Journal of Fluorine Chemistry 131 (2010) 856–860

Contents lists available at ScienceDirect

Journal of Fluorine Chemistry

journal homepage: www.elsevier.com/locate/fluor

Synthesis of *N*-aryl trifluoromethylarylketoimines by palladium-catalyzed Suzuki coupling reaction of *N*-aryltrifluoroacetimidoyl chlorides with aryl boronic acids

Chun-Lin Li, Mu-Wang Chen, Xing-Guo Zhang *

College of Chemistry and Materials Engineering, Wenzhou University, Wenzhou 325035, China

ARTICLE INFO

Article history:
Received 25 March 2010
Received in revised form 30 April 2010
Accepted 30 April 2010
Available online 8 May 2010

Keywords:
Ketoimine
Suzuki reaction
Trifluoroacetimidoyl chlorides

ABSTRACT

A highly efficient Suzuki reaction between *N*-aryltrifluoroacetimidoyl chlorides and aryl boronic acids using $Pd(PPh_3)_4$ as a catalyst has been developed. This route allows for selective synthesis of *N*-aryl trifluoromethylarylketoimines in high yields under mild reaction conditions.

1. Introduction

Organofluorine compounds have attracted considerable attention due to their wide range of applications in the pharmaceutical and agrochemical industries [1]. In particular, trifluoromethyl-substituted molecules have become a subject of intense investigations in recent years because of their relevant properties [2]. Trifluoromethyl arylketoimines, a class of versatile building blocks or precursor products, played an important role in the synthesis of CF_3-containing functional molecules. For example, some fluorinated indolines could be prepared from trifluoromethyl ketoimines and 2-*p*-tolylsulfinylalkylbenzenes by a tandem process [3]. The CF_3-containing chiral amines could also be synthesized from trifluoromethyl arylketoimines by an asymmetric alkylation reaction [4]. Fluorinated bis(phenoxyketimine)titanium complexes, the catalysts for polymerization of propylene, were also prepared from CF_3-containing arylketoimines [5]. Usually, trifluoromethyl arylketoimines were synthesized *via* condensation reaction of trifluoromethyl ketones with amines under high temperature conditions [6]. However, some substituted-aryl trifluoromethylketoimines are unavailable because of the scarcity of 1-(substituted-aryl)-2,2,2-trifluoroethanones. Friedel–Crafts reaction of *N*-aryltrifluoroacetimidoyl chlorides with aromatic compounds provides another access for trifluoromethyl arylketoimines [5,7], but aromatic compounds were limited to electron-rich phenols. Therefore, the discovery of new readily available fluorine sources for efficient and concise synthesis route to trifluoromethyl arylketoimines remains a challenging area for exploration.

The Suzuki cross-coupling reaction is a powerful and widely used method for the formation of carbon-carbon bond and for the synthesis of biaryls and multi-substituted ethylenes [8]. Considerable aryl halides and vinyl halides were coupled with boronic acids to afford aryl- and vinylarenes, respectively. However, imidoyl chlorides which bearing a chlorine atom at sp^2 carbon, have never been explored for the coupling reaction with aryl boronic acids. Usually, phosphine or nitrogen ligands were used to improve the efficiency and to control selectivity of Suzuki coupling reactions, and much attention has been paid to design complicated ligands or palladium complexes [9]. Recently, Sarkar and co-workers described their work in the Suzuki reactions using Schiff bases as effective ligands [10]. *N*-Aryltrifluoroacetimidoyl chlorides [11], bearing Schiff base's structure moiety, are versatile intermediates in the synthesis of CF_3-containing compounds [12]. We envisioned whether they could be used as both ligand and reactant in Suzuki coupling reactions to provide *N*-aryl trifluoromethylarylketoimines which were key materials in our research. Herein, we wish to report a simple and efficient protocol for the synthesis of trifluoromethyl arylketoimines by palladium-catalyzed Suzuki coupling reactions of *N*-aryltrifluoroacetimidoyl chlorides with aryl boronic acids (Scheme 1).

* Corresponding author. Tel.: +86 577 8668 9615; fax: +86 577 8668 9615.
E-mail address: zxg@wzu.edu.cn (X.-G. Zhang).

