

**CuI nanoparticles catalyzed *N*-arylation of NH-containing heterocycles with aryl halides under ligand and additive free conditions****Bojja Sreedhar*[†], Dontaraboina Keerthi Devi, Yella Sowjanya**

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ABSTRACT

CuI nanoparticles were employed for the N-arylation of indole and pyrrole with aryl halides using K₂CO₃ as base under ligand free conditions. This procedure merits simple handling, proceeds efficiently without any ligands and additives, affording the desired products in good to excellent yields. Easy recoverability, efficient recycling, high functional group tolerance, and stability of the catalyst render the protocol economic and sustainable.

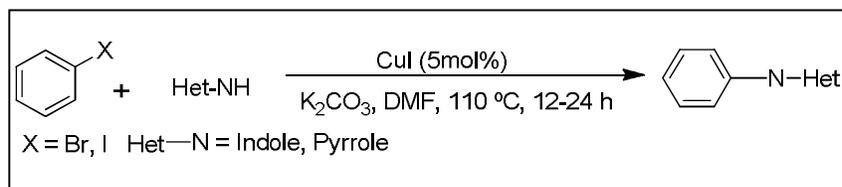
Keywords: *N*-arylation, *N*-arylindole, *N*-arylpyrrole, copper iodide nanoparticles, recyclable.

INTRODUCTION

N-arylheterocycles are prevalent motifs found in numerous biologically active compounds, pharmaceuticals and materials [1]. The subunits of *N*-arylindoles are synthetically challenged and have high medicinal valuable due to their interesting biological activities such as antipsychotic agents [2], anti allergic [3], antiestrogen [4], analgesic [5], cyclooxygenase (COX)-1 inhibitors [6], FTase inhibitors (FTIs) [7], neuroleptic [8], antimicrobial [9], anti HIV-1 agents [10] and herbicides [11]. *N*-arylpyrroles are ubiquitous in biochemical, biological arena and play a crucial role in medicinally related structures and their functions [12]. As for the literature, ligand free Ullmann type reactions are rare. Arylation of heterocyclic nitrogen is a long-standing problem, and traditionally they are synthesized by Ullmann-type coupling using stoichiometric amount of copper reagents under harsh reaction conditions (200 °C), strong bases and often with the use of toxic polar solvents such as hexamethylphosphoramide (HMPA) [13]. Later on various transition metals such as Cu [14-16], Fe [17], Ni [18] and Cd [19], have been well explored and they played vital role in the development of aforementioned cross-coupling reactions, however, harsh conditions still limit the utility of these protocol. Notably, palladium catalysts along with some sterically hindered bulky phosphine ligands which are rare, air-sensitive, poisonous and expensive [20] or other non-commercially available ligands efficiently catalyzed the coupling of aryl halides with *N*-containing compounds resulting in arylated products in good to excellent yields under milder reaction conditions [21, 22]. Although results are inspiring, still the use of expensive palladium catalysts with ligands is not attractive in large scale industrial and economical point of view, hence recently much attention is being paid to cheaper copper catalysts. In this regard various copper-catalyzed Ullmann

arylation reactions have been developed using ligands like bidentate N,N-, N,O-, O,O-, or N,S-ligands such as amino acids, diols and triols, diketones, 4,7-dimethoxy-1,10-phenanthroline, ketone-esters, amino-alcohols, 8-hydroxyquinoline, diamines, diimines, aminoarenethiolate, diethylsalicylamide, phosphine ligands, pyrrolidine-2-phosphonic acid, 2-aminopyrimidine-4,6-diol, phenyl monoester [23, 24] etc. In more recent approaches, the heterogeneous copper catalyst system especially copper nanoparticles has been developed to overcome issues associated with these cross-coupling reactions such as cost, catalytic activity and more prominently toxicity of copper on environment. Kantam et al. reported the N-arylation of various heterocycles including indole nucleus by using nanocrystalline CuO [25]. Subsequently, Punniyamurthy et al. used commercially available CuO nanoparticles as reusable catalyst for the N-arylation of various amines, including indole using iodobenzene [26], Li et al. used cubic Cu₂O nanoparticles/1,10-phenanthroline for N-arylation of indole with various aryl halides [27] and Lamaty et al used recyclable PEG3400-Cu₂O/Cs₂CO₃ system under microwave irradiation [28]. In terms of preparation, simplicity of use, deactivation and recoverability of catalyst, these methods have some inadequacy. Therefore, it is highly desirable to develop new ligand free catalytic systems to replace the current expensive and air sensitive transition metal catalysts.

