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Pd-catalyzed aerobic direct olefination of polyfluoroarenes

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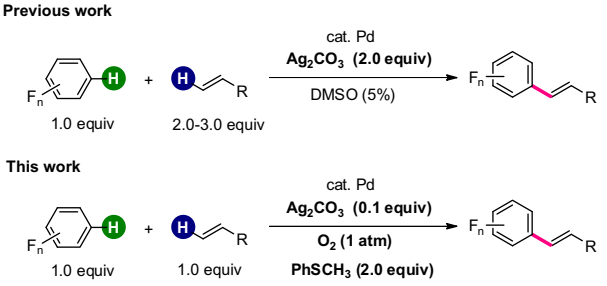
ABSTRACT

The first example of Pd-catalyzed aerobic direct olefination of polyfluoroarenes has been developed. The reaction makes use of molecular O_2 as terminal oxidant, and provides a cost-efficient and environmentally benign access to polyfluoroarene–alkene structures that are of interest in life and material sciences.

Due to the important role of polyfluoroarene derivatives in life and material sciences,[1] in particular in advanced functional materials, such as liquid crystals, organic light-emitting diodes (OLEDs), and field-effect transistors (FETs),[2] it is of great interest to develop new and efficient methods to access such a class of fluorinated compounds.[3] Over the past few years, although considerable progresses have been achieved in transition-metal-catalyzed direct C—H bond functionalization[4,5] of polyfluoroarenes,[6,7] efficient methods for the construction of polyfluorarylated olefins remain few. Very recently, we reported the first example of palladium-catalyzed direct olefination of polyfluoroarenes via C—H bond activation,[7a] which represents one of the rare examples of catalytic direct olefination of electron-deficient arenes.[8] However, one drawback of this method is the requirement of excessive silver salt (Ag_2CO_3), which decreases its atom economy. To address this issue, the use of molecular O_2 as oxidant is appealing, because only water is produced as a byproduct. Inspired by our recent work on palladium-catalyzed oxidative cross-coupling of polyfluoroarenes with thiophenes by using O_2 as the terminal oxidant,[7i] herein, we report the first example of palladium-catalyzed aerobic direct olefination of polyfluoroarenes, which provides a cost-efficient and environmentally benign access to polyfluoroarene–alkene structures (Scheme 1). Furthermore, the use of thioether ($PhSCH_3$) as a ligand enables the reaction conducting with 1:1 ratio of polyfluoroarene and alkene in high efficiency, thus highlighting the advantages of this protocol.



Scheme 1. Pd-catalyzed direct olefination of polyfluoroarenes.

We began this study by treatment of pentafluorobenzene **1a** (1.0 equiv) with *tert*-butyl acrylate **2a** (2.0 equiv) in the presence of $Pd(OAc)_2$ (10 mol %) and $PhSCH_3$ (2.8 equiv) in DMF under 1 atm O_2 at 120 °C (Table 1, entry 1), in which $PhSCH_3$ has been previously demonstrated to be a good ligand to activate the palladium species and benefit the catalytic cycle.[9] However, only a trace amount of the desired product **3a** was detected. The addition of K_2CO_3 or K_3PO_4 to the reaction led to negative results as well (Table 1, entries 2 and 3). Considering that silver salts could facilitate the deprotonation of polyfluoroarene and benefit formation of Pd(polyfluoroaryl) complex,[7i] a catalytic amount of Ag_2CO_3 (0.1 equiv) was employed. To our delight, the yield was dramatically improved to 60% yield (determined by ^{19}F NMR) (Table 1, entry 4). These findings demonstrated that silver plays an essential role in the catalytic cycle. Encouraged by this result, different solvent and thioether were investigated (Table 1, entries 5–13). It was

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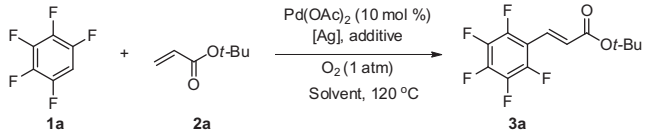
Table 1
Optimization of Pd-catalyzed aerobic direct olefination of pentafluorobenzene **1a** with *tert*-butyl acrylate **2a**[a]