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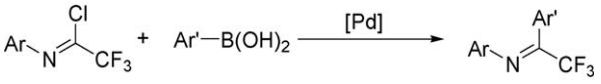
doi:10.1016/j.jfluchem.2010.04.011



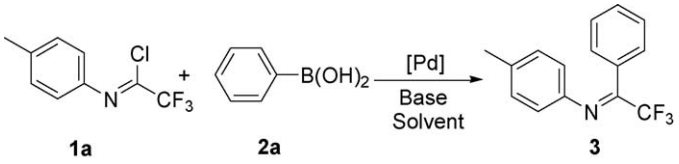
Scheme 1.

2. Results and discussion

The reaction between *N*-(4-tolyl)-2,2,2-trifluoroacetimidoyl chloride (**1a**) and phenyl boronic acid (**2a**) in toluene was selected as a model reaction to optimize the reaction conditions. As shown in Table 1, various palladium catalysts were firstly tested (entries 1–4). The results indicated that the coupling reaction could be catalyzed by either Pd(0) or Pd(II) catalyst, and $Pd(PPh_3)_4$ provided the highest yield of target product **3** (87% entry 4). Subsequently, a series of bases were investigated, the results suggested that bases have dramatic effects on the yields of cross-coupling product (entries 4–8). We were delighted to observe the reaction provided target product **3** in 97% yield in the presence of 3 equiv. of $K_3PO_4{\cdot}3H_2O$ (entry 8). During the examination of solvent (entries 9–11), some polar solvents (such as DMF, THF and dioxane) were found less effective than toluene. We also observed that the yields of product **3** decreased obviously when the amount of $Pd(PPh_3)_4$ reduced or reaction temperature decreased (entries 12 and 13).

With these promising results in hand, we decided to explore the scope of the Suzuki coupling reaction. As listed in Table 2, a series of *N*-aryltrifluoroacetimidoyl chlorides and aryl boronic acids were investigated under the optimized conditions. Initially, a series of aryl boronic acids bearing different substitutes were tested by their reaction with substrate **1a** or **1b** (entries 1–8). The results revealed that both electron-rich and electron-deficient phenyl boronic acids are suitable substrates for the coupling reaction and provided the corresponding trifluoromethyl arylketoimines in good to excellent yields (entries 1–4). The reactions between imidoyl chlorides and polycyclic or heterocyclic aryl boronic acids also proceeded smoothly to provide trifluoromethyl arylketoimines in moderate yields (entries 5–7). Naphthalen-1-yl boronic acid **2f** and furan-3-yl boronic acid 2 g, for instance, underwent the coupling reaction with substrate **1b** successfully to afford the corresponding ketoimines in 61% and 57% yields, respectively (entries 6 and 7). Subsequently, various *N*-aryltrifluoroacetimidoyl chlorides were evaluated by their reaction with phenyl boronic acid **2a** (entries 8–12). The results demonstrated that the reaction was well-tolerated to a range of imidoyl chlorides with different substitutes attaching to benzene ring, such as 4-methoxy, 4-chloro, 2-methyl and 2-nitro. In the further exploration of the scope of *N*-aryltrifluoroacetimidoyl chlorides and aryl boronic acids (entries 13–22), we found that the steric effect affected the reaction to some extent. For example, the reaction between *N*-(2-tol)trifluoroacetimidoyl chloride (**1f**) and 2-methoxyphenyl boronic acid (**2h**) provided desired product in a low yield (58%, entry 18). It is worth noting that the strong electron-withdrawing ability of trifluoromethyl group is essential to this Suzuki coupling reaction. Without the activation of C–Cl bond by trifluoromethyl, the coupling reaction did not work. For example, only trace amount of the desired product could be obtained when *N*-(4-tol)acetimidoyl chloride was treated with phenyl boronic acid (**2a**) under the standard conditions (entry 23).

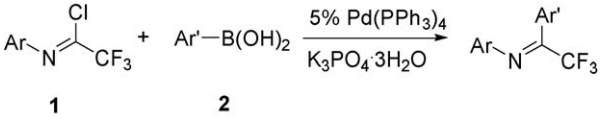
Table 1
Optimization of reaction conditions.[a]