Nano CuI a new functional material [29], proved as highly efficient catalyst for C-N and C-O cross coupling of heterocyclic amines and phenols with chloroarenes [30]. These CuI nanoparticles have shown the advantages like lowering of the reaction temperatures, obviate the use of expensive ligands, high catalyst loadings and can be reused for several reaction cycles without any significant loss in the catalytic activity or yield. In turn to utilize the mentioned advantages we here in explore the novel CuI nanoparticles catalytic system for the synthesis of a variety of N-arylheterocyclic products via coupling reaction of aryl halides with N-heterocyclics.



Scheme 1 N-arylation of indole and pyrrole

MATERIALS AND METHODS

All chemicals were purchased from *Sigma-Aldrich* or *S.D. Fine Chemicals Pvt. Ltd., India* and used as received. Analytical thin layer chromatography (TLC) was carried out using silica gel 60 F₂₅₄ pre-coated plates. Visualization was accomplished with UV lamp or I₂ stain. All the other chemicals and solvents were obtained from commercial sources and purified using standard methods.

General procedure for the catalytic N-arylation of nitrogen-containing heterocycles with aryl halides: An oven-dried 25 mL round-bottomed flask with a magnetic stirring bar was charged with CuI nanoparticles (5 mol %), K₂CO₃ (1.2 mmol), indole/pyrrole (1.2 mmol), aryl chloride (1.0 mmol) and DMF (3 mL) under air. The reaction mixture was stirred for 30 min at room temperature, and then transferred to a pre-heated oil bath at 110 °C. After the completion of reaction as judged by TLC, the catalyst was separated by centrifugation, was washed with EtOAc and reused. The crude reaction mixture was extracted with ethyl acetate and chromatographed on silica gel using hexane/ethyl acetate as an eluent to afford the desired N-arylated product.

RESULTS AND DISCUSSION

A systematic study was first undertaken using indole and iodobenzene as model substrates for the N-arylation of indole reaction with varying the bases in combination with solvents and the results are shown in Table 1. Amongst the various solvents screened, DMF has been found to be the best solvent, whereas DMSO, Toluene and H₂O gave lower yield of the desired product. Further, different bases were introduced

into the coupling reaction in which K_2CO_3 proved to give high yield compared to the other bases such as K^tOBu , K_3PO_4 , KOH and pyridine (Table 1, Entries 1-3, 9).

Notably it was seen that reaction was susceptible to temperature changes, when the reaction was conducted at room temperature only a trace amount of product was obtained (table 1, Entry 11). Increasing the reaction temperature to $70\text{ }^\circ\text{C}$, showed an increase in the yield (table1, Entry 12), It is gratified to observe coupling product formed in high yields on further increasing the temperature to $110\text{ }^\circ\text{C}$ (table1, Entry 6). On the other hand, in the absence of the catalyst as well as base, no coupling product was formed (table 1, Entries 13 and 14), despite prolonged reaction time. Therefore, under the optimized reaction conditions i.e., indole (1.2 mmol), iodobenzene (1 mmol), 5 mol % of CuI nanoparticles as catalyst with DMF as solvent and K_2CO_3 (1.2 mmol) as base at $110\text{ }^\circ\text{C}$ gave the best result for the desired product (table 1, Entry 6).

To assess the scope and generality of the CuI catalyzed protocol a variety of meta and para-substituted aryl halides were coupled with indole under the optimized conditions and the results are summarized in table 2. As can be seen from table 2, coupling of iodobenzenes and bromobenzenes bearing electron-donating (e.g., Me, OMe and Et) or electron-withdrawing groups (e.g., F, Cl and CF_3) afforded the corresponding products in excellent yields (table 2 Entries 1–7 and 8-12). Encouraged by these results, we extended this method to pyrrole. Under the optimized conditions, the reaction worked well for pyrrole and arylhalides with various substituents at different positions of the aryl ring, including electron-withdrawing groups, electron-donating groups and halogen atoms. (table 3, Entries 1–10).

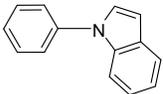
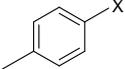
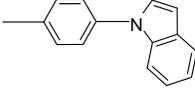
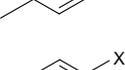
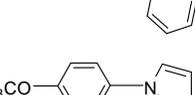
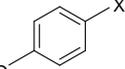
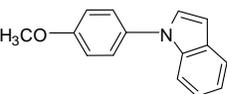
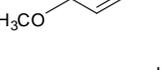
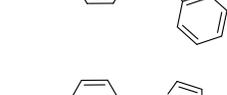
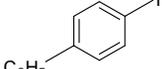
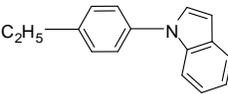
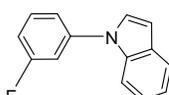
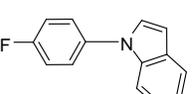
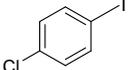
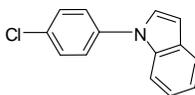
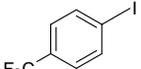
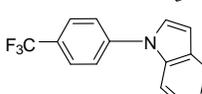
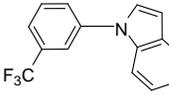
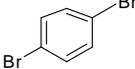
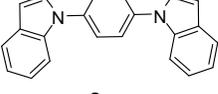
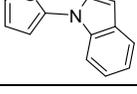
Table 1: Screening of bases and solvents for *N*-arylation of indole with iodobenzene.^a

