A Metal-free Synthesis of Diaryl-1,2-diketones by C–C Triple Bond Cleavage of Alkynones

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Experimental Section

All chemicals were obtained from commercial sources and used without further purification. DMSO was dried by CaH₂. Silica gel was purchased from Qing Dao Hai Yang Chemical Industry Co. All melting points were determined on a Beijing Science Instrument Dianguang Instrument Factory XT4B melting point apparatus and uncorrected. ¹H and ¹³C NMR spectra were measured on a 400 MHz Bruker spectrometer (¹H 400 MHz, ¹³C 100 MHz), using CDCl₃ as the solvent with tetramethylsilane (TMS) as the internal standard at room temperature. HRMSESI spectra were obtained on Agilent 6450 spectrometer. IR data were recorded on a Nicolet IS10 spectrometer. The products listed below were determined by ¹H, ¹³C NMR. PE is petroleum ether (60-90 °C).

General Procedure for the Preparation of alkynones:

\[
\text{Cl} - R^1 \xrightarrow{\text{PdCl}_2(\text{PPh}_3)_2, \text{CuI}, \text{Et}_3\text{N}, \text{THF}, \text{rt}} \rightleftharpoons R^2 \quad \text{O} \quad \text{R}^1 \text{Cl} + \text{R}^2 \quad \text{O} \quad \text{R}^2
\]

To a solution of the acyl chloride (1.0 mmol) and terminal alkyne (1.1 mmol) in anhydrous THF (5 mL) under N₂ protection, was added PdCl₂(PPh₃)₂ (14 mg, 2 mol %) and CuI (7.6 mg, 4 mol %). After stirring for 1 min, Et₃N (1.5 mmol) was added and the mixture was stirred for 15 h at r.t. When the reaction was complete (Monitored by TLC), distilled H₂O was added. The mixture was extracted with CH₂Cl₂. The organic phase was collected, dried (Na₂SO₄), and concentrated. The residue was purified by column chromatography [silica gel, PE/EtOAc (50:1)].

General Procedure for the Synthesis of Diaryl-1,2-diketones 2a-2p:

A mixture of alkynones (0.5 mmol), K₂CO₃ (0.5 mmol) and H₂O/DMSO (40 µl : 2 ml) was stirred at 90 °C for 8h under oxygen atmosphere. After cooling to room temperature, water was added (5 mL). Then the aqueous solution was extracted with ethyl acetate (5 ml × 3). The organic phase was dried over anhydrous Na₂SO₄ and concentrated. The residue was purified by column chromatography [eluent: PE/EtOAc (50:1)] on silica gel to provide the desired product.

benzil (2a)

Yellow solid; ¹H NMR (400 MHz, CDCl₃): δ ppm 8.0 (d, J = 7.4 Hz, 4H), 7.66 (t, J = 7.1 Hz, 2H), 7.51 (t, J = 7.2 Hz, 4H); ¹³C NMR (100 MHz, CDCl₃): δ ppm 194.5, 134.9, 133.0, 129.9, 129.0.
1-(4-methoxyphenyl)-2-phenylethane-1,2-dione (2b)

Yellow solid; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ ppm 7.97-7.93 (m, 4H), 7.63 (t, $J = 7.6$ Hz, 1H), 7.49 (t, $J = 7.8$ Hz, 2H), 6.97 (d, $J = 8.8$ Hz, 2H), 3.86 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ ppm 194.8, 193.1, 165.0, 134.6, 133.1, 132.2, 129.8, 128.9, 126.0, 114.3, 55.6.

1-phenyl-2-(p-tolyl)ethane-1,2-dione (2c)

Yellow oil; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ ppm 7.95 (d, $J = 7.1$ Hz, 2H), 7.87 (d, $J = 8.1$ Hz, 2H), 7.63 (t, $J = 7.4$ Hz, 1H), 7.48 (t, $J = 7.7$ Hz, 2H), 7.29 (d, $J = 8.0$ Hz, 2H), 2.41 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ ppm 194.7, 194.2, 146.1, 134.7, 133.0, 130.5, 129.9, 129.8, 129.7, 128.9, 21.8.

1-(4-(tert-butyl)phenyl)-2-phenylethane-1,2-dione (2d)

Yellow oil; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ ppm 7.98-7.96 (m, 2H), 7.91 (d, $J = 8.6$ Hz, 2H), 7.66-7.62 (m, 1H), 7.53-7.48 (m, 4H), 1.34 (s, 9H); $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ ppm 194.7, 194.3, 159.0, 134.7, 133.1, 130.5, 129.9, 128.9, 126.0, 125.4, 35.4, 30.9.

