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Microwave-assisted efficient oxidation of internal alkynes to 1,2-diaryldiketones with DMSO/I_2

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Abstract. This paper reports the oxidation of functionalized internal alkynes with DMSO in the presence of I_2 under microwave irradiation. This procedure gave 1,2-diaryldiketones in good yields.

Keywords. Oxidation; internal alkynes; microwave irradiation; *a*-diketones.

1. Introduction

The study of oxidation of internal alkynes to *a*-diketones has been an important topic in organic chemistry because *a*-diketones can serve as useful inhibitors of acid corrosion of mild steel,[1] photosensitive agents in photocurable coatings[2] as well as natural compounds.[3] Moreover, *a*-diketones are versatile intermediates in a variety of chemical transformations,[4] especially for the synthesis of biologically active heterocyclic compounds.[5] Katritzky *et al.* and other groups have described several approaches[6] to prepare the *a*-diketones. The most straightforward method to synthesize the *a*-diketones is the oxidation of properly substituted diarylalkynes, which are easily accessible via Sonogashira coupling.[7] DMSO as an oxidant to transform diphenyl acetylene into *a*-diketones has been reported, such as oxidating of alkynes with DMSO/NBS,[8] DMSO/$PdCl_2$,[9] and DMSO/CH_3SO_3H/HCO_2H/HBr.[10] However, these methods have several drawbacks in terms of difficult reaction conditions, long reaction time and low yield. Microwave (MW)-promoted reactions are well known and can be utilized as an alternative energy source for organic reactions ordinarily accomplished by heating. Microwave irradiation increases the reaction rate many fold when compared with conventional reaction conditions. It is also known to accelerate diverse types of organic reactions and it is established as an important technique in organic synthesis. Several reports are available on versatile reactions carried out under microwave irradiation. For example, a recent work concerning the oxidation of alkynes into *a*-diketones with DMSO/$FeBr_3$ under microwave,[11] and this prompted us to report the results of our study. Filimonov *et al*[12] first reported to transform diarylalkynes into 1,2-diphenyl-ethane-1,2-dione with DMSO/I_2. However, their experiments did not demonstrate the scope of the reaction because of long reaction time and hard conditions. In this work, we report a simple and convenient procedure for the synthesis of a range of functionalized benzyl derivatives using DMSO/I_2 as oxidant under the microwave irradiation.

2. Experimental

Column chromatography was carried out on silica gel (200–300 mesh). ^{1}H NMR spectra were recorded on 300 MHz or 400 MHz in $CDCl_3$, chemical shifts were reported in ppm using TMS as internal standard. ^{13}C NMR spectra were recorded on a Varian 75 MHz or Varian 100 MHz spectrometers with complete proton decoupling. IR spectra recorded on Nicolet Nexus 670 FT–TR spectrophotometer as KBr pellets or KBr film. MS spectra were recorded by the EI method on a HP 5998 mass spectrometer. Elemental analysis was performed by Elementar vario EL analyzer. Melting points were determined on a microscopic apparatus and were uncorrected. All products were further characterized by element analysis.

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2.1 *General procedure for the preparation of arylalkynes from aryl halides*

All arylalkynes were known compounds and were prepared according to the following procedure, as exemplified by the formation of 1,2-diphenylethyne. To a mixture of diphenylacetylene (178 mg, 1 mmol), $PdCl_2$ $(PPh3)_2$ (35·1 mg, 0·05 mmol), CuI (19·1 mg, 0·1 mmol) and TEA (404·8 mg, 4·0 mmol) in THF (10 mL), a solution of phenylacetylene (132·6 mg, 1·2 mmol) was added drop-wise under an argon atmosphere. The mixture was stirred at r.t. for overnight. Then Et_2O (20 mL) was added to the crude and the mixture was filtered over a short pad of Celite. The organic layer was washed twice with saturated brine (2 × 5 mL), dried over $MgSO_4$, filtered and concentrated under the reduced pressure. Resulting residue was further purified by flash chromatography.

