-P1 bond distance is 2.1889(17)A° which is less than the values reported by Kuang et. al[31] and Li et. al[32] but larger than the values reported by Alvarez et. al.[30]

Catalytic activity : N-arylation reactions



Scheme 3: An outline for N-arylation of heterocyles.

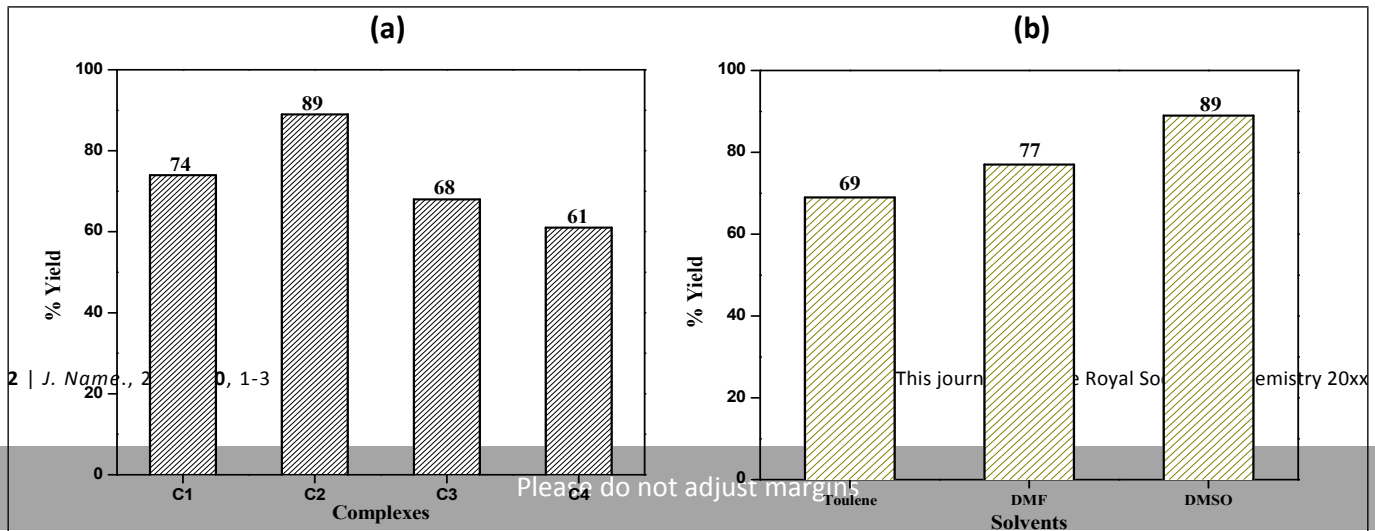


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Figure 2 : Effect of (a) catalysts (**C1**-**C4**) and (b) solvents on N-arylation of benzimidazole using iodobenzene to synthesize 1-phenyl-1H-benzo[d]imidazole.

