Communication

Palladium-catalyzed carbonylative C−H activation of arenes with norbornene as the coupling partner

Jianbin Chen [a], Kishore Natte [a], Xiao-Feng Wu [a, b, *]

[a] Leibniz-Institut für Katalyse an der Universität Rostock e.V, Albert-Einstein-Str. 29a, 18059 Rostock, Germany
[b] Department of Chemistry, Zhejiang Sci-Tech University, Xiasha Campus, Hangzhou 310018, People's Republic of China

A B S T R A C T

An interesting transformation on palladium-catalyzed carbonylative C−H activation of arenes with norbornene as the coupling partner has been developed. By applying molybdenum hexacarbonyl ($Mo(CO)_6$) or paraformaldehyde as the solid CO sources, various 5-(pyridin-2-yl)-hexahydro-7,10-methanophenanthridin-6(5H)-ones were produced in moderate yields in the presence of palladium catalyst. Interestingly, when DDQ was applied the oxidant, the product was over oxidized to the corresponding 5-(pyridin-2-yl)-tetrahydro-7,10-methanophenanthridin-6(5H)-one.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Palladium-catalyzed carbonylation reactions offer promising procedure for the preparation of carbonyl containing compounds. By incorporating one or even more molecules of CO into the parent structure, the carbon chain can be easily increased and the resulted products are ready for further modification which hold their own importance as well [1]. Until nowadays, most of the known carbonylations are focused on the using of ArX (X = I, Br, OTf, N_2BF_4, etc.) as the substrates under pressure of CO gas [1a,1d−f]. However, the requirement of multiple steps for the starting materials preparation and over stoichiometric amounts of wastes generation decrease the overall synthetic efficiency. In order to overcome such drawbacks, directed functionality of the C−H bond of arenes provides alternative pathway [2]. Nevertheless, carbonylative methodologies of directly utilizing the ArH as starting material is still limited compared with ArX [1b,c,3]. Additionally, even CO gas holds non-replaceable advantages in industrial applications [4], the high toxicity character of it as well as the demanding of high pressure instruments limits its application in laboratories [5]. Hence, the

developing of carbonylative C−H activation procedures with CO surrogates is under the current interesting. Among the possible candidates, $Mo(CO)_6$ as an air-stable solid complex was explored and applied in carbonylative transformations [6]. Herein, we wish to report a novel methodology by applying palladium-catalyzed carbonylative C−H activation for the synthesis of (6aS, 10aR)-5-(pyridin-2-yl)-6a,7,8,9,10,10a-hexahydro-7,10-methanophenanthridin-6(5H)-ones. In this procedure, $Mo(CO)_6$ has been applied as the solid CO source with norbornene and N-arylpyridin-2-amines as the substrates. Notably, this is the first study on palladium-catalyzed carbonylative C−H activation of arenes with alkene as the coupling partner via [3+2+1] reaction manner.

2. Results and discussion

We initiated our investigation with alkenes testing, such as 3,3-dimethylbut-1-ene, butyl acrylate, cyclohexene and styrene. Using N-phenylpyridin-2-amine (**1a**) as the substrate in the presence of $Mo(CO)_6$, $Pd(OAc)_2$, L-proline and $Cu(FTA)_2 \cdot xH_2O$ in MeCN at 140 °C for 24 h. Unfortunately, no desired products can be obtained in any of the cases. Then strained alkene norbornene come to our attention and the target product can be observed (entry 1, Table 1). Screen of solvents shown that the combination of toluene

* Corresponding author. Leibniz-Institut für Katalyse an der Universität Rostock e.V, Albert-Einstein-Str. 29a, 18059 Rostock, Germany
E-mail address: xiao-feng.wu@catalysis.de (X.-F. Wu).