2.2 *General procedure for the preparation of a-diketones from alkynes under microwave irradiation*

To a 2–5 mL heat-resistant reaction vessel were added alkyne (0·2 mmol), I_2 (25 mg, 0·1 mmol), in DMSO (1 mL). The reaction vessel was then exposed to microwave irradiation until complete conversion. The reaction was cooled to r.t. The crude product was extracted with ethyl acetate (3 × 10 mL). Organic layers were washed with 10% $Na_2S_2O_3$ solution (2 × 10 mL) and then saturated brine (1 × 10 mL), dried over $MgSO_4$, filtered and concentrated under the reduced pressure. The crude mixture was then purified by column chromatography on silica gel.

2.2a *1,2-Diphenyl-ethane-1,2-dione (2a):* mp: 95°C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7·50 (*t*, *J* = 7·5 Hz, 4 H), 7·65 (*t*, *J* = 7·5 Hz, 2 H), 7·97 (*d*, *J* = 7·5 Hz, 2 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 194·6 (CO), 194·1 (CO), 134·9 (2 C), 132·9 (2 C), 129·9 (4 C), 129·0 (4 C).

Anal. Calcd for $C_{14}H_{12}O_2$: C, 79·98; H, 4·79. Found: C, 80·12; H, 4·84. IR (KBr, cm^{-1}): 1675, 1596. MS (EI): *m*/*z* = 210 [M^+].

2.2b *1-Phenyl-2-p-tolyl-ethane-1,2-dione (2b):* Yellow oil. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2·44 (*s*, 3 H), 7·30 (*t*, *J* = 10·8 Hz, 2 H), 7·50 (*t*, *J* = 7·5 Hz, 2 H), 7·65 (*t*, *J* = 7·5 Hz, 1 H), 7·65 (*d*, *J* = 7·5 Hz, 2 H), 7·97 (*d*, *J* = 7·5 Hz, 2 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 194·7 (CO), 194·3 (CO), 146·2, 134·7, 133·1, 130·6, 130·0 (2 C), 129·8 (2 C), 129·7 (2 C), 128·9 (2 C), 21·9.

Anal. Calcd for $C_{15}H_{12}O_2$: C, 80·34; H, 5·39. Found: C, 80·37; H, 5·42. IR (KBr, cm^{-1}): 1673, 1602. MS (EI): *m*/*z* = 224 [M^+].

2.2c *1-(4-Ethoxyphenyl)-2-phenyl-ethane-1,2-dione (2c):* mp: 64°C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 1·43 (*t*, *J* = 7·2 Hz, 3 H), 2·11 (*q*, *J* = 7·2 Hz, 2 H), 6·95 (*d*, *J* = 7·2 Hz, 2 H), 7·49 (*t*, *J* = 7·5 Hz, 2 H), 7·64 (*t*, *J* = 7·5 Hz, 1 H), 7·98–7·92 (*m*, 4 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ, 194·9 (CO), 193·1 (CO), 164·4, 134·6, 133·2, 132·3 (2 C), 129·8 (2 C), 128·9 (2 C), 125·8, 114·7 (2 C).

Anal. Calcd for $C_{16}H_{14}O_3$: C, 75·57; H, 5·55%. Found: C, 75·50; H, 5·51. IR (KBr, cm^{-1}): 1675, 1597. MS (EI): *m*/*z* = 254 [M^+].

2.2d *1,2-bis(4-Methoxylphenyl)-ethane-1,2-dione (2d):* mp: 133°C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 3·86 (*s*, 6 H), 6·96 (*d*, *J* = 9·0 Hz, 4 H), 7·94 (*d*, *J* = 9·0 Hz, 4 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 193·5 (2 CO), 164·9 (2 C), 132·3 (4 C), 126·2 (2 C), 114·2 (4 C), 55·7 (2 C).

Anal. Calcd for $C_{16}H_{14}O_4$: C, 71·10; H, 5·22. Found: C, 71·13; H, 5·26. IR (KBr, cm^{-1}): 1654, 1598, 1571. MS (EI): *m*/*z* = 270 [M^+].