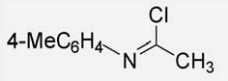


Entry	[Pd] (mol%)	Solvent	Base	*T* (°C)	Yield (%)[b]
1	$PdCl_2$ (5)	Toluene	Cs_2CO_3	100	59
2	$Pd(OAc)_2$ (5)	Toluene	Cs_2CO_3	100	73
3	$Pd_2(dba)_3$ (5)	Toluene	Cs_2CO_3	100	65
4	$Pd(PPh_3)_4$ (5)	Toluene	Cs_2CO_3	100	87
5	$Pd(PPh_3)_4$ (5)	Toluene	NaOH	100	84
6	$Pd(PPh_3)_4$ (5)	Toluene	Et_3N	100	37
7	$Pd(PPh_3)_4$ (5)	Toluene	K_2CO_3	100	79
8	$Pd(PPh_3)_4$ (5)	Toluene	$K_3PO_4{\cdot}3H_2O$	100	97
9	$Pd(PPh_3)_4$ (5)	1,4-dioxane	$K_3PO_4{\cdot}3H_2O$	100	45
10	$Pd(PPh_3)_4$ (5)	DMF	$K_3PO_4{\cdot}3H_2O$	100	8
11	$Pd(PPh_3)_4$ (5)	THF	$K_3PO_4{\cdot}3H_2O$	100	64
12	$Pd(PPh_3)_4$ (2)	Toluene	$K_3PO_4{\cdot}3H_2O$	100	85
13	$Pd(PPh_3)_4$ (5)	Toluene	$K_3PO_4{\cdot}3H_2O$	80	88

[a] *Reaction conditions*: **1a** (0.5 mmol), phenyl boronic (0.6 mmol), base (1.5 mmol), solvent (3 mL) at 100 °C for 8 h.
[b] Isolated yield.

Table 2
Palladium-catalyzed Suzuki coupling reaction.[a]



Entry	**1** Ar=	**2** Ar′=	Product	Yield (%)[b]
1	4-CH_3–C_6H_4 (**1a**)	4-Cl–C_6H_4 (**2b**)	**4**	91
2	4-CH_3–C_6H_4 (**1a**)	4-F–C_6H_4 (**2c**)	**5**	90
3	4-CH_3–C_6H_4 (**1a**)	3-NO_2–C_6H_4 (**2d**)	**6**	79
4	4-CH_3–C_6H_4 (**1a**)	4-CH_3O–C_6H_4 (**2e**)	**7**	81
5	4-CH_3–C_6H_4 (**1a**)	naphthalen-1-yl (**2f**)	**8**	65
6	4-CH_3O–C_6H_4 (**1b**)	naphthalen-1-yl (**2f**)	**9**	61
7	4-CH_3O–C_6H_4 (**1b**)	furan-3-yl (**2g**)	**10**	57
8	4-CH_3O–C_6H_4 (**1b**)	C_6H_5 (**2a**)	**11**	98
9	C_6H_5 (**1c**)	C_6H_5 (**2a**)	**12**	71
10	4-Cl–C_6H_4 (**1d**)	C_6H_5 (**2a**)	**13**	90
11	2-NO_2–C_6H_4 (**1e**)	C_6H_5 (**2a**)	**14**	75
12	2-CH_3–C_6H_4 (**1f**)	C_6H_5 (**2a**)	**15**	78
13	4-Cl–C_6H_4 (**1d**)	2-CH_3O–C_6H_4 (**2h**)	**16**	74
14	4-CH_3–C_6H_4 (**1a**)	2-CH_3O–C_6H_4 (**2h**)	**17**	71
15	4-CH_3O–C_6H_4 (**1b**)	3-NO_2–C_6H_4 (**2d**)	**18**	83
16	2-CH_3–C_6H_4 (**1f**)	4-CH_3O–C_6H_4 (**2e**)	**19**	73
17	2-NO_2–C_6H_4 (**1e**)	4-CH_3–C_6H_4 (**2i**)	**20**	61
18	2-CH_3–C_6H_4 (**1f**)	2-CH_3O–C_6H_4 (**2h**)	**21**	58
19	4-CH_3O–C_6H_4 (**1b**)	4-Cl–C_6H_4 (**2b**)	**22**	95
20	4-CH_3O–C_6H_4 (**1b**)	4-F–C_6H_4 (**2c**)	**23**	94
21	4-Cl–C_6H_4 (**1d**)	4-Cl–C_6H_4 (**2b**)	**24**	74
22	4-Cl–C_6H_4 (**1d**)	4-CH_3O–C_6H_4 (**2e**)	**25**	86
23		C_6H_5 (**2a**)		Trace

[a] *Reaction conditions*: **1** (0.5 mmol), **2** (0.6 mmol), $Pd(PPh_3)_4$ (5 mol%), $K_3PO_4{\cdot}3H_2O$ (1.5 mmol) in toluene (3 mL) at 100 °C for 8 h.
[b] Isolated yield.