Entry	Base	Solvent	Yield (%) ^b
1	K^tOBu	DMF	79
2	K_3PO_4	DMSO	41
3	KOH	DMSO	46
4	KOH	DMF	58
5	K_2CO_3	DMSO	86
6	K_2CO_3	DMF	94
7	K_2CO_3	Toluene	61
8	K_2CO_3	H_2O	Trace
9	Pyridine	DMF	43
10	K_3PO_4	DMF	52
11	K_2CO_3	DMF	Trace ^c
12	K_2CO_3	DMF	48 ^d
13	K_2CO_3	DMF	_e
14	-	DMF	_f

^aReaction conditions : Indole (1.2 mmol), Iodobenzene (1 mmol), CuI (9.5 mg, 5 mol%) K_2CO_3 (1.2 mmol), DMF (3ml), stirred at $110\text{ }^\circ\text{C}$ for overnight, ^bIsolated Yield, ^cAt rt, ^dAt $70\text{ }^\circ\text{C}$, ^eAbsence of CuI nanoparticles, ^fAbsence of base

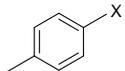
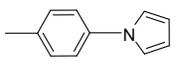
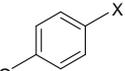
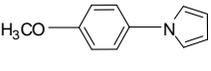
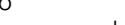
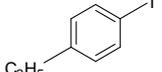
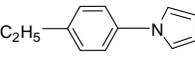
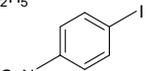
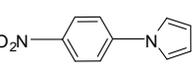
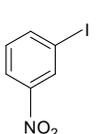
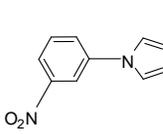
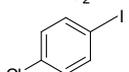
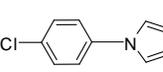
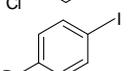
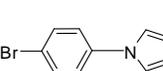
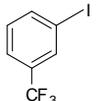
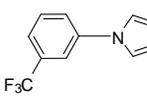
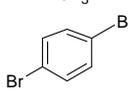
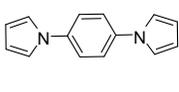
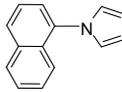
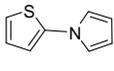
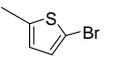
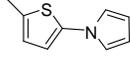
Good to excellent yields were obtained regardless of the electronic nature of the substituent on the aryl iodide, and no significant electronic effects were observed for both meta- and para-substituted aryl iodides. Furthermore, coupling reaction of aromatic and heteroaromatic bromo benzenes with indole (table 2, Entries 1, 3, 5, 13 and 14) and pyrrole (table 3, Entries 1, 3, 11, 13 and 14) also gave *N*-arylated products with moderate to high yields. As expected, iodobenzene provided good yields in shorter reaction time when compared to bromobenzene.

Table 2 : CuI catalyzed *N*-arylation of indole.^a

Entry	Aryl halide	Product	Yield (%) ^b
1	 X= Br		62 ^c
2	 I		94
3	 X= Br		56 ^c
4	 I		89
5	 X= Br		75 ^c
6	 I		96
7	 I		88
8	 I		89
9	 I		91
10	 I		92
11	 I		87
12	 I		86
13 ^d	 Br		60 ^c
14	 Br		57 ^c

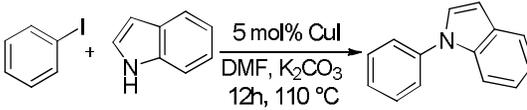
^aReaction conditions: Indole (1.2 mmol), aryl halide (1 mmol), K₂CO₃ (1.2 mmol), CuI (5 mol %), DMF (3 ml) at 110 °C for 12h. ^bIsolated yield after column chromatography. ^c24 h. ^dIndole (2.0 equiv).

