ORGANIC LETTERS

2011
Vol. 13, No. 7
1784–1786

Palladium- and Nickel-Catalyzed Aminations of Aryl Imidazolylsulfonates and Sulfamates

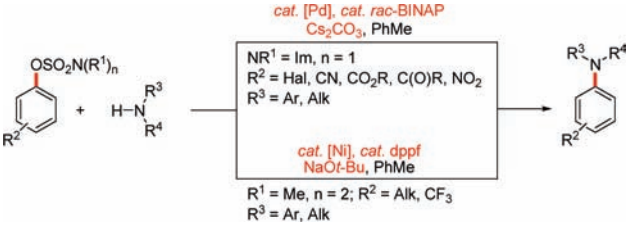
Lutz Ackermann,* René Sandmann, and Weifeng Song

Institut für Organische und Biomolekulare Chemie, Georg-August-Universität, Tammannstrasse 2, 37077 Göttingen, Germany

Lutz.Ackermann@chemie.uni-goettingen.de

Received January 27, 2011

ABSTRACT



A nickel complex derived from dppf, along with NaO*t*-Bu as the base, allowed for challenging aminations of aryl sulfamates. An improved functional group tolerance is observed in novel palladium-catalyzed aminations of imidazolylsulfonates with *rac*-BINAP as the ligand.

Transition-metal-catalyzed arylations of amines with aryl halides are among the most important methods for the selective formation of C−N bonds.[1] Particularly, the use of phenol-derived electrophiles in catalyzed arylations is highly attractive,[2] since they are readily accessible and can be easily implemented as directing groups in site-selective arene functionalization strategies.[2,3] However, the inherently high C−O bond strength in phenols calls for an activation of these precursors, which was largely achieved through the use of rather expensive fluorine-containing reagents.[4] On the contrary, recent progress in the use of phenol-derived electrophiles in catalytic arylations was represented by the use of imidazolylsulfonates and sulfamates, because of their air- and moisture-stable nature, their attractive handling properties, and their low costs.[5,6] While these user-friendly electrophiles were recently employed for efficient C−C bond formations, their use in transition-metal-catalyzed aminations

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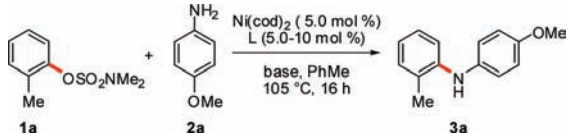
10.1021/ol200267b
Published on Web 02/25/2011

has unfortunately thus far proven elusive. Within our research program on the development of efficient amination reactions for modular heteroarene syntheses,[7] we thus explored various transition metal complexes for catalyzed aminations with aryl sulfamates and imidazolylsulfonates, on which we report herein.

At the outset, we tested various ligands and bases in the nickel-catalyzed amination of sulfamate **1a** (Table 1). While representative monodentate phosphine ligands provided only unsatisfactory results (entries 1−5), nickel complexes derived from N-heterocyclic carbene (NHC) precursors (entries 6 and 7) or bidentate phosphine ligands (entries 8−14) displayed improved catalytic activities. Notably, the best results were accomplished with dppf as the ligand, along with NaO*t*-Bu as the base (entries 12−14).

Table 1. Optimization of Nickel-Catalyzed Amination[a]



entry	L (mol %)	base	yield (%)
1	–	NaO*t*-Bu	–
2	PPh_3 (10)	NaO*t*-Bu	–
3	PCy_3 (10)	NaO*t*-Bu	–
4	S-Phos (10)	NaO*t*-Bu	–
5	X-Phos (10)	NaO*t*-Bu	–
6	IPrHCl (10)	NaO*t*-Bu	85
7	SIPrHCl (10)	NaO*t*-Bu	82
8	*rac*-BINAP (5.0)	NaO*t*-Bu	54
9	1,10-phenanthroline (5.0)	NaO*t*-Bu	8
10	dppe (5.0)	NaO*t*-Bu	52
11	dppp (5.0)	NaO*t*-Bu	–
12	dppf (5.0)	KO*t*-Bu	65
13	dppf (5.0)	Cs_2CO_3	–
14	dppf (5.0)	NaO*t*-Bu	95