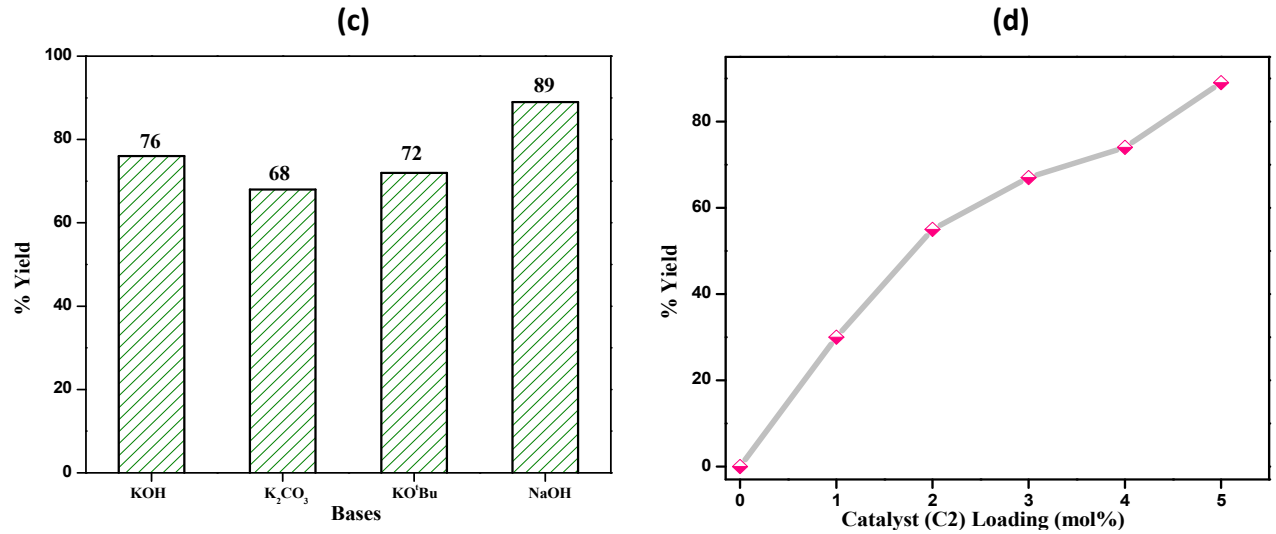

Figure 3 : Effect of (a) bases and (b) catalyst loading (**C2**) on N-arylation of benzimidazole using iodobenzene to synthesize 1-phenyl-1H-benzo[d]imidazole.

Scheme 3 was followed to carry out N-arylation reactions of benzimidazoles and indoles. To find out favourable conditions, different control reactions were performed. When only CuCl metal salt was employed as a catalyst to study N-arylation reaction of benzimidazole and iodobenzene, trace amount (<2%) of product was formed. No reaction was observed when only ligand was utilised as a catalyst We also employed only CuI metal salt as a catalyst for N-arylation of benzimidazole and iodobenzene under similar conditions, <5% product was formed. All the four mentioned complexes (**C1**–**C4**) were employed as a catalyst towards N-arylation reactions. The yields obtained for each complex is given in Figure 2(a). Out of four complexes, **C2** complex was found to be most efficient and provided 89% yield of the product. Optimisation reaction for N-arylation of benzimidazole is shown in Table S3 of supporting file. Further, optimisations were also performed using indole and iodobenzene and yields were depicted in Table S4 and Figure S1 and S2 of supporting file.

The reactions were also carried out in different solvents and the yields obtained using different solvents are presented in Figure 2(b). Dimethyl sulfoxide solvent gave better yield in comparison to N,N-dimethylformamide and toulene solvent. Several bases such as NaOH, KOH, K_2CO_3 and KO^{t}Bu were utilised to study N-arylation

Table 1: Reaction of heterocycles with haloarenes using catalyst **C2**.

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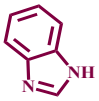
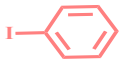
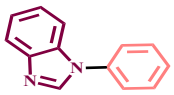
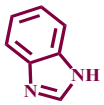
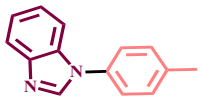
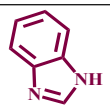
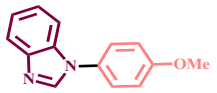
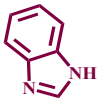
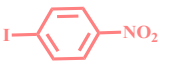
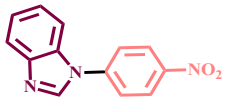
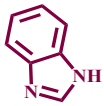
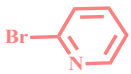
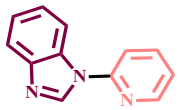
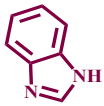
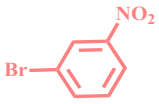
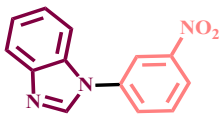
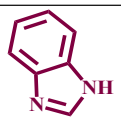
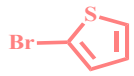
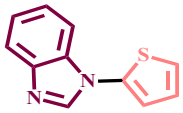
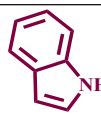
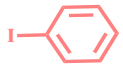
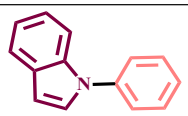
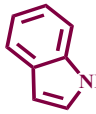
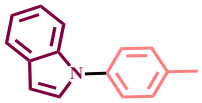
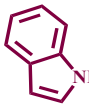
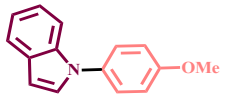
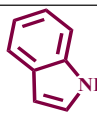
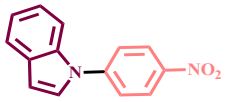
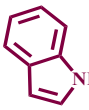
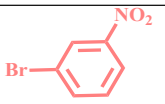
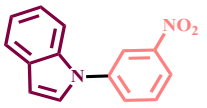
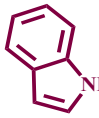
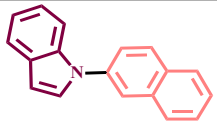
1.			(R1) 	89
2.			(R2) 	82
3.			(R3) 	86
4.			(R4) 	77
5.			(R5) 	68
6.			(R6) 	66
7.			(R7) 	63
8.			(R8) 	87
9.			(R9) 	83
10.			(R10) 	84
11.			(R11) 	78
12.			(R12) 	69
13.			(R13) 	64