1a **2a** **3a**

Entry	**2a** (equiv)	[Ag] (equiv)	Solvent	Additive (equiv)	Yield[b] (%)
1	2.0	—	DMF	$PhSCH_3$(2.8)	Trace
2	2.0	K_2CO_3(0.1)	DMF	$PhSCH_3$(2.8)	10
3	2.0	K_3PO_4(0.1)	DMF	$PhSCH_3$(2.8)	nr
4	2.0	Ag_2CO_3(0.1)	DMF	$PhSCH_3$(2.8)	60
5	2.0	Ag_2CO_3(0.1)	DMSO	$PhSCH_3$(2.8)	44
6	2.0	Ag_2CO_3(0.1)	Dioxane	$PhSCH_3$(2.8)	5
7	2.0	Ag_2CO_3(0.1)	Toluene	$PhSCH_3$(2.8)	Trace
8	2.0	Ag_2CO_3(0.1)	DMA	$PhSCH_3$(2.8)	69
9	2.0	Ag_2CO_3(0.1)	DMA	PhSPh(2.8)	8
10	2.0	Ag_2CO_3(0.1)	DMA	$(t\text{-Bu})_2S$(2.8)	Trace
11	2.0	Ag_2CO_3(0.1)	DMA	$t\text{-BuSCH}_3$(2.8)	40
12	2.0	Ag_2CO_3(0.1)	DMA	CH_3SCH_3(2.8)	41
13	2.0	Ag_2CO_3(0.1)	DMA	DMSO(2.8)	58
14	1.0	Ag_2CO_3(0.1)	DMA	$PhSCH_3$(2.8)	79
15	1.0	Ag_2CO_3(0.1)	DMA	$PhSCH_3$(1.5)	76
16	1.0	Ag_2CO_3(0.1)	DMA	$PhSCH_3$(2.0)	83(73)
17	1.0	Ag_2CO_3(0.1)	DMA	$PhSCH_3$(2.5)	81(72)
18	1.0	Ag_2CO_3(0.1)	DMA	$PhSCH_3$(3.0)	78
19	1.0	Ag_2CO_3(0.1)	DMA	$PhSCH_3$(4.0)	63
20	1.0	AgOAc(0.2)	DMA	$PhSCH_3$(2.0)	65
21	1.0	Ag_2O(0.1)	DMA	$PhSCH_3$(2.0)	75
22[c]	1.0	Ag_2CO_3(0.1)	DMA	$PhSCH_3$(2.0)	9
23[d]	1.0	Ag_2CO_3(0.1)	DMA	$PhSCH_3$(2.0)	nr

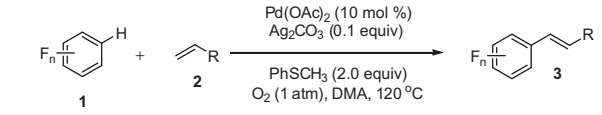
[a] Reaction conditions (unless otherwise specified): **1a** (0.3 mmol, 1 equiv), **2a** (1.0–2.0 equiv), solvent (1 mL) at 120 °C for 8 h.
[b] NMR yield determined by ^{19}F NMR using fluorobenzene as an internal standard (isolated yield in parentheses).
[c] The reaction was carried out in the absence of O_2.
[d] The reaction was carried out in the absence of $Pd(OAc)_2$.

found that polar solvent DMA was the best reaction medium, providing **3a** in 69% yield (Table 1, entry 8), but non-polar solvent toluene failed to afford the desired product (Table 1, entry 7). It was also revealed that the steric effect of the thioethers significantly influenced the reaction efficiency (Table 1, entries 9–12). Thioethers bearing two bulky groups, such as PhSPh and *t*Bu*S*t*B*u almost inhibited the reaction (Table 1, entries 9–10). While synthetically useful yields were obtained by employing $t\text{BuSCH}_3$ or CH_3SCH_3 as an additive (Table 1, entries 11–12). We reasoned that the different reactivities of the tested thioethers might be ascribed to the different coordination abilities of thioethers to palladium. Compared to $PhSCH_3$, the strong or poor coordination of thioether to palladium all led to some palladium intermediates with low catalytic activities. This is in accordance to our previous report.[7] Additionally, DMSO[10] could also be used as an additive and provided **3a** in moderate yields (Table 1, entries 13). Furthermore, we found that the ratio between **1a** and **2a** also influenced the reaction efficiency. Even a higher yield (79%, determined by ^{19}F NMR) of **3a** was obtained, when the reaction was carried out with 1:1 ratio of **1a** and **2a**, thus highlighting the advantage of the present catalytic system (Table 1, entry 14). Other silver salts, such as AgOAc and Ag_2O, were also effective, but provided lower yields than Ag_2CO_3 did (Table 1, entries 20–21). Finally, the optimal reaction conditions were identified by using 2.0 equiv of $PhSCH_3$, with 73% isolated yield of **3a** obtained (Table 1, entry 16). The absence of O_2 or $Pd(OAc)_2$ led to poor yields or no product, thus demonstrating that a palladium redox catalytic cycle is involved in the reaction (Table 1, entries 22–23).

