Accepted Manuscript

Base-assisted, copper-catalyzed N-arylation of (benz)imidazoles and amines with diarylborinic acids

Changwei Guan, Yuanyuan Feng, Gang Zou, Jie Tang

PII: S0040-4020(17)31071-2

DOI: 10.1016/j.tet.2017.10.043

Reference: TET 29046

To appear in: *Tetrahedron*

Received Date: 29 August 2017

Revised Date: 15 October 2017

Accepted Date: 17 October 2017

Please cite this article as: Guan C, Feng Y, Zou G, Tang J, Base-assisted, copper-catalyzed N-arylation of (benz)imidazoles and amines with diarylborinic acids, *Tetrahedron* (2017), doi: 10.1016/j.tet.2017.10.043.

Graphical Abstract

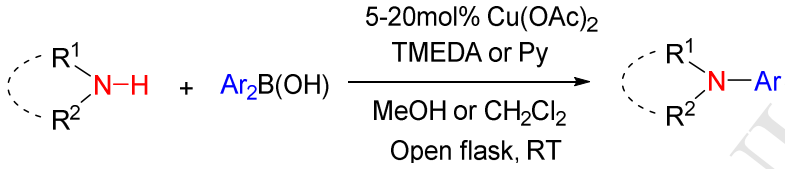
Base-assisted, copper-catalyzed N-arylation of (benz)imidazoles and amines with diarylborinic acids

Leave this area blank for abstract info.

Changwei Guan[a], *Yuanyuan Feng*[a], *Gang Zou*[a,*] *and Jie Tang*[b,*]

a) *School of Chemistry & Molecular Engineering, East China University of Science & Technology, 130 Meilong Rd, Shanghai, China.*

b) *Shanghai Engineering Research Center of Molecular Therapeutics and New Drug Development, Shanghai Key Laboratory of Green Chemistry and Chemical Processes, SCME, East China Normal University,3663 North Zhongshan Rd. Shanghai, China.*



Tetrahedron
journal homepage: www.elsevier.com

Base-assisted, copper-catalyzed N-arylation of (benz)imidazoles and amines with diarylborinic acids

Changwei Guan[a] , Yuanyuan Feng[a], Gang Zou[a,*] and Jie Tang[b,*]

[a] *School of Chemistry & Molecular Engineering, East China University of Science & Technology, 130 Meilong Rd, Shanghai, China. Email: zougang@ecust.edu.cn.*
[b] *Shanghai Engineering Research Center of Molecular Therapeutics and New Drug Development, Shanghai Key Laboratory of Green Chemistry and Chemical Processes, SCME, East China Normal University,3663 North Zhongshan Rd. Shanghai, China. Email: jtang@chem.ecnu.edu.cn.*

ARTICLE INFO

Article history:
Received
Received in revised form
Accepted
Available online

Keywords:
N-Arylation
Diarylborinic acids
Chan-Lam coupling
Copper

ABSTRACT

N-Arylation of (benz)imidazoles and amines with diarylborinic acids as cost-effective aryl source has been efficiently effected via $Cu(OAc)_2$-catalyzed Chan-Lam coupling in assistance of tetramethylethylenediamine (TMEDA) in methanol and pyridine (Py) in dichloromethane, respectively, in air at room temperature. The diarylborinic acids could be well accommodated by the Chan-Lam coupling oxidative conditions containing a proper combination of bases and solvents. The steric hindrance appeared to affect the copper-catalyzed N-arylation using the high-order arylboron reagent more significantly than the electronic factors, especially for low reactive anilines and aliphatic amines.

1. Introduction

Copper-mediated arylation of N-nucleophiles with arylboronic acids, Chan-Lam C_{Ar}-N coupling,[1] has made the N-arylation reaction, which otherwise requires harsh conditions and / or complicated catalyst systems, one of the operationally simplest organic synthesis techniques under the mildest conditions: at room temperature in open vessels. However, under the operational simplicity and mild conditions, the original Chan-Lam N-arylation procedure required excess amount of arylboronic acids, high-loading of copper salts and / or long reaction time. Therefore, a great of efforts have been devoted to improve the original procedure with respect to copper / ligand systems, solvents, bases and oxidative additives.[2] Important progresses have been achieved such as development of catalytic systems,[3] recognition of the key role of solvents,[4] conquest of some difficult substrates[5] and shedding a light on its complicated mechanism.[6] In contrast, arylboronic acids have still overwhelmingly dominated the aryl source in Chan-Lam C_{Ar}-N coupling. In fact, even arylboronic acid pinacol esters have been problematic in coupling with aryl amines until recently.[7]

Compared with arylboronic acids, $Ar_2B(OH)$ could be more economically prepared from aryl halides, magnesium and boronates[8] or amine-boranes[9] under noncryogenic conditions if no hampered by sensitive functional groups. We have shown that high-order arylborons could be used as cost-effective alternatives to arylboronic acids in nickel or palladium-catalyzed carbon-carbon bond forming arylation procedures.[10] However, because of the higher reducing ability of high-order arylborons than the corresponding boronic acids,[11] it seems to be challengeable to use both aryl groups of diarylborinic acids under the oxidative conditions of Chan-Lam coupling because of their fast degradation to arylboronic acids. In fact, only one phenyl group appeared to be useful in a microwave-assisted, copper-mediated N-arylation of sodium tetraphenylborate with primary amines.[12] In continuation of our efforts to develop practical arylation protocols by efficiently using high-order arylborons, we report herein a base-assisted, $Cu(OAc)_2$-catalyzed Chan-Lam N-arylation of (benz)imidazoles, anilines and aliphatic amines with diarylborinic acids, from which both aryl groups could be utilized.

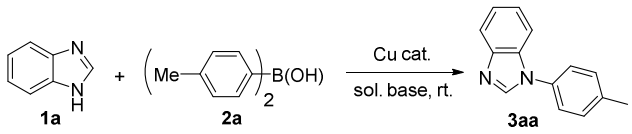
2. Results and Discussion

2.1 N-Arylation of (benz)imidazoles

Imidazoles and benzimidazoles have proven to be highly reactive substrates in Chan-Lam coupling of arylboronic acids. Therefore, we began with (benz)imidazoles to explore the reactivity of diarylborinic acids in Chan-Lam C_{Ar}-N arylation. The cross-coupling of benzimidazole (**1a**) with dehydration-resisting bis(*p*-tolyl)borinic acid (**2a**) was chosen as the model reaction for convenience (Table 1). Although the reaction proceeded sluggishly under a base-free condition the desired product, 1-(*p*-tolyl)benzimidazole (**3aa**), was obtained in good yields with 0.75 equiv. **2a** (1.5 equiv. with respect to aryl) in the presence of 1.0 equiv. tertiary amine, e.g. NEt_3 or 1,4-diazabicyclo[2.2.2]octane (DABCO), in methanol by using 10

mol% $Cu(OAc)_2$ as catalyst at room temperature (Table 1, entries 1-3).