Table 3 : CuI catalyzed *N*-arylation of pyrrole.^a

Entry	Aryl halide	Product	Yield (%) ^b
1	 X = Br		61 ^c
2	 I		88
3	 X = Br		79 ^c
4	 I		96
5	 C ₂ H ₅		84
6	 O ₂ N		91
7	 NO ₂		88
8	 Cl		88
9	 Br		89
10	 CF ₃		86
11 ^d	 Br		58 ^c
12			81
13			57 ^c
14			52 ^c

^aReaction conditions: Pyrrole (1.2 mmol), aryl halide (1 mmol) CuI (5 mol %), K₂CO₃ (1.2 mmol), DMF (3 ml) at 110 °C for 12h. ^bIsolated yield after column chromatography, ^c24h, ^d2.0 equiv of pyrrole.

Table 4 : Recycling of CuI nanoparticles^a

					
Reaction cycle	1 st	2 nd	3 rd	4 th	5 th
Yield (%)	94	92	91	87	84

^aReaction conditions: Indole (1.2 mmol), Iodobenzene (1 mmol), CuI (9.5 mg, 5 mol%), K₂CO₃ (1.2 mmol), DMF (3 mL), stirred at 110 °C for 12h.

Reusability studies of CuI nanocatalyst for *N*-arylation of heterocyclic reactions was carried out using indole and iodobenzene as the model substrate (Table 4). After completion of the reaction, the catalyst was recovered by centrifugation for 5 min at 6000 rpm and washed with 5-10 ml of ethyl acetate to remove organic matter and then the catalyst oven-dried at 65 °C for 2 h. The recovered catalyst was reused under similar conditions for the next run and the catalytic behavior of the CuI nanoparticles gave high yields without loss of its activity for five consecutive cycles.

The CuI nanoparticles were prepared according to the literature procedure [30] and characterized with TEM, XRD, and XPS. Transmission electron microscope (TEM) studies of both fresh and used catalysts were carried out to understand the shape and size of the particles. Figure 1 A and B shows that the shape and size (20-25 nm) of the CuI nanoparticles and does not change even after five cycles, which correlates with the retention of the catalytic activity after recycling.

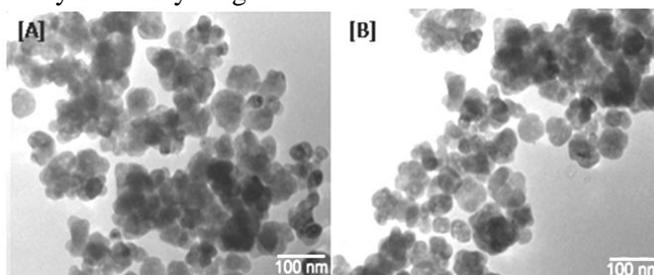


Fig. 1: TEM images of CuI nanoparticles. [A] Fresh and [B] Used after 5th cycle observed at 120 kV.

In order to confirm the crystalline structure of the as-synthesized and reused CuI nano catalyst, powder XRD study was carried out (Figure 2). According to the diffraction data card (JCPDS, 06-0246), all of the peaks can be perfectly indexed to CuI in peak positions. The XRD peaks for CuI were similar to those of the parent CuI, the intensity of CuI (111) reflection peak is apparent at 25.4° confirms the presence of CuI[30].

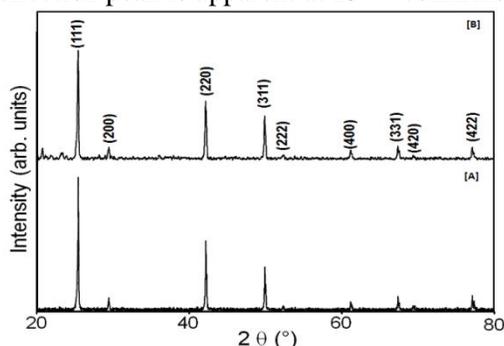


Figure 2. XRD profiles of (A) CuI nanoparticles fresh (B) CuI nanoparticles reused after fifth cycle.

XPS survey scan of CuI nanoparticles showed the presence of carbon, C 1s (at 284.6 eV) copper, Cu 2p (at 933.37 eV), and iodine, I 3d (at 620 eV). XPS high resolution narrow scans of Cu 2p for the fresh and used CuI nanoparticles are shown in Figure 3 A and B. The observed Cu 2p binding energy peaks could be deconvoluted into two peaks, 933.379, 954.721 and 933.395, 953.059 eV for the fresh and used CuI nanoparticles, respectively which are characteristic of 2p_{3/2} and 2p_{1/2} core levels. The observed binding energy peaks can be attributed to the Cu in +1 oxidation state. Similarly, the observed peak of I 3d peak at 620 eV could be deconvoluted into two peaks 3d_{5/2} and 3d_{3/2} at 619.313, 629.724 and 619.808, 630.017 eV for the fresh and used CuI nanoparticles, respectively (Figure 4 A and B). XPS peak values are in coincidence with the literature values[30].