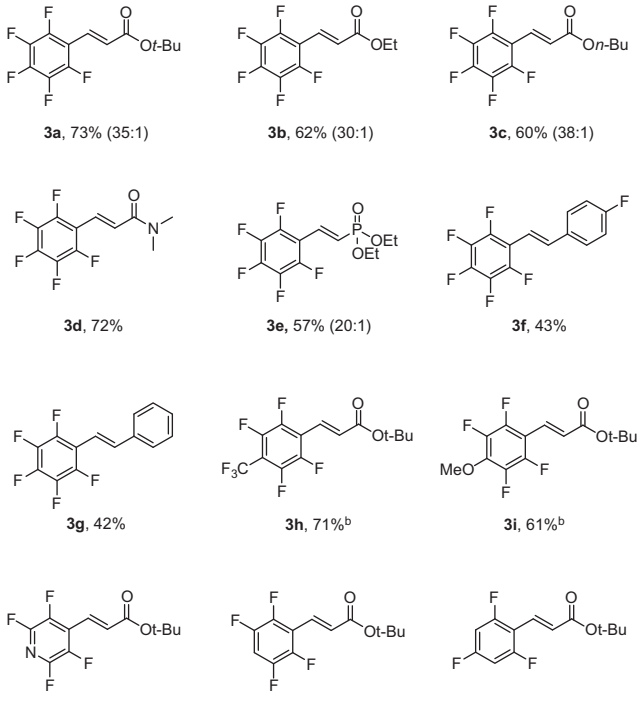
With the optimal reaction conditions in hand, a variety of alkenes were investigated (Table 2). Generally, moderate to good yields with high *E*/*Z* selectivities were obtained through this new catalytic system. Compared to electron-rich alkenes, higher yields were provided when electron-deficient alkenes were employed as coupling partners (**3a–e**). The moderate yields obtained from electron-rich alkenes are because of the formation of some aldehydes that were resulted from the oxidation of aromatic alkenes under O_2 atmosphere (**3f–g**). However, further optimization of the reaction conditions by using 2.0 equiv of alkenes led to poor yields (20–25% determined by ^{19}F NMR). The substrate scope of fluoroarene is not restricted to pentafluorobenzene, variations of fluoroarenes containing 3–4 fluorines were also competent partners. Moderate to good yields were obtained when 2.0 equiv of alkenes were used for 3-substituted tetrafluorobenzenes (**3h–i**). Fluorinated pyridine also furnished its corresponding product in synthetically useful yield (**3j**). For fluoroarenes containing more than one reaction site, moderate yields of monoolefinated products were still observed with using 3.0 equiv of fluoroarenes (**3k–l**).

In conclusion, a palladium-catalyzed aerobic direct olefination of polyfluoroarenes has been developed. The reaction makes use of molecular O_2 as terminal oxidant, thus providing a cost-efficient and environmentally benign access to polyfluoroarene–alkene structures. The silver and thioether play important roles in the reaction efficiency, further investigation of the reaction mechanism is now in progress in our group.

Table 2
Pd-catalyzed aerobic direct olefination of fluoroarenes **4** with various alkenes **2**[a]



1 **2** **3**



3a, 73% (35:1) **3b**, 62% (30:1) **3c**, 60% (38:1)
3d, 72% **3e**, 57% (20:1) **3f**, 43%
3g, 42% **3h**, 71%[b] **3i**, 61%[b]
3j, 42% **3k**, 41% (9%)[c] **3l**, 40% (6%)[c]

[a] Reaction conditions (unless otherwise specified): **1** (0.3 mmol, 1.0 equiv), **2** (1.0 equiv), DMA (1 mL) for 8 h. Number in parentheses is the ratio of *E*/*Z*.
[b] **1** (0.3 mmol, 1.0 equiv) and **2** (2.0 equiv) were used.
[c] **1** (3.0 equiv) and **2** (0.3 mmol) were used. Number in parentheses is dialkenylated product.

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Supplementary data

Supplementary data (detailed experimental procedures, and characterization data for new compounds) associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tetlet.2014.03.096

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