2.2e *1-(4-Methoxyphenyl)-2-phenyl-ethane-1,2-dione (2e):* mp: 66°C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 3·88 (*s*, 3 H), 6·98 (*d*, *J* = 12·0 Hz, 2 H), 7·50 (*t*, *J* = 7·5 Hz, 2 H), 7·64 (*t*, *J* = 7·5 Hz, 1H), 7·98–7·92 (*m*, 4 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 193·3 (CO), 193·1 (CO), 164·9, 134·7, 133·1, 132·3 (2 C), 129·8 (2 C), 128·9 (2 C), 126·0, 114·3.

Anal. Calcd for $C_{15}H_{12}O_3$: C, 74·99; H, 5·03. Found: C, 74·94, H, 4·99. IR (KBr, cm^{-1}): 1673, 1597. MS (EI): *m*/*z* = 240 [M^+].

2.2f *1-Phenyl-2-(3,4,-dimethylphenyl)-ethane-1,2-dione (2f):* mp: 63°C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2·30 (*s*, 3 H), 2·33 (*s*, 3 H), 7·25 (*d*, *J* = 7·8 Hz, 1 H), 7·71–7·47 (*m*, 5 H), 7·97 (*d*, *J* = 7·2 Hz, 2 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 194·8 (CO), 194·6 (CO), 145·0, 137·6, 134·7, 133·1, 130·9, 130·7, 130·2, 129·8 (2 C), 128·9 (2 C), 127·7.

Anal. Calcd for $C_{16}H_{14}O_2$: C, 80·65; H, 5·92. Found: C, 80·69; H, 5·98. IR (KBr, cm^{-1}): 1670, 1602. MS (EI): *m*/*z* = 238 [M^+].

2.2g *1-(4-Methoxyphenyl)-2-p-Chlorophenyl-ethane-1,2-dione (2g):* mp: 132°C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 3·88 (*s*, 3 H), 6·98 (*d*, *J* = 9·0 Hz, 2 H), 7·47 (*d*, *J* = 9·0 Hz, 2 H), 7·91 (*d*, *J* = 5·1, 2 H), 7·94 (*d*, *J* = 5·1 Hz, 2 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 193·3 (CO), 192·4 (CO), 165·1, 141·3, 132·4, 131·5 (2 C), 131·2 (2 C), 129·3 (2 C), 125·8, 114·4, 55·6.

Anal. Calcd for $C_{15}H_{11}O_3Cl$: C, 65·58; H, 4·04. Found: C, 65·55; H, 4·01. IR (KBr, cm^{-1}): 1661, 1598. MS (EI): *m/z* = 274 [M^+].

2.2h *1-(4-Nitrophenyl)-2-p-tolyl-ethane-1,2-dione (2h):* mp: 177°C. ^{1}H NMR ($CDCl_3$, 300 MHz): 2·46 (*s*, 3 H), δ 7·34 (*d*, *J* = 9·0 Hz, 2H), 7·88 (*d*, *J* = 9·0 Hz, 2H), 8·16 (*d*, *J* = 9·0 Hz, 2H), 8·35 (*d*, *J* = 9·0 Hz, 2 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 194·2 (CO), 193·8 (CO), 154·1, 144·5, 139·1, 130·9 (2 C), 130·0, 129·8 (2 C), 129·1 (2 C), 124·4 (2 C).

Anal. Calcd for $C_{15}H_{11}O_4N$: C, 66·91; H, 4·12; N, 5·20. Found: C, 66·57; H, 4·08; N, 5·24. IR (KBr, cm^{-1}): 1657, 1601, 1519. MS (EI): *m/z* = 269 [M^+].

2.2i *1-(4-Nitrophenyl)-2-p-Chlorophenyl-ethane-1,2-dione (2i):* mp: 192°C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7·53 (*d*, *J* = 9·0 Hz, 2 H), 7·95 (*d*, *J* = 9·0 Hz, 2 H), 8·17 (*d*, *J* = 9·0 Hz, 2 H), 8·36 (*d*, *J* = 9·0 Hz, 2 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 193·1 (CO), 192·8 (CO), 153·4, 140·1, 138·8, 131·1, 130·6 (2 C), 129·9 (2 C), 129·3 (2 C), 124·4 (2 C).