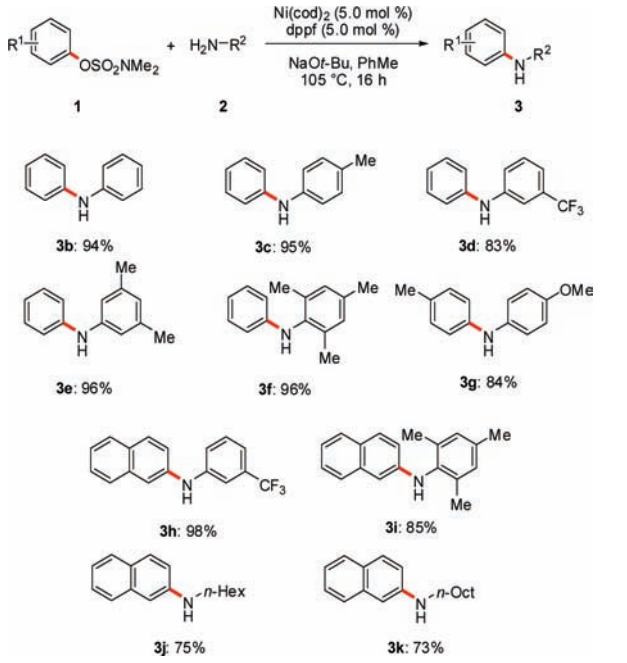
[a] Reaction conditions: **1a** (0.50 mmol), **2a** (0.75 mmol), $Ni(cod)_2$ (5.0 mol %), L (5.0−10 mol %), base (0.75 mmol), PhMe (2.0 mL), 105 °C, 16 h; S-Phos = 2-dicyclohexylphosphino-2′,6′-dimethoxybiphenyl; X-Phos = 2-dicyclohexylphosphino-2′,4′,6′-tri-*iso*-propylbiphenyl; (S)IPrH = *N*,*N*′-bis-(2,6-di-*iso*-propylphenyl)imidazol(in)ium.

With an optimized catalytic system in hand, we explored its scope in the nickel-catalyzed amination of differently substituted sulfamates **1** (Scheme 1). Importantly, aniline derivatives bearing electron-withdrawing as well as electron-donating substituents efficiently provided the desired products **3b**−**3i**, even when being sterically hindered. Moreover, challenging *n*-alkyl amines were converted with comparable catalytic efficacy.

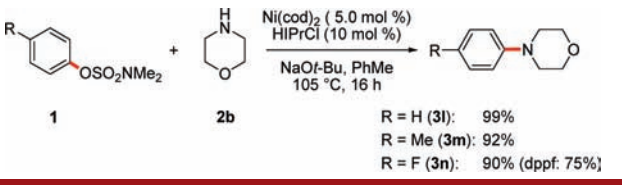
For alkyl-substituted secondary amines, a nickel complex generated *in situ* from an NHC precursor constituted a viable alternative (Scheme 2).

While the optimized nickel complexes displayed promising catalytic activities, they relied on air-sensitive $Ni(cod)_2$,

Scheme 1. Nickel-Catalyzed Amination of Sulfamtes **1**



Scheme 2. Nickel-Catalyzed Arylation of Secondary Amine **2b**



and their functional group tolerance was significantly restricted by the required strong base NaO*t*-Bu. Therefore, we subsequently tested various palladium catalysts for the amination of imidazolylsulfonate **4a** using milder bases (Table 2). Unfortunately, various NHC palladium complexes gave only unsatisfactory yields (entries 1−4). However, among a variety of phosphine ligands (entries 5−16),

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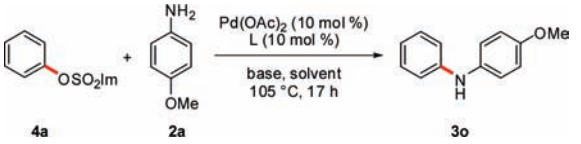
Table 2. Optimization of Palladium-Catalyzed Amination[a]



4a 2a 3o

entry	L	base	solvent	yield (%)
1	–	Cs_2CO_3	PhMe	–
2	sHIPrCl	Cs_2CO_3	PhMe	5[b]
3	HIPrCl	Cs_2CO_3	PhMe	9[b]
4	HIMesCl	Cs_2CO_3	PhMe	–
5	PPh_3	Cs_2CO_3	PhMe	–
6	John-Phos	Cs_2CO_3	PhMe	83
7	X-Phos	Cs_2CO_3	PhMe	90
8	X-Phos	Cs_2CO_3	PhMe	79[c]
9	dppe	Cs_2CO_3	PhMe	–
10	dppf	Cs_2CO_3	PhMe	8[b]
11	*rac*-BINAP	Cs_2CO_3	THF[d]	64
12	*rac*-BINAP	Cs_2CO_3	1,4-dioxane	80
13	*rac*-BINAP	K_3PO_4	PhMe	58
14	*rac*-BINAP	K_2CO_3	PhMe	29[b]
15	*rac*-BINAP	Na_2CO_3	PhMe	–
16	*rac*-BINAP	Cs_2CO_3	PhMe	86