Reaction conditions: Heterocycles (1.0 mmol), Haloarenes (1.0 mmol), **C2** (5 mol%), base (1.0 mmol), DMSO. Temperature (110°C) under inert atmosphere for 20h. (a) Represents the isolated yields.

reaction shown in Figure 3(a). Compared to other bases, NaOH base was found to be more reactive towards N-arylation reaction and provided higher yield of products. Different mol% of catalyst **C2** was utilised to study N-arylation reaction. As the mol% of catalyst **C2** was increased, the isolated yield got increased. The isolated yields obtained with each mol% are shown in Figure 3(b). After performing several optimizations, **C2** complex was found most efficient to perform N-arylation reaction in presence of NaOH base and dimethyl sulfoxide as solvent. We further examined the substrate scope of the reactions of various haloarenes with heterocyles in the presence of catalyst **C2**. The isolated yields obtained for each substrate are given in Table 1. ^{1}H NMR and ^{13}C NMR plots of desired products are given in Figure S3-S28 of supporting file.

Substituted iodobenzene in comparison to bromobenzene derivatives reacted efficiently with benzimidazoles and indoles resulting N-arylation reaction in better yields. Iodobenzene derivatives, on reaction with benzimidazole, formed N-arylated product with up to 77-89% yield (Table 1, entry 1, 2, 3 and 4). We ended up with 78-87- yield. (Table 1, entry 8, 9, 10 and 11), when these derivatives were reacted with indole, Further, the isolated yields were found to be in the range of 63-69%. (Table 1, entry 5, 6, 7, 12 and 13), when bromobenzene derivatives were reacted with benzimidazoles and indoles,

A reaction pathway for N-arylation reaction has been proposed on the basis of literature and was depicted in Figure S29.[8,11] In the first step of the reaction, deprotonation of benzimidazoles/indoles gave rise to coordination of heterocycles to copper centre through nitrogen. In the second step, the oxidative addition of derivatives of aryl halides gave rise to intermediate (C). In the last step, reductive elimination gave rise to N-arylated benzimidazoles and indoles and the reaction continues. It has been found out that iodobenzene derivatives of aryl halides provided higher yields compared to bromo derivatives. This is due to less bond energy of C–I bond compared to C–Br bond present in aryl halides. We have found that electron-donating groups in the bidentate ligands increase the efficiency of the reaction, however, efficiency decreased if electron-withdrawing groups are present in the ligand frame .

In order to investigate the oxidation state of copper during N-arylation reaction, we utilised X-ray photoelectron spectroscopy (XPS) technique to understand the oxidation state of metal ion during catalytic cycle. The 2p core-level lines of **C2** complex were fitted with two main peaks, where Cu 2p1/2 and 2p3/2 peaks at 952.4 eV and 932.8 eV were indicated the presence of Cu(I) species (presented in Figure S30a of supporting file).[33] After treating the complex **C2** with sodium hydroxide base, heterocycle and haloarenes for 30 min in presence of dimethylsulfoxide solvent, the peaks shifted from 952.4 to 952.1 eV, for Cu 2p1/2 and 932.8 eV to 931.4 eV for Cu 2p3/2. These data clearly indicated the formation of Cu(I) species in the reaction mixture.[34] However, two new peaks originated at 953.8 eV and 934.4 eV indicated the formation of Cu(III) species in the reaction mixture shown in Figure S30b of supporting file.[35] Therefore, we proposed that Cu(I) metal centre flips its oxidation state between I and III during N-arylation reaction.

