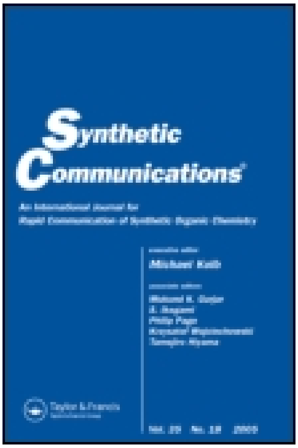

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Weike Su [a] & Can Jin [a]

[a] College of Pharmaceutical Sciences, Zhejiang University of Technology, Hangzhou, 310014, P.R. China

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Ytterbium Triflate Catalyzed Friedel–Crafts Reaction: Facile Synthesis of Diaryl Ketones

Weike Su* and **Can Jin**

College of Pharmaceutical Sciences, Zhejiang University of Technology,
Hangzhou, P.R. China

ABSTRACT

Friedel–Crafts reaction of aromatic compounds (benzenes, thiophene, furan, pyrrole, naphthalene, and benzothiophene) with *bis*(trichloromethyl) carbonate [BTC] was efficiently catalyzed by ytterbium triflate [$Yb(OTf)_3$] to give diaryl ketones with moderate to good yields.

Key Words: Friedel–Crafts reaction; Ytterbium triflate; *Bis*(trichloromethyl) carbonate; diaryl ketones.

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*Correspondence: Weike Su, College of Pharmaceutical Sciences, Zhejiang University of Technology, Hangzhou 310014, P.R. China; Fax: (0086)57188320752; E-mail: suweike@zjut.edu.cn.

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INTRODUCTION

Aromatic ketones play very important roles in organic chemistry. The usual method for preparation of these compounds are well known and are named Friedel–Crafts reaction[1] in the presence of anhydrous $AlCl_3$. This method, which uses a stoichiometric or even excess amounts of conventional Lewis acids, suffers from severe corrosion, waste, and safety problems. In recent decades, as the consciousness of protecting the environment has been strengthened in people, methods that are cheap or environmentally friendly are always advocated. Thus, Lanthanide triflates [$Ln(OTf)_3$], especially $Yb(OTf)_3$, as a new versatile Lewis acid have been widely used in organic chemistry. The stability of $Yb(OTf)_3$ in water and ease of recovery allows its reuse and promotes its environmental benefits.[2] However, this method can only obtain simple aromatic ketones. Substituted diaryl ketones are difficult to prepare by Friedel–Crafts acylation of aromatic compounds with aroyl chlorides, because the substituted aroyl chloride is not always available (such as thiophene-2-carbonyl chloride, *N*-methylpyrrole-2-carbonyl chloride, naphthalene-1-carbonyl chloride).

Also, benzophenones are prepared by decarboxylation of *o*-benzoylbenzoic acid in the presence of copper catalyst.[3] Aromatic ketones are also available from organometallic compounds,[4] etc.[5] However, these methods are limited by low yields, complex products, and extravagant cost. Thus, a simple, efficient approach toward preparation of diaryl ketones is desirable.

BTC was widely used instead of phosgene[6] in synthetic chemistry. These methods avoided toxic phosgene processes. Recently, Peng et al. reported a Friedel–Crafts reaction of benzenes with BTC using $AlCl_3$, $FeCl_3$, $ZnCl_2$ to form benzophenones with good yields.[7] However, the stoichiometric or even excess amounts of catalysts were involved.

Here we report that $Yb(OTf)_3$ is a useful catalyst for Friedel–Crafts reaction of aromatics with BTC without stoichiometric additive (Scheme 1).

$$\underset{\mathbf{1}}{2\,\mathrm{ArH}} + \underset{\mathbf{2}}{1/3\,\mathrm{Cl_3COCOOCCl_3}} \xrightarrow[\text{r.t - 80°C/5h}]{\mathrm{Yb(OTf)_3}} \underset{\substack{\mathbf{3}\\ 40\%\text{-}86\%}}{\mathrm{ArCOAr}}$$

Scheme 1.

RESULTS AND DISCUSSION

In our experiment, the Friedel–Crafts reactions of aromatic compounds with BTC proceeded smoothly in the presence of a catalytic amount of $Yb(OTf)_3$, and the results are summarized in Table 1.

When $Yb(OTf)_3$ was used as the catalyst, the corresponding products **(3)** are prepared in moderate to good yields. The liquid substrates are also used as the solvents in the reactions (entries 1, 4, 5, 7, 8, 9). We also use dichloromethane and chloroform as the solvent, but lower yields are obtained. For example, when the substrate is benzene (**1a**) only afford 50% and 55% yield of benzophenone (**3a**), respectively, in dichloromethane and chloroform at refluxing for 8 h (entry 2). Only 15% yield of the desired product (**3a**) is detected at room temperature for 24 h (entry 1). So, the temperature obviously affects the yields.