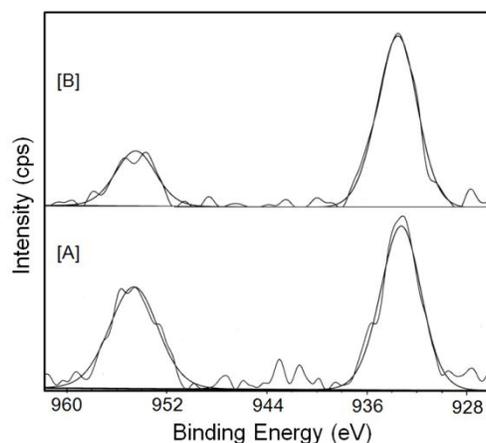


Figure 3. XPS high resolution narrow scan of Cu 2p for CuI nanoparticles. [A] fresh and [B] used (after 5th cycle).

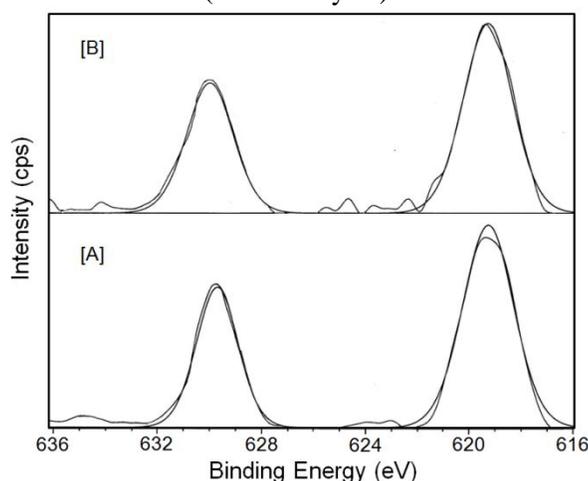


Figure 4. XPS high resolution narrow scan of I 3d for CuI nanoparticles [A] fresh and [B] used (after 5th cycle).

Spectroscopic characterization of the compounds:

1-phenyl-1H-indole (Table 2, entries 1, 2)^{16a}: yellowish oil, 62%, 94 %. ¹H NMR (300 MHz, CDCl₃, ppm): δ= 6.61 (d, 1H *J* = 3.02 Hz) 7.05-7.21 (m, 2H), 7.24-7.36 (m, 2H), 7.41-7.55 (m, 5H), 7.61 (d, 1H *J*=8.30); ¹³C NMR (75 MHz, CDCl₃, ppm): δ =103.5, 110.4, 120.3, 121.0, 122.3,124.3, 126.3, 127.8, 129.5, 135.8, 139.8. EI-MS: *m/z* =193 (M⁺).

1-(p-tolyl)-1H-indole (Table 2, entries 3, 4)³¹: yellowish oil, 56%, 89 %. ¹H NMR (300 MHz, CDCl₃, ppm): δ= 2.46 (s, 3H), 6.62 (d, 1H *J* = 3.02 Hz.), 7.07-7.22 (m, 2H), 7.25-7.44 (m, 5H), 7.50 (d, 1H *J* = 7.55 Hz), 7.64 (d, 1H *J* = 7.55 Hz); ¹³C NMR (75 MHz, CDCl₃, ppm): δ= 20.9, 103.1, 110.4, 120.1, 120.9, 122.1, 124.1, 127.9, 129.1, 130.0, 135.8, 135.8, 136.0, 137.1. EI-MS: *m/z* =207 (M⁺).

1-(4-methoxyphenyl)-1H-indole (Table 2, entries 5, 6)^{16a}: yellowish oil. 75%, 96 %. ¹H NMR (300 MHz, CDCl₃, ppm): δ= 3.76 (s, 3H), 6.51 (d, 1H, *J* = 3.11 Hz), 6.86-6.93 (m, 2H), 6.98-7.15 (m, 3H), 7.26-7.34 (m, 3H), 7.53 (d, 1H *J* =7.79); ¹³C NMR (75 MHz, CDCl₃, ppm): δ = 55.4, 103.0, 110.3, 114.6, 120.1, 121.0, 122.1, 125.9, 128.0, 128.9, 132.9, 158.2. EI-MS: *m/z* = 223 (M⁺).