3. Conclusion

In summary, we have developed a practical palladium-catalyzed coupling method for the synthesis of *N*-aryl trifluoromethylarylketoimines. In the presence of $Pd(PPh_3)_4$ and $K_3PO_4{\cdot}3H_2O$, a variety of *N*-aryltrifluoroacetimidoyl chlorides underwent the palladium-catalyzed Suzuki coupling reactions with various aryl boronic acids successfully to afford the corresponding *N*-aryl trifluoromethylarylketoimines in moderate to excellent yields. Work to extend the application of *N*-aryl trifluoromethylarylketoimines in organic

synthesis is currently underway. For example, these coupling products are being used in asymmetric reduction reaction to prepare CF_3-containing chiral secondary amines.

4. Experimental

Chemicals were either purchased or purified by standard techniques. ^1H NMR and ^{13}C NMR spectra were measured on a 300 or 500 MHz spectrometer (^1H: 300 MHz, ^{13}C: 75 or 125 MHz, ^{19}F: 282.2 MHz), using $CDCl_3$ as the solvent with tetramethylsilane (TMS) as an internal standard at room temperature. Chemical shifts are given in δ relative to TMS, the coupling constants J are given in Hz. All reactions under nitrogen atmosphere were conducted using standard Schlenk techniques. Column chromatography was performed using EM Silica gel 60 (300–400 mesh).

4.1. General procedure for synthesis of N-aryl trifluoromethylarylketoimines

A mixture of *N*-aryltrifluoroacetimidoyl chlorides (0.5 mmol), aryl boronic acids (0.6 mmol), $Pd(PPh_3)_4$ (2.9 mg, 0.025 mmol) and $K_3PO_4{\cdot}3H_2O$ (399 mg, 1.5 mmol) in 3 mL toluene was stirred at 100 °C for 8 h. The reaction was monitored by TLC and GC analysis. After the reaction was finished, the solvent was evaporated under reduced pressure. Purification of the residue and elution with 25:1 petroleum ether/ethyl acetate give the products 3–25.

4.1.1. 4-Methyl-N-(2,2,2-trifluoro-1-phenylethylidene)benzenamine 3

Pale yellow oil. IR (thin film): 3020, 1667, 1198, 1130, 970, 698 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 2.24 (s, 3H), 6.65 (d, J = 8.2 Hz, 2H), 6.98 (d, J = 8.2 Hz, 2H), 7.20–7.38 (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 20.9, 119.9 (J_{C-F} = 277.4 Hz), 121.0, 128.6, 129.4, 130.1, 130.3, 132.4, 135.3, 144.3, 156.4 (J_{C-F} = 33.4 Hz); ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.86; MS (ESI): m/z = 264 ($M+H^+$); HRMS (EI) calcd. for $C_{15}H_{12}F_3N^+$ (M^+) 263.0916, found 263.0919.

4.1.2. N-(1-(4-Chlorophenyl)-2,2,2-trifluoroethylidene)-4-methylbenzenamine 4

Pale yellow oil. IR (thin film): 3022, 1668, 1191, 1129, 1093, 968 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 2.27 (s, 3H), 6.65 (d, J = 8.2 Hz, 2H), 7.02 (d, J = 8.2 Hz, 2H), 7.17 (d, J = 8.4 Hz, 2H), 7.43 (d, J = 8.4 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 20.9, 119.8 (J_{C-F} = 277.4 Hz), 121.6, 127.0, 128.5, 129.3, 130.1, 134.2, 136.5, 144.1, 155.1 (J_{C-F} = 33.8 Hz); ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.87; MS (ESI): m/z = 298 ($M+H^+$); HRMS (EI) calcd. for $C_{15}H_{11}ClF_3N^+$ (M^+) 297.0527, found 297.0528.

4.1.3. 4-Methyl-N-(2,2,2-trifluoro-1-(4-fluorophenyl)ethylidene)benzenamine 5

Pale yellow oil. IR (thin film): 3017, 1670, 1192, 1128, 1058, 966 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 2.27 (s, 3H), 6.66 (d, J = 8.2 Hz, 2H), 6.98–7.03 (m, 4H), 7.20–7.26 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 20.8, 119.8 (J_{C-F} = 277.5 Hz), 120.8, 128.2, 129.0, 129.5, 130.9,131.0, 144.2, 155.3 (J_{C-F} = 33.8 Hz), 163.4 (J_{C-F} = 250.1 Hz); ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.89 (s, 3F), −109.05 (s, 1F); MS (ESI): m/z = 282 ($M+H^+$); HRMS (EI) calcd. for $C_{15}H_{11}F_4N^+$ (M^+) 281.0822, found 281.0826.