1-(4-chlorophenyl)-2-phenylethane-1,2-dione (2e)

Yellow solid; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ ppm 7.97-7.91 (m, 4H), 7.67 (t, $J = 18.3$ Hz, 1H), 7.54-7.48 (m, 4H); $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ ppm 193.8, 193.0, 141.6,
135.0, 132.8, 131.4, 131.2, 129.9, 129.4, 129.1.

1-(4-fluorophenyl)-2-phenylethane-1,2-dione (2f)

Light yellow solid; $^{1}$H NMR (400 MHz, CDCl$_3$): $\delta$ ppm 8.04-7.96 (m, 4H), 7.67 (t, $J$ = 7.2 Hz, 1H), 7.52 (t, $J$ = 7.6 Hz, 2H), 7.19 (t, $J$ = 8.8 Hz, 2H); $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ ppm 194.0, 192.7, 168.0 ($J_{C,F}$ = 256.6 Hz), 135.0, 132.8, 132.7 ($J_{C,F}$ = 9.7 Hz), 129.9, 129.0, 116.5, 116.3.

1,2-bis(4-methoxyphenyl)ethane-1,2-dione (2g)

Yellow solid; $^{1}$H NMR (400 MHz, CDCl$_3$): $\delta$ ppm 7.94 (d, $J$ = 9.0 Hz, 4H), 6.97 (d, $J$ = 8.9 Hz, 4H), 3.88 (s, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ ppm 193.5, 164.8, 132.4, 126.3, 114.3, 55.6.

1,2-di-p-tolylethane-1,2-dione (2h)

Yellow solid; $^{1}$H NMR (400 MHz, CDCl$_3$): $\delta$ ppm 7.86 (d, $J$ = 8.2 Hz, 4H), 7.30 (d, $J$ = 7.9 Hz, 4H), 2.43 (s, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ ppm 194.5, 146.0, 130.7, 130.0, 129.7, 21.9.

1-(4-( tert-butyl)phenyl)-2-(4-methoxyphenyl)ethane-1,2-dione (2i)

Yellow solid; $^{1}$H NMR (400 MHz, CDCl$_3$): $\delta$ ppm 7.92 (m, 4H), 7.51 (d, $J$ = 8.4 Hz, 2H), 7.0 (d, $J$ = 8.8 Hz, 2H), 3.87 (s, 3H), 1.34 (s, 9H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ ppm 194.5, 193.4, 164.9, 158.8, 132.3, 130.6, 129.8, 126.2, 125.9, 114.3, 55.6, 35.3.
1-(4-fluorophenyl)-2-(4-methoxyphenyl)ethane-1,2-dione (2j)

Yellow solid; $^1$H NMR (400 MHz, CDCl$_3$): δ ppm 8.03-8.00 (m, 2H), 7.95 (d, $J = 8.8$ Hz, 2H), 7.18 (t, $J = 8.6$ Hz, 2H), 6.98 (d, $J = 8.8$ Hz, 2H), 3.89 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$): δ ppm 193.0, 192.6, 168.0, 165.2 (d, $J_{C,F} = 30.7$ Hz), 132.7 (d, $J_{C,F} = 9.7$ Hz), 132.4, 129.7, 126.0, 116.3 (d, $J_{C,F} = 22.1$ Hz), 114.4, 55.7.

1,2-bis(4-fluorophenyl)ethane-1,2-dione (2k)

Yellow solid; $^1$H NMR (400 MHz, CDCl$_3$): δ ppm 8.02 (m, $J = 7.0$ Hz, 4H), 7.20 (m, $J = 8.5$ Hz, 4H); $^{13}$C NMR (100 MHz, CDCl$_3$): δ ppm 192.2, 168.1 (d, $J_{C,F} = 256.9$ Hz), 132.8 (d, $J_{C,F} = 9.8$ Hz), 129.4, 116.5 (d, $J_{C,F} = 22.1$ Hz).