1-(4-ethylphenyl)-1H-indole (Table 2, entry 7): A pale yellow oil, 88 %. ¹H NMR (300 MHz, CDCl₃, ppm): δ= 1.23-1.34 (m, 3H), 2.66-2.80 (m, 2H), 6.60 (d, 1H, *J*=3.02), 7.04-7.19 (m, 2H), 7.22-7.43 (m,

5H), 7.48 (d, 1H, $J=8.30$), 7.61 (d, 1H $J=7.55$); ^{13}C NMR (75 MHz, CDCl_3 , ppm): $\delta = 15.6, 28.4, 103.1, 110.5, 120.1, 121.0, 122.1, 124.3, 128.0, 128.9, 142.6$. EI-MS: $m/z = 221$ (M^+).

1-(3-fluorophenyl)-1H-indole (Table 2, entry 8): A pale yellow oil, 89 %. ^1H NMR (300 MHz, CDCl_3 , ppm): $\delta = 6.57$ (d, 1H, $J = 2.96$ Hz), 6.92-6.98 (m, 1H), 7.03-7.28 (m, 5H), 7.34-7.42 (m, 1H), 7.47 (d, 1H $J=7.91$), 7.54 (d, 1H, $J=7.91$); ^{13}C NMR (75 MHz, CDCl_3 , ppm): $\delta = 104.5, 110.3, 111.4, 111.7, 113.0, 113.3, 119.6, 120.8, 122.7, 127.3, 130.8, 135.6, 141.5, 164.9$. EI-MS: $m/z = 211$ (M^+).

1-(4-fluorophenyl)-1H-indole (Table 2, entry 9)^{16a}: yellowish oil, 91 %. ^1H NMR (300 MHz, CDCl_3 , ppm): $\delta = 6.65$ (d, 1H, $J = 2.64$ Hz), 7.08-7.28 (m, 5H), 7.34-7.50 (m, 3H), 7.67 (d, 1H $J=7.36$); ^{13}C NMR (75 MHz, CDCl_3 , ppm): $\delta = 103.5, 110.1, 116.2, 116.5, 120.3, 121.1, 122.3, 126.0, 127.9, 129.0, 135.9, 159.3, 162.5$. EI-MS: $m/z = 211$ (M^+).

1-(4-chlorophenyl)-1H-indole (Table 2, entry 10)^{16a}: yellowish oil, 92 %. ^1H NMR (300 MHz, CDCl_3 , ppm): $\delta = 6.63$ (d, 1H, $J = 3.02$ Hz), 7.08-7.26 (m, 3H), 7.40-7.51 (m, 5H), 7.61 (d, 1H $J=7.55$); ^{13}C NMR (75 MHz, CDCl_3 , ppm): $\delta = 104.0, 110.1, 120.5, 121.1, 122.5, 125.3, 127.5, 129.3, 129.6, 131.8, 135.6, 138.2$. EI-MS: $m/z = 227$ (M^+).

1-(4-(trifluoromethyl)phenyl)-1H-indole (Table 2, entry 11)^{16a}: yellowish oil, 87 %. ^1H NMR (300 MHz, CDCl_3 , ppm): $\delta = 6.66$ (d, 1H, $J = 3.00$ Hz), 7.11-7.30 (m, 3H), 7.49-7.67 (m, 4H), 7.75 (d, 2H $J=8.00$); ^{13}C NMR (75 MHz, CDCl_3 , ppm): $\delta = 103.5, 110.1, 116.2, 120.3, 121.1, 122.3, 126.0, 127.9, 135.9, 159.3, 162.5$. EI-MS: $m/z = 261$ (M^+).

1-(3-(trifluoromethyl)phenyl)-1H-indole (Table 2, entry 12)^{16a}: yellowish oil, 86 %. ^1H NMR (300 MHz, CDCl_3 , ppm): $\delta = 6.41$ (d, 1H, $J=3.11$), 6.95 (d, 1H, $J=3.11$), 7.04 (t, 1H, $J=7.79$), 7.14-7.26 (m, 4H), 7.31 (t, 1H, $J=7.79$), 7.41 (s, 1H), 7.55 (d, 1H, $J=7.79$). ^{13}C NMR (75 MHz, CDCl_3 , ppm): $\delta = 105.0, 107.0, 116.1, 121.3, 121.5, 124.4, 125.1, 127.8, 130.7, 132.5, 133.1, 133.9, 134.5, 138.9, 143.9$. EI-MS: $m/z = 261$ (M^+).

1,4-di(1H-indol-1-yl)benzene (Table 2, entry 13): A pale yellow oil, 60 %. ^1H NMR (300 MHz, CDCl_3 , ppm): $\delta = 6.68$ (d, 2H, $J=3.21$), 7.12 - 7.25 (m, 6H), 7.52 (d, 2H, $J = 7.93$), 7.68 (d, 2H, $J = 7.17$), 7.77-7.94 (m, 4H). ^{13}C NMR (75 MHz, CDCl_3 , ppm): $\delta = 90.5, 104.1, 110.1, 120.5, 121.1, 122.5, 125.8, 127.3, 129.3, 135.3, 138.5, 139.3$. EI-MS: $m/z = 338$ (M^+).