4.1.4. 4-Methyl-N-(2,2,2-trifluoro-1-(3-nitrophenyl)ethylidene)benzenamine 6

Pale yellow oil. IR (thin film): 3018, 1669, 1519, 1351, 1193, 1129, 968 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 2.25 (s, 3H), 6.62 (d, J = 8.2 Hz, 2H), 7.01 (d, J = 8.2 Hz, 2H), 7.52 (m, 2H), 8.12 (s, 1H), 8.21–8.25 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 20.8, 118.5 (J_{C-F} = 276.8 Hz), 120.5 120.7, 123.8, 129.7, 129.9, 131.8, 134.6, 136.2, 143.5, 148.1, 153.9 (J_{C-F} = 33.6 Hz); ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.92; MS (ESI): m/z = 309 ($M+H^+$); HRMS (EI) calcd. for $C_{15}H_{11}F_3N_2O_2^+$ (M^+) 308.0767, found 308.0768.

4.1.5. 4-Methyl-N-(2,2,2-trifluoro-1-(4-methoxyphenyl)ethylidene)benzenamine 7

Pale yellow oil. IR (thin film): 3017, 1663, 1251, 1213, 1188, 1128 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 2.27 (s, 3H), 3.78 (s, 3H), 6.68 (d, J = 8.2 Hz, 2H), 6.80 (d, J = 8.8 Hz, 2H), 7.02 (d, J = 8.2 Hz, 2H), 7.19 (d, J = 8.8 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 20.8, 55.2, 120.1 (J_{C-F} = 277.4 Hz), 120.7, 127.7, 128.7, 129.2, 130.5, 134.9, 144.9, 155.8 (J_{C-F} = 33.0 Hz), 160.8; ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.87; MS (ESI): m/z = 294 ($M+H^+$); HRMS (EI) calcd. for $C_{16}H_{14}F_3NO^+$ (M^+) 293.1022, found 293.1024.

4.1.6. 4-Methyl-N-(2,2,2-trifluoro-1-(naphthalen-1-yl)ethylidene)benzenamine 8

Pale yellow oil. IR (thin film): 1506, 1319, 1212, 1187, 1134, 777 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 2.08 (s, 3H), 6.68 (d, J = 8.2 Hz, 2H), 6.79 (d, J = 8.2 Hz, 2H), 7.42–7.45 (m, 4H), 7.60–7.62 (m, 1H), 7.71–7.87 (m. 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ: 20.8, 120.1 (J_{C-F} = 277.5 Hz), 120.8, 123.4, 124.7, 124.9, 126.5, 127.1, 127.2, 128.5, 129.1, 129.9, 130.4, 133.2, 135.9, 144.1, 156.5 (J_{C-F} = 33.8 Hz); ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.84; MS (ESI): m/z = 314 ($M+H^+$); HRMS (EI) calcd. for $C_{19}H_{14}F_3N^+$ (M^+) 313.1073, found 313.1076.

4.1.7. 4-Methoxy-N-(2,2,2-trifluoro-1-(naphthalen-1-yl)ethylidene)benzenamine 9

Pale yellow oil. IR (thin film): 1601, 1505, 1251, 1212, 1186, 1131, 778 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 2.58 (s, 3H), 6.52 (d, J = 6.8 Hz, 2H), 6.78 (d, J = 6.8 Hz, 2H), 7.42–7.47 (m, 4H), 7.58–7.61 (m, 1H), 7.80–7.90 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ: 55.1,113.7, 120.3 (J_{C-F} = 277.5 Hz), 123.7, 124.8, 125.0, 126.6, 127.1, 127.3, 128.6, 129.5, 129.8, 130.4, 133.3,139.3, 154.7 (J_{C-F} = 33.8 Hz), 158.3; ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.84; MS (ESI): m/z = 330 ($M+H^+$); HRMS (EI) calcd. for $C_{19}H_{14}F_3NO^+$ (M^+) 329.1022, found 329.1026.