Table 1. Establishment of conditions for arylation of benzimidazoles with diarylborinic acids[a]



1a 2a 3aa

Entry	2a/1a[b]	Copper(mol%)	Base[c]	Sol.	Time(h)	Yield%
1	0.75	$Cu(OAc)_2$ (10)	/	MeOH	12	9
2	0.75	$Cu(OAc)_2$(10)	Et_3N	MeOH	12	76
3	0.75	$Cu(OAc)_2$ (10)	DABCO	MeOH	12	84
4	0.75	$Cu(OAc)_2$ (10)	DABCO	EtOH	12	23
5	0.75	$Cu(OAc)_2$ (10)	DABCO	CH_2Cl_2	12	16
6	0.75	$Cu(OAc)_2$ (10)	DABCO	THF	12	11
7	0.75	$Cu(OAc)_2$ (10)	DABCO	CH_3CN	12	38
8	0.75	$Cu(OAc)_2$ (10)	Pyridine	MeOH	12	95
9	0.75	$Cu(OAc)_2$ (10)	DMAP	MeOH	12	17
10	0.75	$Cu(OAc)_2$ (10)	NMI	MeOH	12	25
11	0.75	$Cu(OAc)_2$ (10)	TMEDA	MeOH	4	99
12	0.75	$Cu(OAc)_2$ (5)	TMEDA	MeOH	4	99
13	0.75	$Cu(OAc)_2$ (1)	TMEDA	MeOH	8	99
14	0.65	$Cu(OAc)_2$ (5)	TMEDA	MeOH	4	99
15	0.65	$Cu(OAc)_2$(1)	TMEDA	MeOH	8	81
16	0.55	$Cu(OAc)_2$ (5)	TMEDA	MeOH	4	92
17	0.55	$Cu(OAc)_2$(1)	TMEDA	MeOH	8	75
18	0.65	$Cu(NO_3)_2$(1)	TMEDA	MeOH	8	80
19	0.65	$CuBr_2$ (1)	TMEDA	MeOH	8	62
20	0.65	$CuSO_4$(1)	TMEDA	MeOH	8	55
21	0.65	$CuCl_2$(1)	TMEDA	MeOH	8	50

[a]Isolated yield

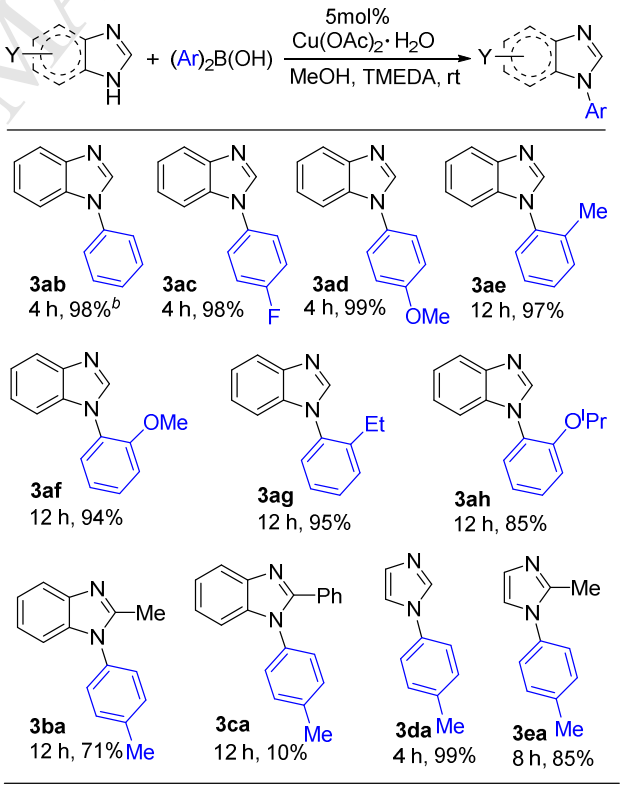
[b]Molar ratio

[c]1.0equiv. used

Attempts to increase the yield by changing solvent met with failure since the common solvents, e.g. EtOH, CH_2Cl_2, THF and CH_3CN, performed much less efficiently than MeOH (Table 1, entries 4-7). However, base screening was fruitful. An excellent yield (95%) could be obtained by using pyridine as the base while 4-dimethylaminopyridine (DMAP) and N-methylimidazole (NMI) performed poorly (Table 1, entries 8-10). Further, when tetramethylethylenediamine (TMEDA) was used as the base the model reaction completed in 4-8 hours with 1-5 mol% $Cu(OAc)_2 \cdot H_2O$ loading to provide **3aa** in almost quantitative yield (99%) (Table 1, entries 11-13). The loading of diarylborinic acid could be reduced to 0.65 equiv. by using 5 mol% $Cu(OAc)_2 \cdot H_2O$ while a slight decrease in yield (92%) was observed when 0.55 equiv. **2a** was used (Table 1, entries 14-17). Given the high reducing ability of diarylborinic acids, it is surprising that more oxidative $Cu(NO_3)_2 \cdot 3H_2O$ performed similarly to $Cu(OAc)_2 \cdot H_2O$ at 1 mol% loading, better than the other copper salts, e.g. $CuSO_4 \cdot 5H_2O$, $CuCl_2$ and $CuBr_2$, in the model reaction, indicating diarylborinic acids could be well accommodated by the oxidative conditions of Chan-Lam coupling (Table 1, entries 18-20). Taking all factors into account, the optimal conditions for the copper-catalyzed Chan-Lam coupling of benzimidazoles with diarylborinic acids were set as 0.65 equiv. diarylborinic acids (1.3 equiv. with respect to aryl) with 5 mol% $Cu(OAc)_2 \cdot H_2O$ catalyst in the presence of 1 equiv. TMEDA as base in methanol at room temperature.

Structural effects of diarylborinic acids on the copper-catalyzed Chan-Lam coupling with (benz)imidazoles were explored under the optimal conditions (Table 2). Both the steric and electronic factors showed negligible influence on the reactivity of diarylborinic acids. For example, an electron-neutral (H, **2b** in form of anhydride), -withdrawing (4-F, **2c**), or -donating group (4-MeO, **2d**; 2-Me, **2e**; 2-MeO, **2f**; or 2-Et, **2g**) on the aromatic ring of diarylborinic acids provided the corresponding 1-arylbenzimidazole (**3ab-3ag**) in excellent yields (94-99%). The sterically demanding bis(2-isopropoxyphenyl)borinic acid (**2h**) also reacted smoothly to give 1-(2-isoproponoxyphenyl)benzimidazole (**3ah**) in 85% yield. However, a large steric effect from a substituent on the 2-position of benzimidazole was observed. For example, 2-methylbenzimidazole (**1b**) reacted with bis(*p*-tolyl)borinic acid (**2a**) to give **3ba** in significantly lower yield (71%) than that of the parent benzimidazole (**1a**). A phenyl group at 2-position of benzimidazole almost completely blocked the reaction, producing 2-phenyl-1-(*p*-tolyl)benzimidazole (**3ca**) in just 10% yield after 12 hours. Imidazoles (**1d** and **1e**) reacted similarly to the corresponding benzimidazoles.

Table 2. Scope of TMEDA-assisted, $Cu(OAc)_2$-catalyzed N-arylation of (benz)imidazoles with diarylborinic acids[a]



[a] Isolated yield.

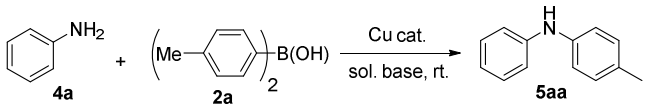
[b]0.3 equiv. anhydride $(Ph_2B)_2O$ used.

2.2 Arylation of amines

Encouraged by the results obtained for (benz)imidazoles, we further explored the reaction of diarylborinic acids with aryl and

alkyl amines which are generally less reactive than (benz)imidazoles in Chan-Lam coupling (Table 3).