1-(2-methoxyphenyl)-2-phenylethane-1,2-dione (2l)

Yellow solid; $^1$H NMR (400 MHz, CDCl$_3$): δ ppm 8.00 (m, 1H), 7.89 (m, 2H), 7.53-7.46 (m, 3H), 7.35 (d, $J = 7.6$ Hz, 1H), 7.27 (m, 1H), 2.70 (s, 3H); $^{13}$C NMR

1-phenyl-2-((o-tolyl)ethane-1,2-dione (2m)

Light yellow solid; $^1$H NMR (400 MHz, CDCl$_3$): δ ppm 7.98 (m, 2H), 7.65 (m, 2H), 7.53-7.46 (m, 3H), 7.35 (d, $J = 7.6$ Hz, 1H), 7.27 (m, 1H), 2.70 (s, 3H); $^{13}$C NMR
1-(2-fluorophenyl)-2-phenylethane-1,2-dione(2n)

Yellow solid; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ ppm 8.07-8.04 (m, 1H), 7.98-7.96 (m, 2H), 7.68-7.61 (m, 2H), 7.54-7.50 (m, 2H), 7.36-7.32 (m, 1H), 7.15-7.10 (m, 1H); $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ ppm 193.0, 191.9, 164.1 (d, $J_{C,F}$ = 256.6 Hz), 136.8 (d, $J_{C,F}$ = 9.1 Hz), 134.7, 132.0, 130.8, 129.8, 129.0, 125.0 (d, $J_{C,F}$ = 3.3 Hz), 122.4 (d, $J_{C,F}$ = 11.1 Hz), 116.6 (d, $J_{C,F}$ = 21.4 Hz).

1-(naphthalen-2-yl)-2-phenylethane-1,2-dione(2o)

Light yellow solid; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ ppm 8.42 (s, 1H), 8.11-8.09 (m, 1H), 8.03 (m, 2H), 7.97 (d, $J = 8.7$ Hz, 1H), 7.91 (t, $J = 7.2$ Hz, 2H), 7.69-7.63 (m, 2H), 7.58-7.51 (m, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ ppm 194.6, 136.4, 134.9, 133.5, 133.1, 132.3, 130.3, 130.0, 129.9, 129.5, 129.2, 129.0, 127.9, 127.2, 123.6.

1-phenyl-2-(thiophen-2-yl)ethane-1,2-dione(2p)

Yellow solid; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ ppm 8.0 (d, $J = 7.6$ Hz, 2H), 7.85-7.81 (m, 2H), 7.66 (t, $J = 7.7$ Hz, 1H); 7.52 (m, 2H), 7.19 (m, 1H); $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ ppm 192.1, 185.6, 139.9, 136.8, 136.7, 134.8, 132.7, 130.2, 128.9, 128.8.
$^{1}H$ NMR spectrum of 2a

$^{13}C$ NMR spectrum of 2a
$^1$H NMR spectrum of 2b

$^{13}$C NMR spectrum of 2b
$^1$H NMR spectrum of 2c

$^{13}$C NMR spectrum of 2c
$^1$H NMR spectrum of 2d

$^{13}$C NMR spectrum of 2d
$^{1}H$ NMR spectrum of 2e

$^{13}C$ NMR spectrum of 2e
$^{1}H$ NMR spectrum of 2f

$^{13}C$ NMR spectrum of 2f
$\text{MeO}^-$

$\text{O}$

$\text{O}$

$\text{OMe}$

$^1\text{H}$ NMR spectrum of $2g$

$^{13}\text{C}$ NMR spectrum of $2g$
$^1$H NMR spectrum of 2h

$^{13}$C NMR spectrum of 2h
$^{1}H$ NMR spectrum of 2i

$^{13}C$ NMR spectrum of 2i
$\text{H NMR spectrum of } 2j$

$\text{^{13}C NMR spectrum of } 2j$
$^1$H NMR spectrum of 2k

$^{13}$C NMR spectrum of 2k
$^1$H NMR spectrum of 2l

$^{13}$C NMR spectrum of 2l
$^{1}H$ NMR spectrum of 2m

$^{13}C$ NMR spectrum of 2m
$^1$H NMR spectrum of 2n

$^{13}$C NMR spectrum of 2n
$^1$H NMR spectrum of 2o

$^{13}$C NMR spectrum of 2o
$^1$H NMR spectrum of $2p$

$^{13}$C NMR spectrum of $2p$
The controlled experiment was conducted involving \( \text{H}_2\text{O}^{18} \), and \( \text{C}_{16}\text{H}_{14}\text{O}_4^{18}\text{O} \) was not observed. HRMS m/z (ESI) calcd for \( \text{C}_{16}\text{H}_{14}\text{O}_4 \text{(M + Na)}^+ \) 293.0790, found 293.0787.

The controlled experiment was conducted involving \( \text{O}_2^{18} \), and HRMS m/z (ESI) calcd for \( \text{C}_{16}\text{H}_{14}\text{O}_3^{18}\text{O} \text{(M + Na)}^+ \) 295.0832, found 295.0830; HRMS m/z (ESI) calcd for \( \text{C}_{16}\text{H}_{14}\text{O}_2^{18}\text{O}_2 \text{(M + Na)}^+ \) 297.0875, found 297.0872.