4.1.8. 4-Methoxy-N-(2,2,2-trifluoro-1-(furan-3-yl)ethylidene)benzenamine 10

Pale yellow oil. IR (thin film): 1653, 1505, 1244, 1211, 1185, 1166, 1132, 740 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 3.82 (s, 3H), 5.97 (s, 1H), 6.77–6.81 (m, 2H), 6.87–6.92 (m, 2H), 7.26–7.27 (m, 1H), 7.56 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ: 55.4, 109.8, 113.9, 115.2, 119.9 (J_{C-F} = 276.3 Hz), 120.0, 141.6, 142.8, 146.3, 148.6 (J_{C-F} = 33.8), 157.4; ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.84; MS (ESI): m/z = 270 ($M+H^+$); HRMS (EI) calcd. for $C_{13}H_{10}F_3NO_2^+$ (M^+) 269.0658, found 269.0659.

4.1.9. 4-Methoxy-N-(2,2,2-trifluoro-1-phenylethylidene)benzenamine 11

Ref. [6a], Pale yellow oil. Yield IR (thin film): 1668, 1506, 1250, 1211, 1197,1129, 780 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 3.74 (s, 3H), 6.74–6.78 (m, 4H), 7.24–7.27 (m, 2H), 7.32–7.39 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 55.2, 118.2, 120.0 (J_{C-F} = 276.8 Hz), 133.3, 128.6, 130.1, 130.7, 138.1, 139.7, 155.4 (J_{C-F} = 33.0 Hz), 157.8; ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.86; MS (ESI): m/z = 280 ($M+H^+$).

4.1.10. N-(2,2,2-Trifluoro-1-phenylethylidene)benzenamine 12

Ref. [6a], Pale yellow oil. IR (thin film): 2916, 1669, 1196, 1133, 971, 698 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 6.73–6.76 (m, 2H), 7.02–7.06 (m, 1H), 7.17–7.22 (m, 3H), 7.25–7.35 (m, 4H); ^{13}C NMR (125 MHz, $CDCl_3$) δ:119.8 (J_{C-F} = 277.5 Hz), 120.5, 125.3, 128.5, 128.7, 128.8, 130.0, 130.2, 147.1, 157.0 (J_{C-F} = 33.8); ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.84; MS (ESI): m/z = 250 ($M+H^+$).

4.1.11. 4-Chloro-N-(2,2,2-trifluoro-1-phenylethylidene)benzenamine **13**

Ref. [6a], Pale yellow oil. IR (thin film): 3080. 1667, 1191, 1128, 1090, 768 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 6.67 (d, J = 8.4 Hz, 2H), 7.13–7.21 (m, 4H), 7.31–7.35 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 119.8 (J_{C-F} = 277.5 Hz), 122.1, 125.3, 128.7, 129.1, 130.2, 131.0, 137.1, 145.6, 157.7 (J_{C-F} = 33.9 Hz); ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.93; MS (ESI): m/z = 284 ($M+H^+$).

4.1.12. 2-Nitro-N-(2,2,2-trifluoro-1-phenylethylidene)benzenamine **14**

Ref. [13], Pale yellow oil. IR (thin film): 1670, 1521, 1352, 1194, 1129, 753 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 6.02 (d, J = 8.3 Hz, 1H), 7.16–7.22 (m, 1H), 7.35–7.45 (m, 6H), 8.08 (d, J = 8.3 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 119.3 (J_{C-F} = 278.9 Hz), 120.5, 125.0, 125.2, 128.1, 128.7, 129.4, 129.8, 130.1, 131.1, 143.1, 156.9 (J_{C-F} = 33.6 Hz); ^{19}F NMR (282.2 MHz, $CDCl_3$): δ: −69.95; MS (ESI): m/z = 295 ($M+H^+$).

4.1.13. 2-Methyl-N-(2,2,2-trifluoro-1-phenylethylidene)benzenamine **15**

Ref. [6a], Pale yellow oil. IR (thin film): 3032, 1666, 1197, 1128, 746 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 2.25 (s, 3H), 6.43 (d, J = 8.7 Hz, 1H), 6.97 (m, 2H), 7.15–7.17 (m, 1H), 7.22–7.36 (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 17.7, 118.5, 119.9 (J_{C-F} = 277.5 Hz), 125.1, 126.1, 127.2, 128.2, 128.5, 128.8, 130.3, 130.4, 146.1, 156.6 (J_{C-F} = 33.2 Hz); ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.82; MS (ESI): m/z = 264 ($M+H^+$).