The best thing about our complexes is that we can utilise different kind of substituents in the ligand frame. We compared our results of N-arylation reaction with the literature reports. For N-arylation of benzimidazoles and indoles, 5 mol% of catalyst loading was required. Among reported results, our catalyst loading was low. Tahsini and coworkers utilised 10 mol% of N-heterocyclic carbene (NHC)-copper (I) catalysts to study N-arylation of benzimidazoles and indoles which is less effective compared to our catalyst loading.[28] Peng et. al reported N-arylation of benzimidazoles using 20 mol% of N-(4-thiazolylmethyl)morpholine N-Oxide ligand and 10 mol% of CuI metal salt and their catalyst amount is high and less effective in comparison to our catalyst.[26] Buchwald and co-workers carried out N-arylation of indoles using 20 mol% of diamine ligand and 5 mol% of CuI metal salt in presence of K_3PO_4 base which was also high compared to our catalyst loading.[36] However, our results are comparable with the data reported by Hayashi and co-workers where they have utilised 5 mol% of 2-(2'-pyridyl)benzimidazole ligand and 5 mol% of CuI for N-arylation of indoles.[27]

Conclusions

The following are the conclusions of the present study:

I. To study a new methodology for N-arylation reaction, four mononuclear Cu(I) complexes were synthesized. Molecular structure of the complex **C1** was determined by single crystal X-ray method.

II. Above mentioned complexes were utilised as a catalyst for N-arylation reaction. 5 mol% of complex was employed for the N-arylation study. The major advantage of our complexes is that we can tune different kind of substituents in the ligand frame to tune the reactivity of metal complexes.

III. For substrate scope, a total of thirteen N-arylated compounds were isolated using column chromatography and were characterized by ^{1}H NMR and ^{13}C NMR spectral studies.

IV. In terms of catalytic efficiency, order of catalysts were found to be **C2**>**C1**>**C3**>**C4**. The efficiency order of the catalysts to catalyze N-arylation reaction indicated the role of electron donating group present in the ligand frame of catalyst.

Applications of these catalysts in other organic transformation are under progress.

Materials and Measurements

All reagents obtained for synthesis and catalysis are of standard quality. Solvents were highly purified by the distillation process. N-arylation catalysis was performed under an inert atmosphere.

Methods and instrumentation

IR spectra were analysed using KBr pellets with Thermo Nikolet Nexus FT-IR spectrometer. The UV-Vis spectra were obtained from Thermo Scientific UV-Visible spectrophotometer. ^{1}H, ^{13}C and ^{31}P NMR spectral data was collected by Jeol, 400 MHz and 500 MHz spectrometer. The single-crystal X-ray data for complex **C1** was collected by Bruker Kappa Apex-II CCD diffractometer. X-ray photoelectron spectrophotometer (XPS; ULVAC – PHI, INC, Japan) was utilised to determine the oxidation state.

Syntheses of ligands and metal complexes

Ligands (L^{1-4}) were synthesized by the previously reported methods and Scheme 2 was followed to synthesize Cu(I) complexes (**C1**-**C4**).[29] Syntheses of metal complexes: **[Cu(L^{1-4})Cl(PPh_3)]** complexes were prepared using the resulting method given below.

[Cu(L^1)(PPh_3)Cl] (C1): This complex was prepared in acetonitrile solution by using L^1 and CuCl in inert atmosphere. Rest of the procedure was similar to procedure described in our previous report.[29] Theoretical. calcd. for $C_{36}H_{30}ClCuN_3P$ (634.61): C, 68.13; H, 4.76; N, 6.62. Found: C, 68.25; H, 4.69; N, 6.51.

[Cu(L^2)(PPh_3)Cl] (C2): Same procedure as described in our previous report[29] was followed to obtain **C2**. Theoretical. calcd. for $C_{38}H_{35}ClCuN_4P$ (677.68): C, 67.35; H, 5.21; N, 8.27. Found: C, 67.49; H, 5.36; N, 8.39.