1-H Pyrrole is unsuitable for this reaction because of the direct acylation on the nitro atom to form amide. It is interesting that when the *N*-methyl pyrrole (**1g**) is the substrate, high yield (86%) of *bis*-(1-methyl-1H-pyrrole-2-yl)-methanone (**3g**) is obtained after 5 h at 80°C. Thiophene (**1e**) and furan (**1f**) were excellent substrates in the same condition.

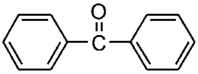
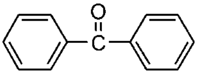
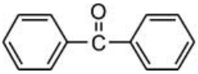
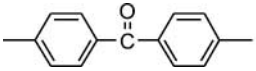
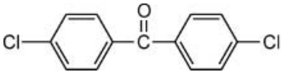
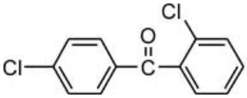
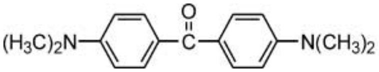
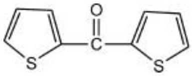
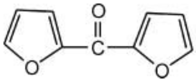
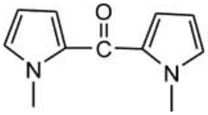
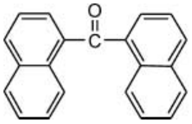
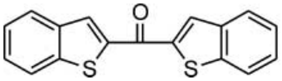
The products of toluene (**1b**) are complex. Another two isomers (di-*o*-tolyl-methanone and *o*-tolyl-*p*-tolyl-methanone) are detected in the mixture, and the ratio is 1 : 4.35 [determined by high-performance liquid chromatography (HPLC)]. But, mostly the product is **3b** with isolated yield 60%. The condition of chlorobenzene was similar to that of toluene but more complex. When benzothiophene (**1i**) was the substrate, another product [*bis*(benzothioph-3-yl)methanone] is isolated with 8% yield. However, *N*,*N*-dimethyl benzene (**1d**), thiophenes (**1e**), furan (**1f**), pyrrole (**1g**), or naphthalene (**1h**) only afford one product.

In addition, it was noteworthy that when furan and thiophene were used for preparation of ketones in the presence of $AlCl_3$ according to Ref.,[7] we got very complex products, and the majority was the ring-opening products.

Thus, $Yb(OTf)_3$ is active for the preparation of diaryl ketones via Friedel–Crafts reaction. The most important characteristic is that a catalytic amount of ytterbium triflate was enough and was effective for the reaction.

To summarize, in contrast to a vast majority of other approaches, this work involves the use of common reagents and a simple operation. Other advantages of this method are its good yields, ease of handing of reagents, mild conditions, and the possibility of working on large scales. The present work gives a facile and efficient way to prepare diaryl ketones.

Table 1. Yb(OTf)$_3$ (5% mol, based on BTC) catalyzed Friedel–Crafts reactions of aromatic compounds with BTC.

Entry	ArH	Product	Yield[a] %
1	C_6H_6 (**1a**)	 **3a**	68 (15)[b]
2	C_6H_6 (**1a**)	 **3a**	50[e] (55)[f]
3	C_6H_6 (**1a**)	 **3a**	71[g]
4	C_7H_8 (**1b**)	 **3b**	60
5	C_6H_5Cl (**1c**)	 **3c**  **3′c**	40[c]
6	$(CH_3)_2NC_6H_5$ (**1d**)	 **3d**	58[d]
7	C_4H_4S (**1e**)	 **3e**	77
8	C_4H_4O (**1f**)	 **3f**	76
9	N-$CH_3C_4H_4N$ (**1g**)	 **3g**	86[f]
10	$C_{10}H_8$ (**1h**)	 **3h**	57[d]
11	C_8H_6S (**1i**)	 **3i**	70

[a] Based on 1/3 BTC.

[b] At r.t for 24 h.

[c] Total yield of **3c** and **3′c**.

[d] Refluxing in chloroform for 8 h; the yield was based on aromatics.

[e] Dichloromethane is used as the solvent; the yield was based on benzene.

[f] Chloroform is used as the solvent; the yield was based on aromatics.

[g] 50% mol (based on BTC) of Yb(OTf)$_3$ was used.

EXPERIMENTAL

^{1}H NMR and ^{13}C NMR spectra were recorded on a Varian-400 MHz instrument using $CDCl_3$ as the solvent. Infrared (IR) spectra were recorded on a AVATAR-370 infrared spectrophotometer. Melting points were determined on a digital melting point apparatus WRS-1B and were uncorrected. Ytterbium triflate was prepared according to the literature.[8]

General Experimental Procedure

Preparation of Benzophenone Using $Yb(OTf)_3$

To a solution of benzene (2 mL) containing *bis*(trichloromethyl) carbonate [BTC] (2 mmol, 0.594 g), then $Yb(OTf)_3$ (0.1 mmol, 0.062 g) was added at room temperature. The mixture was stired for 1 h at room temperature, and it was allowed slowly to reach 80°C. After 5 h at 80°C, when the mixture turned dark red, the solvent was distilled off, then the residue was treated with 5 mL water and 5 mL saturated $NaHCO_3$ solution, subsequently. The corresponding product **3a** was obtained by TLC in 68% (0.74 g) yield. Mp: 46.5°C (Lit.[7] 47–48°C); ^{1}H NMR δ (ppm): 7.83 (*d*, $J = 8.0$ Hz, 4H, ArH), 7.60 (*t*, $J = 7.4$ Hz, 2H, ArH), 7.50 (*t*, $J = 7.8$ Hz, 4H, ArH); IR (cm^{-1}): 3032, 1668 (CO).