Table 3. Optimization of Chan-Lam C_{Ar}-N coupling of amines with diarylborinic acids[a]



Entry	**2a**/**4a**[b]	Cat.(mol%)	Base	Sol.	Yield %[c]
1	0.65	$Cu(OAc)_2$(10)	TMEDA(1)	MeOH	15
2	1	$Cu(OAc)_2$(10)	TMEDA(1)	MeOH	17
3	1	$Cu(OAc)_2$(100)	TMEDA(1)	MeOH	35
4	1	$Cu(NO_3)_2$ (10)	TMEDA(1)	MeOH	12
5	1	$Cu(NO_3)_2$ (100)	TMEDA(1)	MeOH	27
6	1	$Cu(OAc)_2$ (100)	Py (1)	MeOH	60
7	0.65	$Cu(DMAP)_4I_2$ (10)	Py (1)	MeOH	47
8	0.65	$Cu(DMAP)_4I_2$ (10)	/	MeOH	51
9	1	$Cu(OAc)_2$ (100)	Py (2)	MeOH	73
10	1	$Cu(OAc)_2$ (100)	Py (2)	CH_2Cl_2	93
11	1	$Cu(OAc)_2$ (100)	Py (1)	CH_2Cl_2	87
12	1	$Cu(OAc)_2$ (100)	TMEDA(1)	CH_2Cl_2	61
13	1	$Cu(OAc)_2$ (100)	DABCO(2)	CH_2Cl_2	46
14	1	$Cu(OAc)_2$ (100)	NEt_3 (2)	CH_2Cl_2	34
15	1	$Cu(OAc)_2$(10)	Py(2)	CH_2Cl_2	85
16	1	$Cu(OAc)_2$ (20)	Py (2)	CH_2Cl_2	92
17	1	$Cu(OAc)_2$ (20)	Py(1)	CH_2Cl_2	68
18	0.75	$Cu(OAc)_2$ (20)	Py(2)	CH_2Cl_2	90
19	0.65	$Cu(OAc)_2$ (20)	Py(2)	CH_2Cl_2	81
20	0.75	$Cu(DMAP)_4I_2$ (10)	Py(2)	CH_2Cl_2	Trace[d]
21	0.75	$Cu(DMAP)_4I_2$ (10)	/	CH_2Cl_2	Trace[d]

[a] Reaction was run in 1mmol scale with respect to **4a** for 24h.

[b] mol/mol.

[c] Isolated yield.

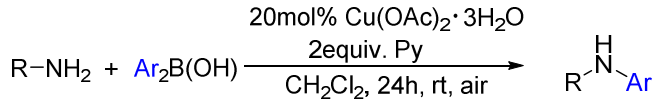
[d]The homocoupling of **2a,** instead of its Chan-Lam coupling with **4a**, occurred overwhelmingly to give 4,4'-dimethylbiphyl in 90% yield

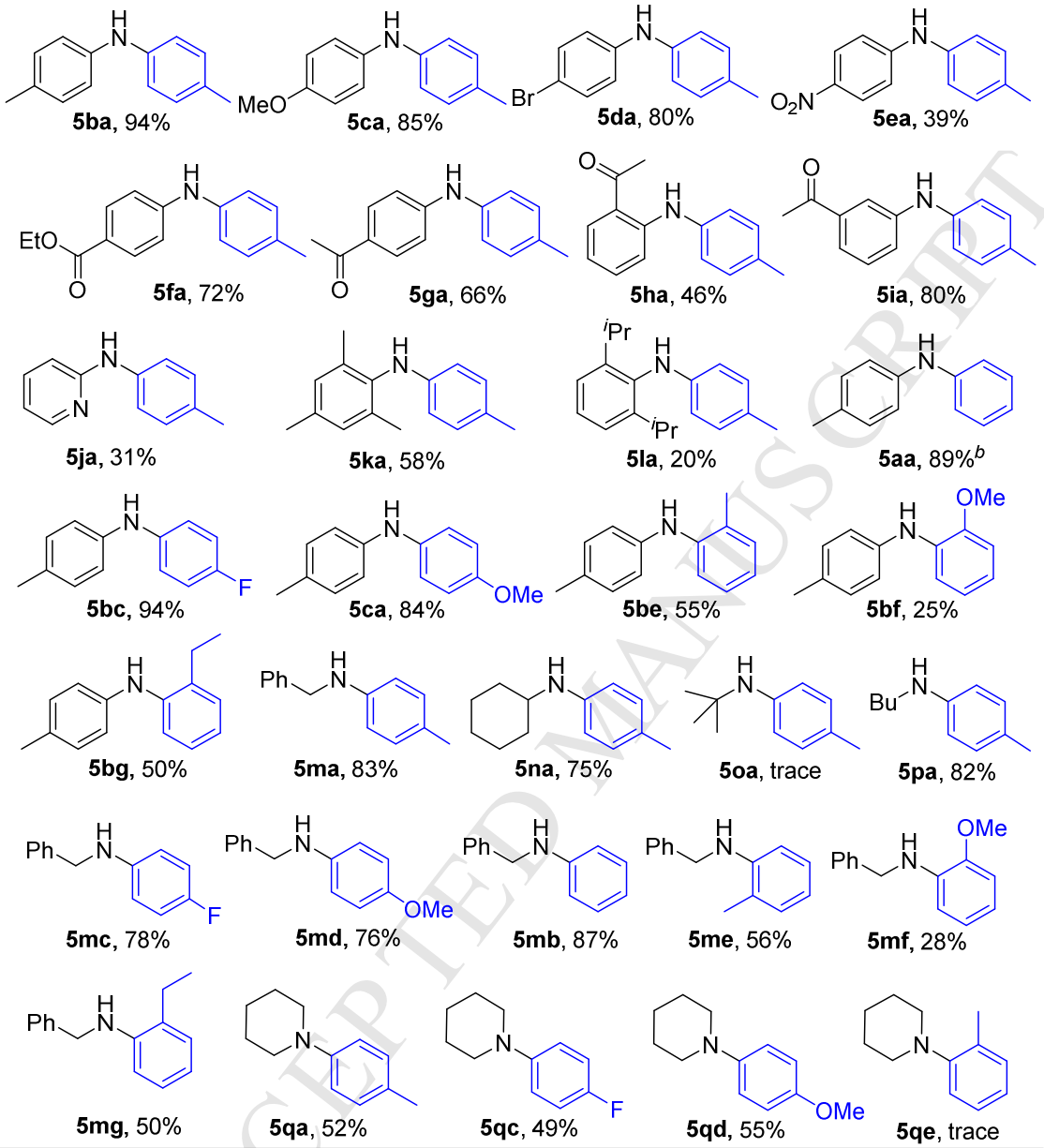
The reaction of bis(*p*-tolyl)borinic acid (**2a**) with aniline (**4a**) gave the desired diarylamine, 4-methyl-N-phenylaniline (**5aa**), in just 15% yield under the optimal conditions established for (benz)imidazoles in 24 hours (Table 3, entry 1). Using high loadings of copper catalyst ($Cu(OAc)_2 \cdot H_2O$, 100 mol%) or / and bis(*p*-tolyl)borinic acid (**2a**) (2 equiv. with respect to aryl group) just slightly increased the yields of **5aa** (17-35%). Copper nitrate ($Cu(NO_3)_2 \cdot 3H_2O$), which catalyzed the arylation of (benz)imidazoles as efficiently as $Cu(OAc)_2 \cdot H_2O$, also performed poorly. However, when pyridine was used as base in placement of TMEDA, **5aa** could be isolated in 60% yield, implying a crucial role of bases in the Chan-Lam C_{Ar}-N arylation of diarylborinic acids (Table 3, entry 6). Only modest yields (47-51%) for **5aa** were obtained with 10 mol% $Cu(DMAP)_4I_2$ as the catalyst that was reported to catalyze Chan-Lam coupling of amines with a variety of boronic acids in minutes under base-free conditions (Table 3, entries 7 and 8).[3f] A proper combination of solvents and bases also proved to be crucial in the coupling of amines. The yields of **5aa** could be increased to 87-93% from 73% by changing solvents from MeOH to CH_2Cl_2 by using 100 mol% $Cu(OAc)_2 \cdot H_2O$ in the assistance with 1-2 equiv. pyridine while TMEDA, NEt_3 and DABCO gave lower yields (34-61%) (Table 3, entries 9-14). In fact, the reaction also proceeded smoothly with catalytic amount of $Cu(OAc)_2$ (20 mol%) and 0.75 equiv. borinic acid (**2a**) to give **5aa** in 90% yield in the presence of 2 equiv. pyridine although the yields decreased significantly when further lowering the loadings of $Cu(OAc)_2$ (10 mol%, 85%) or pyridine (1 equiv., 68%) or borinic acid (**2a**, 0.65 equiv., 81%) (Table 3, entries 15, 17 and 19). Therefore, the optimal conditions for the copper-catalyzed N-arylation of amines with diarylborinic acids were set as 0.75 equiv. borinic acids loading, 20 mol% $Cu(OAc)_2 \cdot H_2O$ as catalyst in the presence of 2 equiv. pyridine as base in CH_2Cl_2 at room temperature in air for 24 h.