1-(thiophen-2-yl)-1H-indole (Table 2, entry 14): A pale yellow oil, 57 %. ^1H NMR (300 MHz, CDCl_3 , ppm): $\delta = 6.65$ (d, 1H, $J = 2.83$), 6.99-7.11 (m, 2H), 7.12-7.36 (m, 4H), 7.55-7.72 (m, 2H); ^{13}C NMR (75 MHz, CDCl_3 , ppm): $\delta = 104.0, 110.5, 120.2, 120.7, 120.9, 121.5, 122.7, 125.9, 129.2, 136.9, 141.5$. EI-MS: $m/z = 215$ (M^+).

1-*p*-tolyl-1H-pyrrole (Table 3, entries 1, 2)³¹: white solid, mp 83-85 °C; 61%, 88 %. ^1H NMR (300 MHz, CDCl_3 , ppm): $\delta = 2.37$ (s, 3H), 6.33 (t, 2H, $J = 2.26$ Hz), 7.06 (t, 2H, $J = 2.26$ Hz), 7.18-7.35 (m, 4H); ^{13}C NMR (75 MHz, CDCl_3 , ppm): $\delta = 20.7, 110.0, 119.3, 120.4, 129.9, 135.2, 138.4$. EI-MS: $m/z = 157$ (M^+).

1-(4-methoxyphenyl)-1H-pyrrole (Table 3, entries 3, 4)^{16a}: white solid, mp 111-113 °C; 79%, 96 %. ^1H NMR (300 MHz, CDCl_3 , ppm): $\delta = 3.78$ (s, 3H), 6.32 (t, 2H, $J = 2.26$ Hz), 6.64-6.743 (m, 2H), 6.89-6.99 (m 2H), 7.29-7.36 (m, 2H); ^{13}C NMR (75 MHz, CDCl_3 , ppm): $\delta = 55.5, 109.7, 114.5, 119.6, 122.1, 134.4, 157.6$. EI-MS: $m/z = 173$ (M^+).

1-(4-ethylphenyl)-1H-pyrrole (Table 3, entry 5): white solid, mp 67-70 °C; 84 %. ^1H NMR (300 MHz, CDCl_3 , ppm): $\delta = 1.25$ (t, 3H, $J = 7.58$ Hz), 2.65 (q, 2H, $J = 7.57$ Hz), 6.29 (t, 2H, $J = 2.23$ Hz), 7.01 (t,

2H, $J = 2.23$ Hz), 7.20 (d, 2H, $J = 8.02$ Hz), 7.27 (d, 2H, $J = 8.02$ Hz); $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 , ppm): $\delta = 15.8, 28.4, 96.2, 110.3, 119.1, 120.7, 128.8, 138.9, 141.4$. EI-MS: $m/z = 171$ (M^+).

1-(4-nitrophenyl)-1H-pyrrole (Table 3, entry 6): white Solid, mp 180-183 $^{\circ}\text{C}$; 91 %. $^1\text{H-NMR}$ (300 MHz, CDCl_3 , ppm): $\delta = 6.37$ (t, 2H, $J = 2.26$ Hz), 7.12 (t, 2H, $J = 2.26$ Hz), 7.51 (q, 2H, $J = 9.06$ Hz), 8.24-8.39 (m, 2H); $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 , ppm): $\delta = 112.4, 119.0, 119.3, 125.5, 144.6, 145.1$. EI-MS: $m/z = 188$ (M^+).

1-(3-nitrophenyl)-1H-pyrrole (Table 3, entry 7): yellow oil; mp 72-75 $^{\circ}\text{C}$; 88% $^1\text{H-NMR}$ (300 MHz, CDCl_3 , ppm): $\delta = 6.41$ (t, 2H, $J = 2.26$ Hz); 7.16 (t, 2H, $J = 2.26$ Hz), 7.53-7.65 (m, 1H), 7.68-7.77 (m, 1H), 8.08 (d, 1H, $J = 8.30$ Hz), 8.25 (t, 1H, $J = 2.26$ Hz); $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 , ppm): $\delta = 111.8, 114.7, 119.0, 119.8, 125.5, 130.4, 138.1, 141.4$. EI-MS: $m/z = 188$ (M^+).