Preparation of Di(naphthalen-1-yl)methanone Using $Yb(OTf)_3$ in $CHCl_3$

To a solution of chloroform (5 mL) containing *bis*(trichloromethyl) carbonate [BTC] (2 mmol, 0.594 g) and naphthalene (12 mmol, 1.54 g), then $Yb(OTf)_3$ (0.1 mmol, 0.06 g) was added at room temperature. The mixture was stired for 1 h at room temperature, and it was allowed slowly to reflux. After 5 h, when the mixture turned dark red, the solvent was distilled off, and the residue was treated with 5 mL water and 5 mL saturated $NaHCO_3$ solution, subsequently. The corresponding product 3 h was obtained by TLC in 52% (0.88 g) yield. Mp: 100°C (Lit.[4b] 100–101°C); ^{1}H NMR δ (ppm): 8.53–8.58 (m, 2H, ArH), 8.00–8.03 (m, 2H, ArH), 7.92–7.96 (m, 2H, ArH), 7.51–7.62 (m, 6H, ArH), 7.39–7.44 (m, 2H, ArH); ^{13}C NMR (100 MHz): 199.1, 137.1, 133.8, 133.1, 131.2, 130.5, 128.5, 127.8, 126.6, 125.8, 124.4; IR (cm^{-1}): 1645 (CO).

Other Reactions Were Performed as Above and the Data Were Followed

4,4′-Dimethylbenzophenone (**3b**): Mp: 90.5–92°C (Lit.[7] 94–95°C); ^{1}H NMR δ (ppm): 7.72 (*dd*, $J = 8.4$ Hz, $J = 1.8$ Hz, 4H, ArH), 7.24

(*dd*, $J = 8.4$ Hz, $J = 1.8$ Hz, 4H, ArH), 2.38 (s, 6H, CH_3); IR (cm^{-1}): 3034, 1647 (CO).

4,4′-Dichlorobenzophenone (**3c**): Mp: 144.8–145.5°C (Lit.[7] 145–147°C); ^{1}H NMR δ (ppm): 7.48 (*d*, $J = 8.3$, 1.2 Hz, 4H, ArH), 7.69 (*d*, $J = 8.3$, 1.2 Hz, 4H, ArH); IR (cm^{-1}): 3022, 1665 (CO).

4,4′-*Bis*(dimethylamino)benzophenone (Michlers ketone) (**3d**): Mp: 177.5°C (Lit.[7] 175–177°C); ^{1}H NMR δ (ppm): 7.75 (*d*, $J = 8.2$ Hz, 4H, ArH), 6.68 (*d*, $J = 8.2$ Hz, 4H, ArH), 3.04 (*s*, 12H, CH_3); IR (cm^{-1}): 3033, 1615 (CO).

Di(thiophen-2-yl)methanone (**3e**): Mp: 85–86°C (Lit.[4f] 86–88°C); ^{1}H NMR δ (ppm): 7.11 (*dd*, $J = 5.0$, 4.0 Hz, 2H, ArH), 7.61 (*dd*, $J = 5.0$, 1.0 Hz, 2H, ArH), 7.74 (*dd*, $J = 4.0$, 1.0 Hz, 2H, ArH); IR (cm^{-1}): 1658 (CO).

Di(furan-2-yl)methanone (**3f**): Mp: 30.5°C (Lit.[4f] 30–32°C); ^{1}H NMR δ (ppm): 7.54 (*dd*, $J = 1.7$, 0.8 Hz, 1H, ArH), 7.25 (*dd*, $J = 3.7$, 0.8 Hz, 1H, ArH), 6.58 (*ddd*, $J = 3.7$, 1.7, 0.8 Hz, 1H, ArH); IR (cm^{-1}): 1645 (CO).

Bis(*N*-methyl-1H-pyrrol-2-yl)methanone (**3g**): Mp: 23°C (Lit.[4f] 24–26°C); ^{1}H NMR δ (ppm): 6.95–6.98 (m, 2H, ArH), 6.78–6.81 (m, 2H, ArH), 6.11–6.15 (*m*, 2H, ArH), 3.94 (*s*, 6H, CH_3); IR (cm^{-1}): 1641 (CO).

Bis(benzothiophen-2-yl)methanone (**3i**): Mp: 165.5°C (Lit.[4f] 167–169°C); ^{1}H NMR δ (ppm): 8.01 (*s*, 2H, ArH), 7.05–7.86 (*m*, 8H, ArH); ^{13}C NMR (100 MHz): 176.1, 151.8, 148.1, 143.6, 140.8, 134.1, 123.8, 122.9, 122.6; IR (cm^{-1}): 1639 (CO).

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