[Cu(L^3)(PPh_3)Cl] (C3): Same procedure as described in our previous report[29] was followed to obtain **C3**. Theoretical. calcd. for $C_{36}H_{29}Cl_2CuN_3P$ (669.06): C, 64.63; H, 4.37; N, 6.28. Found C, 64.74; H, 4.48; N, 6.35.

[Cu(L^4)(PPh_3)Cl] (C4): Same procedure as described in our previous report[29] was followed to obtain **C4**. Theoretical. calcd. for $C_{36}H_{29}ClCuN_4O_2P$ (679.61): C, 63.62; H, 4.30; N, 8.24;. Found: C, 63.56; H, 4.41; N, 8.20.

Single X-ray crystallography

Crystal of [Cu(L^1)(Cl)(PPh_3)] (**C1**) were attained by slow evaporation of acetonitrile and dichloromethane solvent. The X-ray data collection for complex **C1** was performed on a Bruker Kappa Apex-II CCD diffractometer by using graphite monochromated Mo-Kα radiation (λ = 0.71073 Å) at 293K. Structural outline of complex **C1** was resolved using WinGX software. Crystal structures were solved by direct methods. Structure solutions, refinement and data output were carried out with the SHELXTL program.[37-39] All atoms except hydrogen were refined anisotropically. ORTEP view was achieved using MERCURY software.

Catalytic studies

5 mole % of catalyst, NaOH (1.0 mmol), Heterocycles (1 mmol), Haloarenes (1 mmol), and 4ml dimethyl sulfoxide were taken in a round bottom flask and refluxed with stirring at 110°C for 20h under inert surroundings. After it, the solvent was removed and extracted with ethyl acetate and water. Ethyl acetate solvent was mixed with silica to make slurry and it was passed through column to get pure compound. The desired compounds obtained were analysed utilizing ^{1}H and ^{13}C NMR techniques.

R1. 1-phenyl-1H-benzo[d]imidazole {$C_{13}H_{10}N_2$} (89%, 173mg) ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.11 (s, 1H), 7.89 – 7.87 (m, 1H), 7.58 – 7.52 (m, 3H), 7.50 (m, 2H), 7.47 – 7.44 (m, 1H), 7.35 – 7.30 (m, 2H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.96, 142.18, 136.27, 133.62, 129.96, 127.95, 123.96, 123.61, 122.71, 120.51, 110.37 ppm.[40]

R2. 1-(p-tolyl)-1H-benzo[d]imidazole {$C_{14}H_{12}N_2$} (82%, 171mg). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.09 (s, 1H), 7.89 – 7.86 (m, 1H), 7.52 – 7.50 (m, 1H), 7.38 (d, *J* = 6.6 Hz, 4H), 7.34 – 7.30 (m, 2H), 2.46 (s, 3H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.85, 142.30, 138.04, 133.79, 133.69, 130.49, 123.91, 123.50, 122.59, 120.43, 110.40, 21.05 ppm.[41]

R3. 1-(4-methoxyphenyl)-1H-benzo[d]imidazole {$C_{14}H_{12}N_2O$} (86%, 193mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.05 (s, 1H), 7.87-7.85 (m, 1H), 7.47-7.43 (m, 1H), 7.40 (d, *J* = 8.9 Hz, 2H), 7.35-7.28 (m, 2H), 7.08 – 7.05 (m, 2H), 3.88 (s, 3H) ppm. ^{13}C NMR (100MHz, $CDCl_3$): δ = 159.24, 143.71, 142.48, 134.14, 129.05, 125.67, 123.45, 122.54, 120.40, 115.06, 110.31, 55.57 ppm.[42]

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DOI: 10.1039/D0NJ02568B

R4. 1-(4-nitrophenyl)-1H-benzo[d]imidazole {$C_{13}H_9N_3O_2$} (77%, 184mg). ^{1}H NMR (400 MHz, $CDCl_3$): δ ^{1}H NMR (400 MHz,) δ 8.44 (d, *J* = 8.9 Hz, 2H), 8.18 (s, 1H), 7.88-7.86 (m, 1H), 7.72 (d, *J* = 8.9 Hz, 2H), 7.61 – 7.58 (m, 1H), 7.41 – 7.36 (m, 2H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): *δ* = 146.37, 144.28, 141.58, 141.49, 132.66, 125.74, 124.48, 123.62, 123.51, 121.03, 110.20 ppm.[40]