Anal. Calcd for $C_{14}H_8O_4NCl$: C, 58·05; H, 2·78; N, 4·84. Found: C, 58·09, H, 2·81; N, 4·89. IR (KBr, cm^{-1}): 1670, 1602, 1526. MS (EI): *m/z* = 289 [M^+].

2.2j *1-(4-Nitrophenyl)-2-phenyl-ethane-1,2-dione (2j):* mp: 138°C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7·55 (*t*, *J* = 7·5 Hz, 2 H), 7·71 (*t*, *J* = 7·5 Hz, 1 H), 7·99 (*d*, *J* = 7·5 Hz, 2 H), 8·17 (*d*, *J* = 7·5 Hz, 2 H), 8·36 (*d*, *J* = 9·0 Hz, 2 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 192·8 (CO), 192·0 (CO), 151·1, 137·3, 135·4, 132·3, 130·9 (2 C), 130·0 (2 C), 129·2 (2 C), 124·1 (2 C).

Anal. Calcd for $C_{14}H_9O_4N$: C, 65·88; H, 3·55, N, 5·49. Found: C, 65·92; H, 3·58, N, 5·50. IR (KBr, cm^{-1}): 1661, 1599, 1526. MS (EI): *m/z* = 255 [M^+].

2.2k *1-(m-Chlorophenyl)-2-phenyl-ethane-1,2-dione (2k):* mp: 92°C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7·41–7·99 (*m*, 9 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 193·65 (CO), 192·9 (CO), 135·4, 135·1, 134·7, 134·4, 132·6, 130·3, 129·9 (2 C), 129·5, 129·1 (2 C), 128·1.

Anal. Calcd for $C_{14}H_9O_2Cl$: C, 68·72; H, 3·71. Found: C, 68·75, H, 3·72. IR (KBr, cm^{-1}): 1677, 1682. MS (EI): *m/z* = 244 [M^+].

2.2l *1-(4-Chlorophenyl)-2-phenyl-ethane-1,2-dione (2l):* mp: 70°C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ, 7·98–7·90 (*m*, 4 H), 7·70–7·64 (*m*, 2 H), 7·55–7·47 (*m*, 4 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 193·8 (CO), 193·0 (CO), 141·6, 135·0, 132·8, 131·3, 131·2 (2 C), 129·9 (2 C), 129·4 (2 C), 129·0 (2 C).

Anal. Calcd for $C_{14}H_9O_2Cl$: C, 68·72; H, 3·71. Found: C, 68·78, H, 3·74. IR (KBr, cm^{-1}):1669, 1589. MS (EI): *m/z* = 244 [M^+].

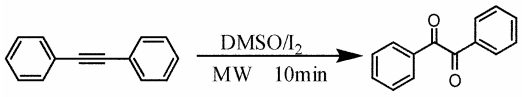
2.2m *1,4-bis(phenylglyoxaloyl)benzene (2 m):* mp: 125°C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7·53 (*t*, *J* = 7·5 Hz, 4 H), 7·69 (*t*, *J* = 7·5 Hz, 2 H), 7·97 (*d*, *J* = 7·5 Hz, 4 H), 8·11 (*s*, 4 H). ^{13}C NMR ($CDCl_3$, 75 MHz): δ 193·4 (CO), 193·2 (CO), 137·1 (2 C), 135·2 (2 C), 132·5 (2 C), 130·2 (4 C), 129·9 (4 C), 129·1 (4 C).

Anal. Calcd for $C_{22}H_{14}O_4$: C, 77·18; H, 4·12. Found: C, 77·21; H, 4·15. IR (KBr, cm^{-1}): 1670, 1596. MS (EI): *m/z* = 342 [M^+].