Generality of the base-assisted, copper-catalyzed N-arylation of amines with diarylborinic acids was explored (Table 4). Both electronic and steric effects from aromatic amines were obviously observed. Reactions of bis(*p*-tolyl)borinic acid (**2a**) with electron-deficient anilines, e.g. 4-bromoaniline (**4d**), 4-nitroaniline (**4e**), 4-aminobenzoate (**4f**), 4-acetylaniline (**4g**) and pyridin-2-amine (**4j**), gave the diarylamines **5da**-**5ja** in lower yields (31-80%) than those of electron-neutral and -rich ones, e.g. aniline (**4a**, 92%), *p*-toluidine (**4b**, 94%) and 4-methoxyaniline (**4c**,85%). The highest yield (80%) obtained from 3-acetylaniline (**4i**) among the ortho-, meta-, and para-isomers also reflected both the electronic and steric effects from aromatic amines. Electron-rich but sterically demanding anilines, mesidine (**4k**), and 2,6-diisopropylaniline (**4l**), could couple with **2a** to give diarylamines **5ka** and **5la** albeit in low yields of 58% and 20%, respectively. The electronic influence from diarylborinic acids appeared to be small while a large steric effect was observed. For example, diarylborinic acids bearing an electron-neutral (H, **2b** in form of anhydride), -withdrawing (F, **2c**) or -donating (MeO, **2d**) group on the phenyl rings, reacted with *p*-toluidine (**4b**) to give the corresponding diarylamines (**5aa, 5bc, 5ca**) in excellent yields (84-94%). However, the reactions of diarylborinic acids with an ortho-substituent on the phenyl rings, e.g. 2-methyl (**2e**), 2-methoxy (**2f**) and 2-ethyl (**2g**) with *p*-toluidine (**4b**) gave the N-arylation products (**5be**-**5bg**) in much lower yields (25-55%) than those of their para-isomers.

Aliphatic amines could also be N-arylated with diarylborinic acids under the above optimal conditions for anilines to give N-alkyl anilines in modest to good yields. Steric hindrance from both amines and borinic acids affected the coupling remarkably. The yields of N-alkyl *p*-toluidines (**5ma**-**5pa**) decreased along the increase of steric hindrance in primary alkyl amines, benzyl (**4m**, 83%), butyl (**4p**, 82%), cyclohexyl (**4n**, 75%) and tert-butyl (**4o**, trace) in the reaction with bis(*p*-tolyl)borinic acid (**2a**). Similarly, diarylborinic acids bearing a substituent like methyl (**2e**), methoxy (**2f**) or ethyl (**2g**) at ortho-position of aryl groups reacted with benzyl amine (**4m**) to give N-benzylanilines in lower yields (28-56%) than those of their analogs without an ortho-substituent (76-87%). Further, piperidine, a sterically undemanding secondary amine, could react with diarylborinic acids with a group at para-position of aryl groups to offer N-aryl piperidines in modest yields while almost no reaction occurred for bis(*o*-tolyl)borinic acid (**2e**) under the otherwise identical conditions.

Table 4. Scope of Py-assisted, $Cu(OAc)_2$-catalyzed N-arylation of amines with diarylborinic acids[a]





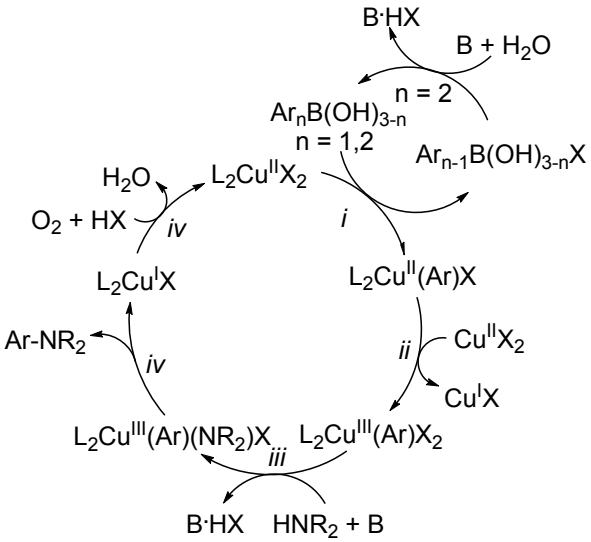
[a] Isolated yield.

[b] 0.35 equiv. anhydride $(Ph_2B)_2O$ used.

2.3 Mechanistic discussion

Although the mechanism of Chan-Lam coupling is still rather controversial,[2] the results obtained in present work appear to be consistent with the catalytic cycle proposed by Stahl et al.,[6] in which the rate-determining steps involve transmetalations between copper and boron species (i) and / or N-centered nucleophiles (iii) depending on reaction conditions (Scheme 1). The additives, TMEDA or Py, play dual roles: promote the transmetalations as base and stabilize copper species as supporting ligand. Both aryl groups of diarylborinic acids could take part in the arylation since transfer of the first one generates arylboronic derivatives, the aryl source in original Chan-Lam coupling. For highly reactive imidazole substrates, trans-metalation between $L_2Cu^{II}X_2$ and $Ar_nB(OH)_{3-n}$ or $Ar_{n-1}B(OH)_{3-n}X$ determines the turnover rate, which could be facilitated by base as well as protic solvents, particularly methanol. However, for the less reactive substrates, e.g. amines, the rate-determining step switches to involve transmetalation between $L_2Cu^{III}(Ar)X_2$ and HNR_2, requiring a different copper catalytic system, e.g. solvent (CH_2Cl_2), ligand (Py), and base (Py), from that for (benz)imidazole (TMEDA/MeOH). The better performance of Py than TMEDA in the amine arylation could be attributed to the higher electrophilicity of Py-ligated aryl copper intermediates $(Py)_2Cu^{III}(Ar)X_2$ than the more stable TMEDA-chelated one, thus facilitating the rate-determining transmetalation with HNR_2. However, the low stability of the former, thus high tendency to decompose, led to the requirement of high loadings of catalyst (20mol%) and borinic acids (0.75equiv.) for the pyridine-assisted

copper-catalyzed arylation of amines. The observed large steric effects from both diarylborinic acids and amines are also consistent with the rate-determining role of transmetaltion between $(Py)_2Cu^{III}(Ar)X_2$ and amines in the catalytic cycle.



Scheme 1. A plausible mechanism stemming from Stahl's postulation

3. Conclusions

In summary, N-arylation of (benz)imidazoles and amines with diarylborinic acids as cost-effective aryl source has been efficiently effected via base-assisted, $Cu(OAc)_2$-catalyzed Chan-Lam C_{Ar}-N cross-coupling by using proper combinations of bases and solvents. (Benz)imidazoles, except for those bearing a substituent at 2-position, showed high reactivities, coupling with slight excess (0.65 equiv., 1.3 equiv. with respect to aryl) of electronically and sterically various diarylborinic acids to give 1-aryl (benz)imidazoles in excellent yields by using 5 mol% copper acetate in the presence of 1 equiv. TMEDA in methanol at room temperature in air. The reaction of less reactive substrates, anilines and aliphatic amines, required higher loadings of $Cu(OAc)_2$ (20 mol%) and borinic acids (0.75 equiv.) with the assistance of 2 equiv. pyridine in CH_2Cl_2 to proceed smoothly and was significantly affected by steric factors from amines and / or diarylborinic acids while the electronic influences appeared to be small or negligible. These results indicated that the relatively less oxygen-tolerant diarylborinic acids could be also efficiently used as aryl sources even under oxidative conditions, provided that a proper catalyst system could be developed.