Table 1
Optimization of the benchmark reaction parameters.[a]

Entry	Ligand	Oxidant	Solvent	Yield
1	L-proline	Cu(TFA)$_2$·xH$_2$O	MeCN	8%
2	L-proline	Cu(TFA)$_2$·xH$_2$O	Tol.	15%
3	L-proline	Cu(TFA)$_2$·xH$_2$O	Diox.	16%
4	L-proline	Cu(TFA)$_2$·xH$_2$O	Diox.-Tol.[b]	17% 9%[c]
5	—	Cu(TFA)$_2$·xH$_2$O	Diox.-Tol.[b]	11%
6	—	—	Diox.-Tol.[b]	19%
7	L-proline	AgOAc	Diox.-Tol.[b]	0
8	L-proline	CeO$_2$	Diox.-Tol.[b]	11%
9	L-proline	BQ	Diox.-Tol.[b]	25%
10	—	BQ	HOAc	27%
11	—	BQ	DMF	0
12	—	BQ	tAmylOH	7%
13	—	BQ	DMSO	0
14	—	BQ	Diox.-HOAc[d]	(58%)
15	—	BQ	Diox.-HOAc[d,e]	69% 54%[f]
16	—	BQ	Diox.-HOAc[d,e]	78%[g,h] (74%)
17	—	BQ	Diox.-HOAc[d,e]	38%[i,h]
18	—	BQ	Diox.-HOAc[d]	70%[g,h]
19	—	BQ	Diox.[e,j]	9%
20	—	BQ	Diox.[e,k]	<5%
21	—	BQ	Diox.[e,l]	<5%
22	—	BQ	Diox.-HOAc[e,m]	0

[a] Reaction conditions: unless otherwise noted, substrate (0.2 mmol, 1 equiv.), Mo(CO)$_6$ (0.8 equiv.), norbornene (2 equiv.), Pd(OAc)$_2$ (5 mol %), ligand (20 mol %), oxidant (2 equiv.), solvent (2 mL), 140 °C, 24 h, GC yields with hexadecane as internal standard, isolated yields in parentheses.
[b] Diox. − Tol. = 1.5−0.5 mL.
[c] 120 °C.
[d] Diox. − HOAc = 2−0.1 mL.
[e] Pd(OAc)$_2$ (10 mol %).
[f] Under O$_2$.
[g] 150 °C.
[h] 48 h.
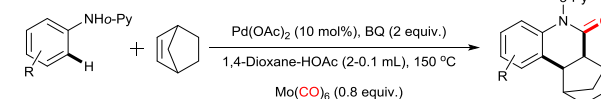[i] 130 °C.
[j] HOAc (2 equiv.).
[k] PivOH (2 equiv.).
[l] p-TsOH (2 equiv.).
[m] LiCl (2 equiv.) Tol. = toluene, Diox. = 1,4-dioxane, BQ = p-benzoquinone.

with 1,4-dixoane increased the yield to 17% (entries 2−4, Table 1). As we can see, ligand was not indispensable in our system (entry 5, Table 1). Regarding the effects of oxidants, AgOAc was found to be not suitable for this reaction and BQ can gave the target product in 25% yield (entries 6−9, Table 1). Then the influences of solvents were checked again. We found DMF, DMSO, t-AmylOH resulted in no or low yields, while 58% yield of the final product was isolated in using a mixture solvent of 1,4-dixoane and HOAc (entries 11−14, Table 1). The best yield was achieved when the loading of palladium catalyst was increased to 10 mol % at 150 °C for 48 h (entries 15−16, Table 1). A sharply decrease of the yield was obtained when the benchmark reaction was conducted at 130 °C (entry 17, Table 1). Notably, treatment stoichiometric amount of the acid such as HOAc, PivOH, p-TsOH as the additive in 1,4-dixoane only generated trace or very low yields in all those cases (entries 19−21, Table 1). Applying LiCl as the additive totally shut down the reaction (entry 22, Table 1). In respect of the metal carbonyl complexes, decreased yield was delivered when Co$_2$(CO)$_8$ or Fe$_3$(CO)$_{12}$ was treated as the CO source.

Table 2
Palladium-catalyzed oxidative carbonylative C−H activation.[a]

Entry	Substrate	Product	Yield
1			74%
2		R = o-Py 2b R = H 2b′	35% 2b:2b′ = 1.3:1
3			21%[b]
4			20%[b]
5			26%
6			18%
7			32%[c]
8			51%[c]
9			23%[b]
10			18%[d]
11			45%[c]