R5. 1-(pyridin-2-yl)-1H-benzo[d]imidazole {$C_{12}H_9N_3$} (68%, 133mg). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.59 (d, *J* = 4.9 Hz, 1H), 8.58 (s, 1H), 8.05 (d, *J* = 7.3 Hz, 1H), 7.87 (t, *J* = 7.6 Hz, 2H), 7.55 (d, *J* = 8.2 Hz, 1H), 7.40-7.33 (m, 2H), 7.28-7.27 (m, 1H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$) δ 149.77, 149.34, 144.56, 141.22, 138.82, 132.02, 124.10, 123.18, 121.72, 120.51, 114.19, 112.56.[43]

R6. 1-(3-nitrophenyl)-1H-benzo[d]imidazole {$C_{13}H_9N_3O_2$} (66%, 158mg). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.40 (t, *J* = 2.1 Hz, 1H), 8.30 (m, 1H), 8.16 (s, 1H), 7.90 – 7.86 (m, 2H), 7.78 (t, *J* = 8.1 Hz, 1H), 7.56 – 7.52 (m, 1H), 7.38 – 7.34 (m, 2H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$) δ 149.16, 144.08, 141.61, 137.42, 132.99, 131.11, 129.32, 124.37, 123.43, 122.45, 120.95, 118.61, 109.90 ppm.[44]

R7. 1-(thiophen-2-yl)-1H-benzo[d]imidazole {$C_{11}H_8N_2S$} (63%, 126mg). ^{1}H NMR (400 MHz, $CDCl_3$) ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.08 (s, 1H), 7.87 – 7.84 (m, 1H), 7.58 – 7.54 (m, 1H), 7.37 – 7.34 (m, 2H), 7.32 (d, *J* = 5.5 Hz, 1H), 7.17 (d, *J* = 3.7 Hz, 1H), 7.13 – 7.10 (m, 1H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.54, 143.09, 137.08, 134.71, 126.41, 124.13, 123.42, 123.20, 121.92, 120.58, 110.52 ppm.[45]

R8. 1-phenyl-1H-indole {$C_{14}H_{11}N$} (87%, 168mg). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.76 (d, *J* = 7.7 Hz, 1H), 7.64 (d, *J* = 8.2 Hz, 1H), 7.57 (d, *J* = 4.6 Hz, 4H), 7.43-7.40 (m, 2H), 7.29 (t, *J* = 7.6 Hz, 1H), 7.24 (t, *J* = 7.4 Hz, 1H), 6.75 (d, *J* = 3.2 Hz, 1H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$) δ 139.84, 135.87, 129.57, 129.32, 127.91, 126.41, 124.36, 122.32, 121.10, 120.33, 110.47, 103.55 ppm.[46]

R9. 1-(p-tolyl)-1H-indole {$C_{15}H_{13}N$} (83%, 172mg). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.71 (d, *J* = 8.4 Hz, 1H), 7.56 (d, *J* = 8.2 Hz, 1H), 7.42 (d, *J* = 8.3 Hz, 2H), 7.34 (m, 3H), 7.25 – 7.22 (m, 1H), 7.19 (t, *J* = 7.4 Hz, 1H), 6.70 (d, *J* = 3.9 Hz, 1H), 2.47 (s, 3H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$) δ 137.31, 136.32, 136.01, 130.12, 129.17, 128.05, 124.34, 122.18, 121.03, 120.16, 110.49, 103.17, 21.02 ppm.[47]

R10. 1-(4-methoxyphenyl)-1H-indole {$C_{15}H_{13}NO$} (84%, 187mg). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.78 (d, *J* = 7.6 Hz, 1H), 7.56 (d, *J* = 8.1 Hz, 1H), 7.48 (d, *J* = 8.9 Hz, 2H), 7.36 (d, *J* = 3.2 Hz, 1H), 7.30 (d, *J* = 8.1 Hz, 1H), 7.26 (d, *J* = 7.9 Hz, 1H), 7.10 (d, *J* = 8.9 Hz, 2H), 6.75 (d, *J* = 3.8 Hz, 1H), 3.94 (s, 3H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$) δ 158.20, 136.30, 132.80, 128.93, 128.22, 125.91, 122.10, 120.97, 120.03, 114.87, 114.69, 110.32, 102.85, 55.50 ppm.[47]