4. Experimental Section

4.1. Materials and instruments

All reactions were carried out in air unless otherwise stated. Commercially available chemicals were used as received. Diarylborinic acids[13] and $[Cu(DMAP)_4I]I$[3f] were prepared according to previously reported procedures.^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ or DMSO-d_6 at ambient temperature. Chemical shifts in NMR are reported in ppm (δ), relative to the internal standard of tetramethylsilane (TMS).

4.2. General procedure for arylation of (benz)imidazoles

To a 25 mL flask were added (benz)imidazoles (1.0 mmol), diarylborinic acid (0.65 mmol, 1.3 equiv. with respect to aryl group), TMEDA (1.0 mmol), $Cu(OAc)_2 \cdot H_2O$ (0.05 mmol, 5 mol%), and MeOH (10 mL). The mixture was stirred at room temperature in air monitored by TLC until the starting materials were completely consumed. The solvent was removed by rotavapor to give a residue, from which the product was isolated by column chromatography on silica gel with $MeOH/CH_2Cl_2$ or EtOAc/petroleum ether as eluents.

*4.3. 1-(4-Methylphenyl)benzimidazole (**3aa**).*[2a]

Pale yellow liquid (0.206 g, 99%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.20 (s, 1H), 7.94-7.91 (m, 1H), 7.51-7.49 (m, 1H), 7.39-7.31 (m, 6H), 2.45 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 143.9, 142.4, 138.1, 133.9, 133.8, 130.6, 124.0, 123.6, 122.7, 120.5, 110.5, 21.2.

*4.4.1-Phenylbenzimidazole (**3ab**).*[5]

Pale yellow liquid (0.190 g, 98%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.12 (s, 1H), 7.90-7.88 (m, 1H), 7.60-7.45 (m, 6H), 7.36-7.31 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 144.0, 142.3, 136.4, 133.7, 130.1, 128.1, 124.1, 123.7, 122.8, 120.6, 110.5.

*4.5 1-(4-Flurophenyl)benzimidazole (**3ac**).*[14]

White solid (0.208 g, 98%); m.p. 114-115 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.07 (s, 1H), 7.89-7.87 (m, 1H), 7.50-7.45 (m, 3H), 7.35-7.25 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 162.0 (d, J = 246.9 Hz), 143.9, 142.3, 133.9, 132.4 (d, J = 3.1 Hz), 126.1 (d, J = 8.6 Hz), 123.8, 122.9, 120.7, 117.1 (d, J = 22.8 Hz), 110.2.

*4.6. 1-(4-Methoxyphenyl)benzimidazole (**3ad**).*[5]

Pale yellow solid (0.222 g, 99%); m.p. 94-95 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.05 (s, 1H), 7.88-7.86 (m, 1H), 7.47-7.44 (m, 1H), 7.42-7.39 (m, 2H), 7.34-7.29 (m, 2H), 7.09-7.05 (m, 2H), 3.89 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 159.3, 143.8, 142.6, 134.2, 129.2, 125.7, 123.5, 122.6, 120.5, 115.1, 110.4, 55.7.

*4.7. 1-(2-Methylphenyl)benzimidazole (**3ae**).*[5]

Pale yellow liquid (0.202 g, 97%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.97 (s, 1H), 7.89 (d, J = 7.6 Hz, 1H), 7.44-7.41 (m, 2H), 7.39-7.28 (m, 4H), 7.14 (d, J = 7.6 Hz, 1H), 2.10 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 143.3, 143.0, 135.4, 134.8, 134.7, 131.5, 129.4, 127.7, 127.2, 123.5, 122.5, 120.4, 110.5, 17.6.

*4.8. 1-(2-Methoxyphenyl)benzimidazole (**3af**).*[5]

Pale yellow liquid (0.211 g, 94%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.11 (s, 1H), 7.91-7.89 (m, 1H), 7.50-7.44 (m, 2H), 7.36-7.31 (m, 3H), 7.16-7.13 (m, 2H), 3.82 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 154.0, 143.9, 143.3, 134.5, 129.8, 127.3, 124.8, 123.3, 122.4, 121.0, 120.2, 112.5, 110.8, 55.8.

*4.9. 1-(2-Ethylphenyl)benzimidazole (**3ag**).*

Pale yellow liquid (0.211 g, 95%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.99 (s, 1H), 7.91 (d, J = 8.0 Hz, 1H), 7.52-7.48 (m, 2H), 7.41-7.28 (m, 4H), 7.16 (d, J = 7.6 Hz, 1H), 2.43 (q, J = 7.6 Hz, 2H), 1.07 (t, J = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 143.2, 141.6, 135.3, 134.1, 129.8, 129.7, 128.1, 127.1, 123.5, 122.5, 120.4, 110.5, 24.1, 15.0. HRMS (ESI) m/z $[M+1]^+$ calcd for $C_{15}H_{15}N_2$ 223.1235, found 223.1234.

*4.10. 1-(2-Isopropoxyphenyl)benzimidazole (**3ah**).*

Pale yellow liquid (0.214 g, 85%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.13 (s, 1H), 7.90-7.88 (m, 1H), 7.46-7.30 (m, 5H), 7.16-7.10 (m, 2H), 4.55-4.49 (m, 1H), 1.21 (d, J = 6.0 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 152.2, 144.0, 143.3, 129.4, 127.2, 126.0, 123.1, 122.2, 121.0, 120.1, 115.5, 110.9, 71.4, 21.8. HRMS (ESI) m/z $[M+1]^+$ calcd for $C_{16}H_{17}N_2O$ 253.1341, found 253.1337.

*4.11. 2-Methyl-1-p-tolylbenzimidazole (**3ba**).*[15]

Pale yellow solid (0.158 g, 71%); m.p. 94-96 °C; ^{1}H NMR (400 MHz, DMSO-d_6) δ: 7.63 (d, *J* = 7.2 Hz, 1H), 7.40 (dd, J_1 = 14.4, J_2 = 8.4 Hz, 4H), 7.22-7.14 (m, 2H), 7.09 (d, *J* = 8.0 Hz, 1H), 2.51 (s, 3H), 2.41 (s, 3 Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ: 151.5, 142.3, 138.3, 136.1, 133.0, 130.4, 126.6, 122.2, 121.8, 118.4, 109.7, 20.7, 14.0.

*4.12. 2-Phenyl-1-p-tolylbenzimidazole (**3ca**).*[16]

Pale yellow liquid (0.028 g, 10%); ^{1}H NMR (400 MHz, DMSO-d_6) δ: 7.79 (d, *J* = 7.6 Hz, 1H), 7.56-7.53 (m, 2H), 7.43-7.26 (m, 9H), 7.18 (d, *J* = 7.2 Hz, 1H), 2.41 (s, 3H); ^{13}C NMR (100 MHz, DMSO-d_6) δ: 152.3, 142.9, 138.9, 137.7, 134.3, 131.0, 130.3, 130.0, 129.5, 128.8, 127.7, 123.8, 123.1, 119.8, 110.9, 21.2.

*4.13. 1-(p-Tolyl)imidazole (**3da**).*[2a]

Pale yellow oil (0.157 g, 99%); ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm): 7.82 (s, 1H), 7.27 (s, 4H), 7.25 (s, 1H), 7.19 (s, 1H), 2.40 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ (ppm): 137.5, 135.6, 135.0, 130.4, 130.2, 121.5, 118.4, 21.0.

*4.14. 2-Methyl-1-(p-tolyl)imidazole (**3ea**).*[3a]

Pale yellow oil (0.146 g, 85%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.27 (d, *J* = 8.0 Hz, 2H), 7.17 (d, *J* = 8.4 Hz, 2H), 7.01 (s, 1H), 7.00 (s, 1H), 2.42 (s, 3H), 2.34 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 144.8, 138.2, 135.5, 130.0, 127.5, 125.3, 120.7, 21.1, 13.7.