1-(4-chlorophenyl)-1H-pyrrole (Table 3, entry 8): white solid, mp 88-91; 88% $^1\text{H-NMR}$ (300 MHz, CDCl_3 , ppm): $\delta = 6.28$ (t, 2H, $J = 1.88$ Hz), 6.97 (t, 2H, $J = 2.26$ Hz), 7.18-7.45 (m, 4H), $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 , ppm): $\delta = 110.7, 119.1, 121.5, 129.5, 130.9, 139.2$. EI-MS: $m/z = 177$ (M^+).

1-(4-bromophenyl)-1H-pyrrole (Table 3, entry 9): 89% yellow oil, $^1\text{H-NMR}$ (300 MHz, CDCl_3 , ppm): $\delta = 6.36$ (t, 2H, $J = 1.95$ Hz), 7.05 (t, 2H, $J = 2.07$ Hz), 7.27 (d, 2H, $J = 8.12$ Hz), 7.54 (d, 2H, $J = 8.68$ Hz), $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 , ppm): $\delta = 110.8, 118.6, 119.1, 121.8, 132.5$. EI-MS: $m/z = 221$ (M^+).

1-(3-trifluoromethylphenyl)-1H-pyrrole (Table 3, entry 10): yellow oil, 86% $^1\text{H-NMR}$ (300 MHz, CDCl_3 , ppm): $\delta = 6.39$ (t, 2H, $J = 2.26$ Hz); 7.12 (t, 2H, $J = 2.26$ Hz), 7.40-7.72 (m, 4H); $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 , ppm): $\delta = 111.2, 117.0, 119.1, 122.0, 123.3, 130.1, 141.0$. EI-MS: $m/z = 211$ (M^+).

1-(4-1H-pyrrol-1-yl)phenyl)-1H-pyrrole (Table 3, entry 11): white solid; mp 234-238 $^{\circ}\text{C}$; 58%. $^1\text{H-NMR}$ (300 MHz, CDCl_3 , ppm): $\delta = 6.36$ (t, 4H, $J = 2.07$ Hz); 7.02-7.20 (m, 8H); $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 , ppm): $\delta = 110.8, 119.2, 121.5, 138.5$. EI-MS: $m/z = 208$ (M^+).

1-(naphthalen-1-yl)-1H-pyrrole (Table 3, entry 12)^{15d}: pale yellow oil; 81% $^1\text{H-NMR}$ (300 MHz, CDCl_3 , ppm): $\delta = 6.41$ (s, 2H), 7.00 (s, 2H), 7.32-7.61 (m, 4H), 7.66-8.03 (m, 3H); $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 , ppm): $\delta = 108.9, 123.2, 125.2, 126.5, 126.9, 127.8, 128.0, 134.2, 138.1$. EI-MS: $m/z = 193$ (M^+).

1-(thiophen-2-yl)-1H-pyrrole (Table 3, entry 13): white solid; mp 75-78 $^{\circ}\text{C}$; 57%. $^1\text{H-NMR}$ (300 MHz, CDCl_3 , ppm): $\delta = 6.23$ (t, 2H, $J = 2.07$), 6.83-6.99 (m, 5H); $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 , ppm): $\delta = 110.4, 115.4, 119.0, 121.2, 126.0, 150.6$. EI-MS: $m/z = 149$ (M^+).

1-(5-methylthiophen-2-yl)-1H-pyrrole (Table 3, entry 14): yellow oil 52% $^1\text{H-NMR}$ (300 MHz, CDCl_3 , ppm): $\delta = 2.45$ (s, 3H), 6.19 (t, 2H, $J = 2.07$ Hz), 6.49-6.55 (m 1H), 6.62 (d, 1H, $J = 3.58$), 6.84 (t, 2H, $J = 2.07$); $^{13}\text{C-NMR}$ (75 MHz, CDCl_3 , ppm): $\delta = 15.3, 110.0, 115.5, 121.2, 123.6, 133.7, 135.9, 141.3$. EI-MS: $m/z = 163$ (M^+).

APPLICATIONS

The synthesized CuI nanoparticles act as heterogeneous catalyst for the synthesis of N-arylation of indoles and pyrrole. The protocol discussed in this communication is efficient, easily recyclable and is ligand free synthesis of fine chemicals.

CONCLUSIONS

In conclusion, we have developed a simple, efficient, cheap and easily recyclable catalyst system for the cross-coupling of *N*-heterocycles and substituted aryl halides with CuI nanoparticles under ligand free

conditions. The merits of the above demonstrated procedure are high operational simplicity, high functional group tolerance and environmentally benign catalyst. The CuI nanoparticles can be recovered and reused for several cycles with consistent activity. Therefore, this protocol renders an attractive and alternative method for the assembly of *N*-arylated products and finds high interest for industrial scale synthesis.

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