4.1.14. 4-Chloro-N-(2,2,2-trifluoro-1-(2-methoxyphenyl)ethylidene)benzenamine **16**

IR (thin film): 1667, 1252, 1190, 1127, 1094, 1042, 748 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 3.60 (s, 3H), 6.67–6.70 (m, 2H), 6.78(d, J = 9.0 Hz, 1H), 6.86–6.91 (m, 1H), 7.08–7.12 (m, 3H), 7.28–7.31 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 55.3, 119.6 (J_{C-F} = 277.5 Hz), 120.6, 121.3, 128.5, 128.7, 129.2, 130.8, 132.0, 133.6, 146.2, 156.6, 156.8 (J_{C-F} = 34.8 Hz); ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.85. MS (ESI): m/z = 314 ($M+H^+$); HRMS (EI) calcd. for $C_{15}H_{11}ClF_3NO^+$ (M^+) 313.0476, found 313.0478.

4.1.15. 4-Methyl-N-(2,2,2-trifluoro-1-(2-methoxyphenyl)ethylidene)benzenamine **17**

Pale yellow solid IR (thin film): 3020, 1665, 1251, 1211, 1195, 1126,1043, 852 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 2.20 (s, 3H), 3.62 (s, 3H), 6.67 (d, J = 8.2 Hz, 2H), 6.90–6.95 (m, 2H), 7.08–7.10 (m, 1H), 7.28–7.32 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 20.9, 55.4, 119.8 (J_{C-F} = 277.4 Hz), 120.5, 128.5, 128.7, 129.0, 129.4, 129.9, 130.2, 135.2, 145.0, 155.6 (J_{C-F} = 34.5 Hz), 156.8; ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.83; MS (ESI): m/z = 294 ($M+H^+$); HRMS (EI) calcd. for $C_{16}H_{14}F_3NO^+$ (M^+) 293.1022, found 293.1024.

4.1.16. 4-Methoxy-N-(2,2,2-trifluoro-1-(3-nitrophenyl)ethylidene)benzenamine **18**

Pale yellow oil. 1670, 1521, 1352, 1252,1196, 1128, 1042, 873 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 3.75 (s, 3H), 6.70–6.75 (m, 4H), 7.52–7.55 (m, 2H), 8.23–8.27 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 55.3, 119.6 (J_{C-F} = 276.8 Hz), 123.2, 123.8, 125.0, 125.2, 130.0, 132.2, 134.6, 138.7, 148.3, 152.4 (J_{C-F} = 34.5 Hz), 158.3; ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.93; MS (ESI): m/z = 325 ($M+H^+$); HRMS (EI) calcd. for $C_{15}H_{11}F_3N_2O_3^+$ (M^+) 324.0716, found 324.0717.

4.1.17. 2-Methyl-N-(2,2,2-trifluoro-1-(4-methoxyphenyl)ethylidene)benzenamine **19**

Pale yellow oil. IR (thin film): 1664, 1250, 1211, 1196, 1127, 1041, 846 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 2.21 (s, 3H), 3.76 (s, 3H), 6.49 (m, 1H), 6.78 (d, J = 8.8 Hz, 2H), 7.00–7.02 (m, 2H), 7.16–7.21 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 17.6, 55.1, 118.4, 120.1 (J_{C-F} = 278.3 Hz), 122.0, 124.8, 126.2, 127.7, 128.0, 130.2, 130.5, 146.6, 156.0 (J_{C-F} = 33.0 Hz), 161.0; ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.85; MS (ESI): m/z = 294 ($M+H^+$); HRMS (EI) calcd. for $C_{16}H_{14}F_3NO^+$ (M^+) 293.1022, found 293.1024.

4.1.18. 2-Nitro-N-(2,2,2-trifluoro-1-p-tolylethylidene)benzenamine **20**

Pale yellow oil. IR (thin film): 3019, 1670, 1518, 1350, 1194, 1128, 763 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 2.22 (s, 3H), 6.61 (d, J = 8.9 Hz, 1H), 6.92–7.00 (m, 2H), 7.13–7.16 (m, 1H), 7.20–7.22 (m, 2H), 7.29–7.35 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 17.8, 118.5, 119.8 (J_{C-F} = 277.5 Hz), 125.1, 126.1, 128.2, 128.4, 128.5, 130.1, 130.3, 130.4, 146.1, 156.5 (J_{C-F} = 33.8 Hz); ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.92; MS (ESI): m/z = 309 ($M+H^+$); HRMS (EI) calcd. for $C_{15}H_{11}F_3N_2O_2^+$ (M^+) 308.0767, found 308.0768.