4.15. General Procedure for Arylation of Amines.

To a 25 mL flask were added aniline or alkylamine (1.0 mmol), diarylborinic acid (0.75 mmol, 1.5 equiv. with respect to aryl group), Cu(OAc)·H_2O (48.40 mg, 0.2 mmol) and pyridine (162 ul, 2 mmol) and CH_2Cl_2 (10 ml). The mixture was stirred at room temperature in air for 24 h. The reaction mixture was diluted with CH_2Cl_2 (20 mL), followed by washing with H_2O (2 × 10 mL). The organic layer was dried over Na_2SO_4, filtered, and evaporated under reduced pressure to give crude product, which was purified by column chromatography on silica gel with MeOH/CH_2Cl_2 or EtOAc/petroleum ether as eluents.

*4.16. N-Phenyl-4-methylaniline (**5aa**).*[17]

Pale yellow solid (0.170 g, 93%); m.p. 90-91°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.15 (t, *J* = 7.8 Hz, 2H), 7.00 (d, *J* = 8.0 Hz, 2H), 6.93-6.90 (m, 4H), 6.79 (t, *J* = 7.4 Hz, 1H), 5.50 (br s,1H), 2.22 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 142.9, 139.2, 129.9, 128.8, 128.3, 119.2, 117.8, 115.8, 19.6.

*4.17. Di-p-Tolylamine (**5ba**).*[17]

Pale solid (0.185 g, 94%); m.p. 77-80 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.15 (d, *J* = 8.4 Hz, 4H), 7.03 (d, *J* = 8.4 Hz, 4H), 5.57 (br s, 1H), 2.39 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 141.2, 130.2, 130.0, 118.0, 20.7.

*4.18. 4-Methoxy-N-(p-tolyl)aniline (**5ca**).*[2a]

Pale solid (0.181 g, 85%);m.p. 82-84°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.04-7.00 (m, 4H), 6.85-6.82 (m, 4H), 5.38 (br s,1H), 3.78 (s, 3H), 2.27 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 154.8, 142.4, 136.7, 129.8, 129.3, 121.1, 116.5, 114.7, 55.6, 20.6.

*4.19. 4-Bromo-N-(p-tolyl)aniline (**5da**).*[18]

Pale solid (0.218 g, 80%); m.p. 99-101 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.22 (d, *J* = 8.8 Hz, 2H), 7.01 (d, *J* = 8.0 Hz, 2H), 6.89 (d, *J* = 8.4 Hz, 2H), 6.78 (d, *J* = 8.8 Hz, 2H), 5.49 (br s, 1H), 2.23 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 142.2, 138.5, 131.0, 130.6, 128.9, 118.4, 117.0, 110.7, 19.7.

*4.20. 4-Methyl-N-(4-nitrophenyl)aniline (**5ea**).*[19]

Pink solid (0.103 g, 39%); m.p. 139-140°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.08 (d, *J* = 9.2 Hz, 2H), 7.19 (d, *J* = 8.4 Hz, 2H), 7.11 (d, *J* = 8.4 Hz, 2H), 6.86 (d, *J* = 9.2 Hz, 2H), 6.36 (br s,1H), 2.36 (s, 3H); ^{13}CNMR (100 MHz, $CDCl_3$) δ: 150.9, 139.4, 136.8, 134.8, 130.3, 126.3, 122.7, 113.2, 20.9.

*4.21. Ethyl 4-(p-tolylamino)benzoate (**5fa**).*[3d]

White solid (0.174 g, 72%); m.p. 104-106°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.89 (d, *J* = 8.8 Hz, 2H), 7.14 (d, *J* = 8.4 Hz, 2H), 7.07 (d, *J* = 8.0 Hz, 2H), 6.91 (d, *J* = 8.8 Hz, 2H), 6.01 (br s, 1H), 4.32 (q, *J* = 7.2 Hz, 3H), 2.33 (s, 3H), 1.36 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 166.6, 148.7, 138.2, 133.1, 131.4, 130.0, 121.3, 120.9, 114.0, 60.4, 20.8, 14.4.

*4.22. 1-(4-(p-Tolylamino)phenyl)ethanone (**5ga**).*[3d]

Pale solid (0.144 g, 66%); m.p. 117-118°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.87 (d, *J* = 8.8 Hz, 2H), 7.19 (d, *J* = 8.0 Hz, 2H), 7.12 (d, *J* = 8.0 Hz, 2H), 6.95 (d, *J* = 8.8 Hz, 2H), 6.18 (br s, 1H), 2.55 (s, 3H), 2.37 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 196.5, 149.1, 137.8, 133.4, 130.7, 130.1, 128.5, 121.6, 113.8, 26.2, 20.9.

*4.23. 1-(2-(p-Tolylamino)phenyl)ethanone (**5ha**).*[20]

Pale yellow liquid (0.103 g, 46%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 10.46 (br s, 1H), 7.78 (dd, J_1 = 8.4, J_2 = 1.6 Hz, 1H), 7.28-7.24 (m, 1H), 7.16-7.12 (m, 5H), 6.70-6.66 (m, 1H), 2.62 (s, 3H), 2.34 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 201.1, 148.6, 137.6, 134.6, 133.9, 132.6, 130.0, 123.8, 118.6, 116.1, 114.0, 28.1, 21.0.

*4.24. 1-(3-(p-Tolylamino)phenyl)ethanone (**5ia**).*

Pale solid (0.180 g, 80%); m.p. 95-97°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.55 (t, *J* = 2.0 Hz, 1H), 7.41 (d, *J* = 7.6 Hz, 1H), 7.29 (t, *J* = 7.6 Hz, 1H), 7.19-7.17 (m, 1H), 7.10 (d, *J* = 8.4 Hz, 2H), 7.01 (d, *J* = 8.4 Hz, 2H), 5.83 (br s, 1H), 2.55 (s, 3H), 2.31 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 198.4, 144.7, 139.5, 138.3, 131.8, 130.1, 129.5, 120.7, 120.1, 119.6, 115.6, 26.8, 20.8. HRMS (ESI) m/z $[M+1]^+$ calcd for $C_{15}H_{16}NO$ 226.1232, found 226.1229.

*4.25. N-(p-Tolyl)pyridin-2-amine (**5ja**).*[21]

White solid (0.057 g, 31%); m.p. 101-103°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.20 (d, *J* = 2.8 Hz, 1H), 7.49 (m, 1H), 7.22 (d, *J* = 8.4 Hz, 2H), 7.16 (d, *J* = 8.0 Hz, 2H), 6.85 (d, *J* = 8.4 Hz, 1H), 6.74-6.71 (m, 2H), 2.36 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 156.6, 148.3, 137.7, 137.7, 132.9, 129.9, 121.3, 114.6, 107.7, 20.9.

*4.26. 2,4,6-Trimethyl-N-(p-tolyl)aniline (**5ka**).*[3d]

Pink liquid (0.140 g, 58%); ^{1}H NMR (400 MHz, $CDCl_3$) δ:6.87 (d, *J* = 8.0 Hz, 2H), 6.85 (s, 2H), 6.33 (d, *J* = 8.4 Hz, 2H), 4.92 (br s, 1H), 2.22 (s, 3H), 2.15 (s, 3H), 2.08 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 143.3, 134.9, 134.6, 134.0, 128.7, 128.2, 126.1, 112.4, 19.8, 19.4, 17.2.

*4.27. 2,6-Diisopropyl-N-(p-tolyl)aniline (**5la**).*[22]

Pale yellow liquid (0.054 g, 20%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.29-7.19 (m, 3H), 6.93 (d, *J* = 8.4 Hz, 2H), 6.40 (d, *J* = 8.4 Hz, 2H), 5.02 (br s, 1H), 3.23-3.16 (m, 2H), 2.22 (s, 3H), 1.13 (d, *J* = 6.8 Hz, 12H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 147.4, 145.9, 135.7, 129.8, 127.0, 126.9, 123.8, 113.1, 28.3, 23.9, 20.5.