R11. 1-(4-nitrophenyl)-1H-indole {$C_{14}H_{10}N_2O_2$} (78%, 186mg). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.41 (d, *J* = 9.0 Hz, 2H), 7.75 (d, *J* = 7.8 Hz, 1H), 7.69 (d, *J* = 9.0 Hz, 3H), 7.41 (d, *J* = 3.4 Hz, 1H), 7.34 (t, *J* = 7.7 Hz, 1H), 7.28 (t, *J* = 7.0 Hz, 1H), 6.82 (d, *J* = 3.4 Hz, 1H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$) δ 145.15, 144.97, 135.19, 130.06, 127.04, 125.41, 123.35, 123.21, 121.61, 121.53, 110.41, 106.11 ppm.[48]

R12. 1-(3-nitrophenyl)-1H-indole {$C_{14}H_{10}N_2O_2$} (69%, 164mg). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.42 (t, *J* = 2.1 Hz, 1H), 8.23 (d, *J* = 7.0 Hz, 1H), 7.90 (d, *J* = 8.0 Hz, 1H), 7.74 (m, 2H), 7.62 (d, *J* = 7.7 Hz, 1H), 7.41 (d, *J* = 3.3 Hz, 1H), 7.32 (t, *J* = 7.2 Hz, 1H), 7.29-7.25 (m, 1H), 6.80 (d, *J* = 3.3 Hz, 1H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$) δ 149.11, 140.89, 135.43, 130.53, 129.66, 129.52, 127.15, 123.17, 121.52, 121.19, 120.75, 118.68, 109.96, 105.34 ppm.[49]

R13. 1-(naphthalen-2-yl)-1H-indole {$C_{18}H_{13}N$} (64%, 156mg). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.97 (d, *J* = 8.1 Hz, 2H), 7.76 (d, *J* = 7.9 Hz, 1H), 7.61 – 7.53 (m, 3H), 7.46 (d, *J* = 8.0 Hz, 1H), 7.44 – 7.39 (m, 1H), 7.37 (d, *J* = 3.2 Hz, 1H), 7.21 – 7.16 (m, 1H), 7.16 – 7.11 (m, 1H), 7.05 – 6.99 (m, 1H), 6.78-6.77 (m, 1H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$) δ 138.03, 136.09, 134.48, 130.60, 129.78, 128.46, 128.24, 126.93, 126.63, 125.49, 125.14, 123.41, 122.13, 120.90, 120.10, 110.82, 102.90 ppm.[50]

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

KG is thankful to CSIR, New Delhi, India for financial assistance No. 01(2942)/18/EMR-II dated 01-05-2018). SK and VK are thankful to CSIR, KM is thankful to UGC, AR and AM are thankful to MHRD, India for financial assistance.

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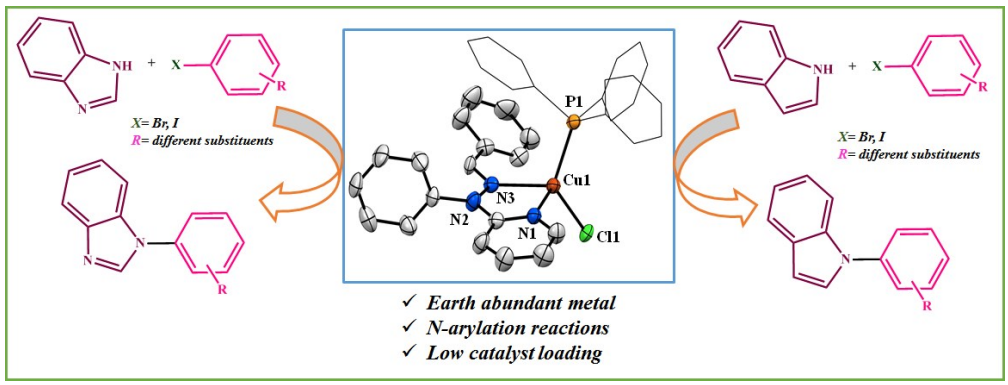
DOI: 10.1039/D0NJ02568B



307x115mm (96 x 96 DPI)