4.1.19. 2-Methyl-N-(2,2,2-trifluoro-1-(2-methoxyphenyl)ethylidene)benzenamine **21**

Pale yellow oil. IR (thin film): 3020, 1665, 1250, 1196, 1127,1042, 756 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 2.27 (s, 3H), 3.61 (s, 3H), 6.38 (d, J = 7.7 Hz, 1H), 6.77 (d, J = 8.3 Hz, 1H), 6.83–6.95 (m, 3H), 7.12 (m, 2H), 7.26–7.33 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 17.6, 55.2, 114.0 (J_{C-F} = 277.8 Hz), 117.4, 118.0, 119.9, 120.4, 125.2, 125.5, 129.0, 129.3, 130.0, 131.6, 146.5, 156.6 (J_{C-F} = 33.0 Hz), 164.5; ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.84; MS (ESI): m/z = 294 ($M+H^+$); HRMS (EI) calcd. for $C_{16}H_{14}F_3NO^+$ (M^+) 293.1022, found 293.1024.

4.1.20. N-(1-(4-Chlorophenyl)-2,2,2-trifluoroethylidene)-4-methoxybenzenamine **22**

Ref. [14], Pale yellow oil. IR (thin film): 3079. 1665, 1250, 1192, 1128, 1093, 1042, 848 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 3.76 (s, 3H), 6.75–6.79 (m, 4H), 7.19 (d, J = 8.4 Hz, 2H), 7.32–7.34 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 55.3, 119.9 (J_{C-F} = 277.1 Hz), 123.2, 128.9, 129.3, 129.6, 130.1, 136.4, 139.4, 153.9 (J_{C-F} = 33.2 Hz), 158.0; ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.90; MS (ESI): m/z = 314 ($M+H^+$).

4.1.21. 4-Methoxy-N-(2,2,2-trifluoro-1-(4-fluorophenyl)ethylidene)benzenamine **23**

Pale yellow oil. IR (thin film): 1669, 1253,1194, 1128, 1042, 846 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 3.74 (s, 3H), 6.74–6.77 (m, 4H), 7.00–7.05 (m, 2H), 7.22–7.26 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 55.2, 119.9 (J_{C-F} = 277.5 Hz), 123.2, 126.5, 130.8, 131.0, 133.0, 139.5, 154.3, (J_{C-F} = 33.8 Hz), 155.0, 163.4 (J_{C-F} = 250.5 Hz); ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.91(s, 3F), −109.04 (s, 1F); MS (ESI): m/z = 298 ($M+H^+$); HRMS (EI) calcd. for $C_{15}H_{11}F_4NO^+$ (M^+) 297.0771, found 297.0774.

4.1.22. 4-Chloro-N-(1-(4-chlorophenyl)-2,2,2-trifluoroethylidene)benzenamine **24**

Pale yellow oil. IR (thin film): 3081, 1668, 1193, 1128, 1092, 848 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 6.67–6.71 (m, 2H), 7.14–7.22 (m, 4H), 7.29–7.34 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ: 119.6 (J_{C-F} = 277.7 Hz), 121.9, 125.1, 128.7, 129.2, 130.0, 131.3, 136.9, 145.2, 156.4 (J_{C-F} = 34.2 Hz); ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.93; MS (ESI): m/z = 318 ($M+H^+$); HRMS (EI) calcd. for $C_{14}H_8ClF_3N^+$ (M^+) 316.9980, found 316.9982.

4.1.23. 4-Chloro-N-(2,2,2-trifluoro-1-(4-methoxyphenyl)ethylidene)benzenamine **25**

Pale yellow solid. IR (thin film): 3080, 1666, 1251, 1189, 1128, 1093, 1042, 846 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ: 3.80 (s, 3H), 6.67 (d, J = 8.6 Hz, 2H), 6.78 (d, J = 8.6 Hz, 2H), 7.12–7.18 (m, 4H);

^{13}C NMR (75 MHz, $CDCl_3$) δ: 55.2, 119.9 (J_{C-F} = 277.5 Hz), 121.9, 127.7, 129.1, 130.5, 130.6, 133.4, 146.0, 157.3 (J_{C-F} = 33.5 Hz), 161.1; ^{19}F NMR (282.2 MHz, $CDCl_3$) δ: −69.88; MS (ESI): m/z = 314 ($M+H^+$); HRMS (EI) calcd. for $C_{15}H_{11}ClF_3NO^+$ (M^+) 313.0476, found 313.0478.

Acknowledgments

We thank the National Natural Science Foundation of China (No. 20872112) and Zhejiang Provincial Natural Science Foundation of China (Nos. Y407116 and Y4080169) for financial support.

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