*4.28. 4-Fluoro-N-(p-tolyl)aniline (**5bc**).*[23]

Pink solid (0.190 g, 94%); m.p. 49-50°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.14 (d, *J* = 8.0 Hz, 2H), 7.03-6.97 (m, 6H), 5.54 (br s, 1H), 2.37 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 157.7 (d, *J* = 237.7 Hz), 141.1, 139.8, 130.6, 130.0, 119.4 (d, *J* = 7.7 Hz), 117.9, 115.9 (d, *J* = 22.3 Hz), 20.7.

*4.29. 2-Methyl-N-(p-tolyl)aniline (**5be**).*[23]

Pink liquid (0.109 g, 55%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.24-7.12 (m, 5H), 6.98-6.91 (m, 3H), 5.35 (br s, 1H), 2.36 (s, 3H), 2.30 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 142.1, 141.1, 130.9, 129.9, 127.0, 126.8, 121.1, 118.7, 117.2, 20.7, 17.9.

*4.30. 2-Methoxy-N-(p-tolyl)aniline (**5bf**).*[3d]

Pink liquid (0.053 g, 25%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.29-7.27 (m, 1H), 7.18-7.12 (m, 4H), 6.94-6.85 (m, 3H), 6.14 (br s, 1H), 3.94 (s, 3H), 2.37 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ:147.9, 140.0, 133.9, 131.1, 129.9, 120.9, 119.7, 119.2, 113.7, 110.4, 55.6, 20.8.

*4.31. 2-Ethyl-N-(p-tolyl)aniline (**5bg**).*[24]

Pink liquid (0.106 g, 50%); ^{1}H NMR (400 MHz, $CDCl_3$) δ:7.29-7.24 (m, 2H), 7.20-7.12 (m, 3H), 7.02-6.94 (m, 3H), 5.39 (br s, 1H), 2.67 (q, *J* = 7.6 Hz, 2H), 2.36 (s, 3H), 1.32 (t, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 141.6, 141.4, 133.4, 130.2, 129.9, 128.9, 126.7, 121.7, 118.5, 118.3, 24.3, 20.7, 13.8.

*4.32. N-Benzyl-4-methylaniline (**5ma**).*[25]

Pale yellow liquid (0.164 g, 83%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.45-7.28 (m, 5H), 7.06 (d, *J* = 8.4 Hz, 2H), 6.63 (d, *J* = 8.4 Hz, 2H), 4.37 (s, 2H), 3.96 (br s, 1H), 2.32 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 146.0, 139.7, 129.8, 128.7, 127.6, 127.2, 126.8, 113.1, 48.7, 20.5.

*4.33. N-Cyclohexyl-4-methylaniline (**5na**).*[3d]

Pale yellow liquid (0.143 g, 75%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.05 (d, *J* = 8.4 Hz, 2H), 6.60 (d, *J* = 8.4 Hz, 2H), 3.33-3.26 (m, 1H), 2.31 (s, 3H), 2.15-2.11 (m, 2H), 1.86-1.80 (m, 2H), 1.75-1.70 (m, 1H), 1.49-1.39 (m, 2H), 1.35-1.15 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 145.2, 129.8, 126.1, 113.5, 52.1, 33.6, 26.1, 25.1, 20.5.

*4.34. N-Butyl-4-methylaniline (**5pa**).*[24]

Pale liquid (0.135 g, 82%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.03 (d, *J* = 8.0 Hz, 2H), 6.59 (d, *J* = 8.4 Hz, 2H), 3.13 (t, *J* = 7.2 Hz, 2H), 2.29 (s, 3H), 1.68-1.60 (m, 2H), 1.52-1.43 (m, 2H), 1.00 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 146.3, 129.7, 126.3, 112.9, 44.1, 31.8, 20.4, 20.4, 14.0.

*4.35. N-Benzyl-4-fluoroaniline (**5mc**).*[26]

Pale yellow liquid (0.157 g, 78%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.42-7.29 (m, 5H), 6.94 (t, *J* = 8.8 Hz, 2H), 6.63-6.60 (m, 2H), 4.34 (s, 2H), 3.98 (br s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 155.9 (d, *J* = 233.6 Hz), 144.5, 139.3, 128.7, 127.5, 127.4, 115.7 (d, *J* = 22.3 Hz), 113.7 (d, *J* = 7.4 Hz), 48.9.

*4.36. N-Benzyl-4-methoxyaniline (**5md**).*[25]

Pale yellow solid (0.162 g, 76%); m.p. 48-49 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.47-7.34 (m, 5H), 6.87 (d, *J* = 9.2 Hz, 2H), 6.68 (d, *J* = 9.2 Hz, 2H), 4.36 (s, 2H), 3.82 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 152.2, 142.6, 139.8, 128.7, 127.6, 127.3, 115.0, 114.2, 55.9, 49.3.

*4.37. N-Benzylaniline (**5mb**).*[7b]

Pale yellow solid (0.160 g, 87%); m.p. 34-35 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.48-7.43 (m, 4H), 7.40-7.36 (m, 1H), 7.28 (t, *J* = 8.0 Hz, 2H), 6.83 (t, *J* = 7.6 Hz, 1H), 6.73 (d, *J* = 8.0 Hz, 2H), 4.42 (s, 2H), 4.11 (br s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 148.3, 139.6, 129.4, 128.8, 127.6, 127.3, 117.7, 113.0, 48.4.

*4.38. N-Benzyl-2-methylaniline (**5me**).*[26]

Pale solid (0.110 g, 56%); m.p. 56-57 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.53-7.47 (m, 4H), 7.44-7.40 (m, 1H), 7.26-7.21 (m, 2H), 6.82 (t, *J* = 7.4 Hz, 1H), 6.75 (d, *J* = 7.6 Hz, 1H), 4.50 (s, 2H), 3.99 (br s, 1H), 2.30 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 146.1, 139.6, 130.2, 128.8, 127.6, 127.3, 127.3, 122.0, 117.3, 110.0, 48.4, 17.7.

*4.39. N-Benzyl-2-methoxyaniline (**5mf**).*[26]

Pale yellow liquid (0.059 g, 28%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.38-7.31 (m, 4H), 7.27-7.24 (m, 1H), 6.85-6.77 (m, 2H), 6.69-6.65 (m, 1H), 6.58 (dd, J_1 = 7.6 Hz, J_2 = 1.2 Hz, 1H), 4.62 (br s, 1H), 4.34 (s, 2H), 3.83 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 146.8, 139.6, 138.2, 128.6, 127.6, 127.2, 121.3, 116.7, 110.1, 109.4, 55.4, 48.1.

*4.40. N-Benzyl-2-ethylaniline (**5mg**).*[27]

Pale yellow liquid (0.106 g, 50%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.55-7.49 (m, 4H), 7.45-7.42 (m, 1H), 7.28-7.25 (m, 2H), 6.89 (t, *J* = 7.4 Hz, 1H), 6.79 (d, *J* = 8.8 Hz, 1H), 4.52 (s, 2H), 4.11 (br s, 1H), 2.67 (q, *J* = 7.6 Hz, 2H), 1.43 (t, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 145.6, 139.8, 128.9, 128.0, 127.7, 127.4, 127.2, 117.6, 48.5, 24.1, 13.1.

*4.41. 1-(p-Tolyl)piperidine (**5qa**).*[3d]

Colorless liquid (0.091 g, 52%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.11 (d, *J* = 8.4 Hz, 2H), 6.91 (d, *J* = 8.8 Hz, 2H), 3.14 (t, *J* = 5.6 Hz, 4H), 2.31 (s, 3H), 1.79-1.73 (m, 4H), 1.63-1.57 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 150.3, 129.6, 128.8, 117.0, 51.4, 26.0, 24.3, 20.5.

*4.42. 1-(4-Fluorophenyl)piperidine (**5qc**).*[28]

Pale yellow liquid (0.088 g, 49%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.00-6.90 (m, 4H), 3.09 (t, *J* = 5.4 Hz, 4H), 1.78-1.72 (m, 4H), 1.62-1.56 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 157.0 (d, *J* = 236.9 Hz), 149.1, 118.4 (d, *J* = 7.5 Hz), 115.4 (d, *J* = 21.8 Hz), 51.9, 26.0, 24.1.