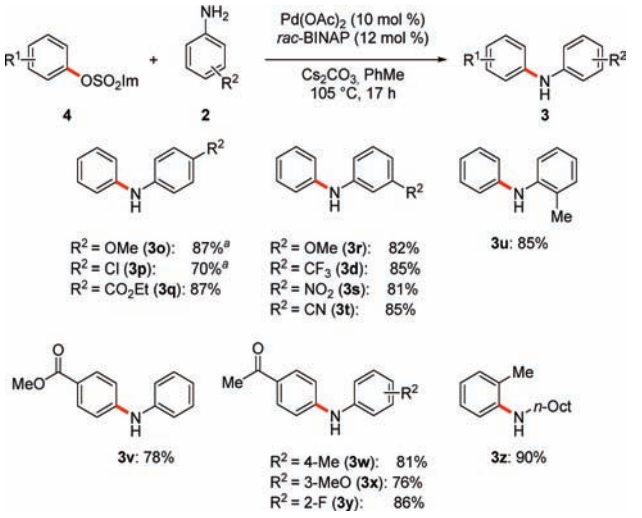
[a] Reaction conditions: **4a** (0.50 mmol), **2a** (0.60−0.75 mmol), $Pd(OAc)_2$ (10 mol %), L (10 mol %), base (0.65−1.25 mmol), solvent (2.0 mL), 105 °C, 17 h; John-Phos = 2-di(*tert*-butyl)phosphinobiphenyl. [b] GC conversion. [c] $Pd(OAc)_2$ (2.0 mol %), L (4.0 mol %). [d] 65 °C.

particularly X-Phos[8] and *rac*-BINAP turned out to be superior (entries 11−16).

The optimized reaction conditions were thereafter employed for evaluating the scope of palladium-catalyzed aminations of imidazolylsulfonates **4** (Scheme 3). Notably, differently substituted aniline derivatives were successfully converted, as was an alkyl-substituted amine. Contrary to reactions with nickel complexes (*vide supra*), the palladium-catalyzed amination proved tolerant of valuable electrophilic functional groups, such as fluoro-, nitro-, or cyano-substituents, as well as ester or ketone functionalities. An additional valuable asset of the catalytic system is *inter alia* represented by its chemoselectivity in the conversion of chloro-substituted aryl imidazolylsulfonates **4**, which is complementary to the one observed in palladium-catalyzed aminations with aryl tosylates[5d] or mesylates[5c] as electrophiles.

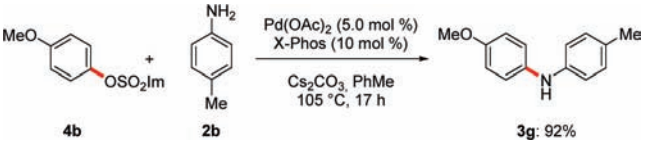
When using electron-rich aryl imidazolylsulfonates, a palladium complex of phosphine ligand X-Phos delivered high yields as well (Scheme 4).

Scheme 3. Scope of Palladium-Catalyzed Aminations of Imidazolylsulfonates **4**



[a] [Pd] (5.0 mol %).

Scheme 4. Palladium-Catalyzed Amination of Electron-Rich Imidazolylsulfonate **4b**



In summary, we have disclosed unprecedented general metal-catalyzed aminations of aryl sulfamates and imidazolylsulfonates. Hence, a nickel catalyst derived from ligand dppf allowed for arylations with challenging sulfamates as electrophiles, provided that NaO*t*-Bu was used as the base. On the contrary, palladium complexes of *rac*-BINAP set the stage for widely applicable aminations of aryl imidazolylsulfonates, a notable feature of which is constituted by their excellent functional group tolerance. Further studies on applications of these electrophiles in catalytic arylations are currently ongoing in our laboratories and will be reported in due course.

Acknowledgment. Support by the DFG and the Chinese Scholarship Council (fellowship to W.S.) is gratefully acknowledged.

Supporting Information Available. Experimental procedures, characterization data, and ^1H and ^{13}C NMR spectra for new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

(7) For representative examples, see: (a) Ackermann, L.; Song, W.; Sandmann, R. *J. Organomet. Chem.* **2011**, *696*, 195–201. (b) Ackermann, L.; Barfüsser, S.; Potukuchi, H. K. *Adv. Synth. Catal.* **2009**, *351*, 1064–1072. (c) Ackermann, L.; Sandmann, R.; Kaspar, L. T. *Org. Lett.* **2009**, *11*, 2031–2034. (d) Ackermann, L.; Sandmann, R.; Kondrashov, M. V. *Synlett* **2009**, 1219–1222. (e) Ackermann, L.; Sandmann, R.; Villar, A.; Kaspar, L. T. *Tetrahedron* **2008**, *64*, 769–777. (f) Ackermann, L.; Spatz, J. H.; Gschrei, C. J.; Born, R.; Althammer, A. *Angew. Chem., Int. Ed.* **2006**, *45*, 7627–7630. (g) Ackermann, L.; Born, R. *Angew. Chem., Int. Ed.* **2005**, *44*, 2444–2447 and references cited therein.

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