*4.43. 1-(4-Methoxyphenyl)piperidine (**5qd**).*[3f]

Pale yellow liquid (0.105 g, 55%); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 6.98-6.94 (m, 2H), 6.89-6.85 (m, 2H), 3.80 (s, 3H), 3.06 (t, *J* = 5.4 Hz, 4H), 1.79-1.73 (m, 4H), 1.61-1.55 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 153.7, 146.7, 118.9, 114.3, 55.5, 52.5, 26.1, 24.2.

Acknowledgments

We are grateful for financial support provided by the National Natural Science Foundation of China (21472041) and National Key Technology R&D Program, the Ministry of Science and Technology of China (2015BAK44B00).

References and notes

1. (a) Chan, D. M. T.; Monaco, K. L.; Wang, R.-P.; Winters, M. P. *Tetrahedron Lett.* **1998**, *39*, 2933-2936. (b) Lam, P. Y. S.; Clark,

C. G.; Saubern, S.; Adams, J.; Winters, M. P.; Chan, D. M. T.; Combs, A. *Tetrahedron Lett.* **1998**, *39*, 2941-2944.
2. (a) Rao, K. S.; Wu, T.-S. *Tetrahedron* **2012**, *68*, 7735-7754. (b) Qiao, J. X.; Lam, P. Y. S. *Synthesis* **2011**, *6*, 829-856. (c) Bariwal, J.; Eycken, E. V. *Chem. Soc. Rev.* **2013**, *43*, 9283-9303.
3. For catalytic copper, see: (a) Collman, J. P.; Zhong, M.; Zhang, C.; Costanzo, S. *Org. Lett.* **2000**, 2, 1233-1236. (b) Collman, J. P.; Zhong, M.; Zhang, C.; Costanzo, S. *J. Org. Chem.* **2001**, *66*, 7892-7897. (c) Lam, P. Y. S.; Vincent, G.; Clark, C. G.; Deudon, S.; Jadhav, J. K. *Tetrahedron Lett.* **2001**, 42, 3415-3418. (d) Kwong, F. Y.; Klapars, A.; Buchwald, S. L. *Org. Lett.* **2002**, *4*, 581-584. (e) Quach, T. D.; Batey, R. A. *Org. Lett.* **2003**, *5*, 4397-4400. (f) Roy, S.; Sarma, M. J.; Kashyap, B.; Phukan, P. *Chem. Commun.* **2016**, *52*, 1170-1173.
4. Lan, J.-B.; Chen, L.; Yu, X.-Q.; You, J.-S.; Xie, R.-G. *Chem. Commun.* **2004**, *40*, 188-189.
5. Wentzel, M. T.; Hewgley, J. B.; Kamble, R. M.; Wall, P. D.; Kozlowski, M. C. *Adv. Synth. Catal.* **2009**, *351*, 931-937.
6. King, A. E.; Brunold, T. C.; Stahl, S. S. *J. Am. Chem. Soc.* **2009**, *131*, 5044-5045.
7. (a) Tzschucke, C.; Murphy, J.; Hartwig, J. F. *Org. Lett.* **2007**, *9*, 761-764. (b) Sueki, S.; Kuninobu, Y. *Org. Lett.* **2013**, *15*, 1544-1547. (c) McGarry, K. A.; Duenas, A. A.; Clark, T. B. *J. Org. Chem.* **2015**, *80*, 7193-7204. (d) Vantourout, J. C.; Law, R. P.; Albert, I.-L.; Atkinson, S. J.; Watson, A. J. B. *J. Org. Chem.* **2016**, *81*, 3942-3950.
8. (a) Cole, T. E.; Haly, B. D. *Organometallics* **1992**, *11*, 652-657. (b) Brown, H. C.; Racherla, U. S. *J. Org. Chem.* **1986**, *51*, 427-432.
9. (a) Marciasini, L.; Cacciuttolo, B.; Vaultier, M.; Pucheault, M. *Org. Lett.* **2015**, *17*, 3532-3535. (b) Richard, J.; Birepinte, M.; Charbonnier, J. B.; Liautard, V.; Pinet, S.; Pucheault, M. *Synthesis*, **2017**, *49*, 736-744.
10. (a) Chen, X.; Ke, H.; Chen, Y.; Guan, C.; Zou, G. *J. Org. Chem.* **2012**, *77*, 7572-7578. (b) Chen, X.; Ke, H.; Zou, G. *ACS Catal.* **2014**, *4*, 379-385. (c) Ke, H.; Chen, X.; Zou, G. *J. Org. Chem.* **2014**, *79*, 7132-7140. (d) Li, X.; Zou, G. *J. Organomet. Chem.* **2015**, *794*, 136-145. (e) Si S.; Wang C.; Zhang N.; Zou G. *J. Org. Chem.* **2016**, *81*, 4364−4370. (f) Wang, C.; Zhang, J.; Tang, J.; Zou G. *Adv. Synth. Catal.* **2017**, *359*, 2514-2519. (g) Zhang N.; Wang C.; Zou G.; Tang J. *J. Organomet. Chem.* **2017**, *842*, 54-58.
11. (a) Turner, W. R.; Elving, P. J. *Anal. Chem.* **1965**, *37*, 207−211. (b) Geske, D. H. *J. Chem. Phys.* **1959**, *63*, 1062-1070.
12. Das, P.; Basu, B. *Synth. Commun.* **2004**, *34*, 2177-2184.
13. Li, X.; Feng, Y.; Lin, L.; Zou, G. *J. Org. Chem.* **2012**, *77*, 10991-10995.
14. Diness, F.; Fairlie, D. *Angew. Chem. Int. Ed.* **2012**, *51*, 8012-8016.
15. Yang, D.; Fu, H.; Hu, L.; Jiang, Y.; Zhao, Y. *J. Org. Chem.* **2008**, *73*, 7841-7844.
16. Zhao, D.; Hu, J.; Wu, N.; Huang, X.; Qin, X.; Lan, J.; You, J. *Org. Lett.* **2011**, *13*, 6516-6519.
17. Li, G. Y.; Zheng, G.; Noonan, A. F. *J. Org. Chem.* **2001**, *66*, 8677-8681.
18. Yu, J.; Wang, Y.; Zhang, P.; Wu, J. *Synlett* **2013**, *24*, 1448-1454.
19. Liu, X.; Zhang, S. *Synlett* **2011**, *8*, 1137-1142.
20. Wray, B. C.; Stambuli, J. P, *Org. Lett.* **2010**, *12*, 4576-4579.
21. Wang, H.; Wang, Y.; Peng, C.; Zhang, J.; Zhu, Q. *J. Am. Chem. Soc.* **2010**, *132*, 13217-13219.
22. Reddy, C. V.; Kingston, J. V.; Verkade, J. G. *J. Org. Chem.* **2008**, *73*, 3047-3062.
23. Hajra, A.; Wei, Y.; Yoshikai, N. *Org. Lett.* **2012**, *14*, 5488-5491.
24. Samblanet, D. C.; Schmidt, J. A. R. *J. Organomet. Chem.* **2012**, *720*, 7-18.
25. Zhang, H.; Cai, Q.; Ma, D. *J. Org. Chem.* **2005**, *70*, 5164-5173.
26. Zhou, W.; Fan, M.; Yin, J.; Jiang, Y.; Ma, D. *J. Am. Chem. Soc.* **2015**, *137*, 11942-11945.
27. Corre, Y.; Iali, W.; Hamdaoui, M.; Trivelli, X.; Djukic, J.-P.; Agbossou-Niedercorn, F.; Michon, C. *Catal. Sci. Technol.*, **2015**, *5*, 1452-1458.
28. Lerma, I. C.; Cawley, M. J.; Cloke, F. G. N.; Arentsen, K.; Scott, J. S.; Pearson, S. E.; Hayler, J.; Caddick, S. *J. Organomet. Chem.* **2005**, *690*, 5841-5848.