3. Results and discussion

In preliminary experiments, we attempted to transform diarylalkynes into 1,2-diphenyl-ethane-1,2-dione using different amount I_2 in DMSO under microwave irradiation to explore the optimum reaction conditions. The results are summarized in table 1. It was observed that the amount of I_2 influenced the yield. The use of 10 mol% of I_2 for the reaction

Table 1. Oxidation of diarylalkyne **1a** to benzil **2a** using different amount of I_2[a].

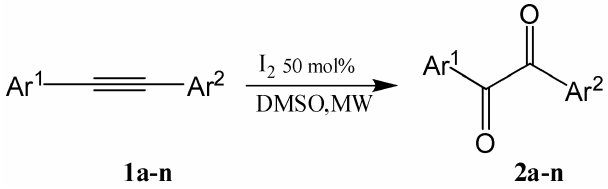


1a **2a**

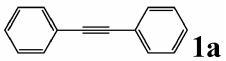
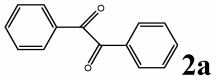
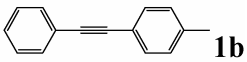
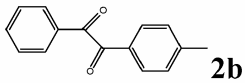
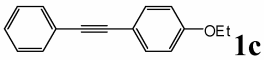
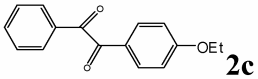
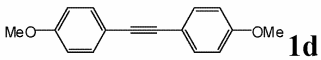
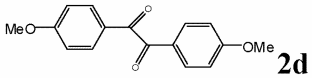
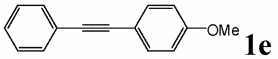
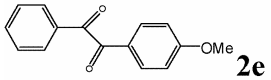
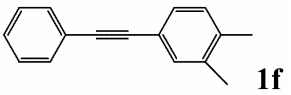
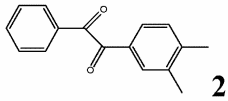
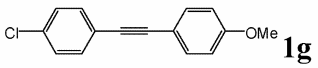
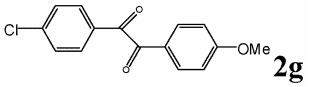
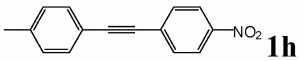
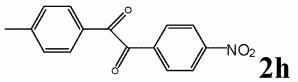
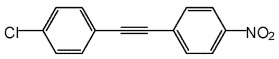
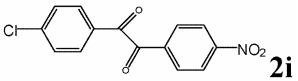
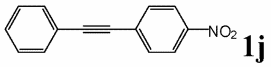
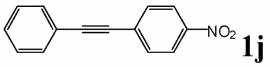
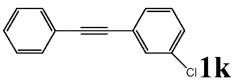
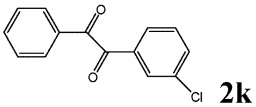
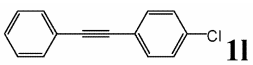
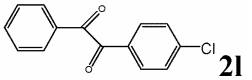
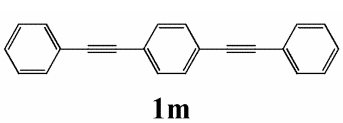
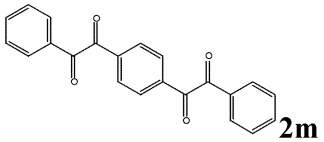
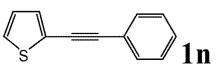
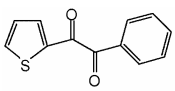
Entry	I_2 (mol%)	Yield[b] (%)
1	10	19
2	20	21
3	30	64
4	40	74
5	50	95

[a]Reactions were carried out in 0·2 mmol scale in 0·5 mL DMSO under microwave irradiation
[b]Isolated yield

Table 2. Oxidation of diarylalkynes **1** to benzyl derivatives **2** under microwave irradiation[a].



1a-n **2a-n**

Entry	Alkynes	Bzenils	Time (min)	Yied[b] (%)
1	 **1a**	 **2a**	10	95
2	 **1b**	 **2b**	11	85
3	 **1c**	 **2c**	7	93
4.	 **1d**	 **2d**	14	94
5	 **1e**	 **2e**	10	81
6	 **1f**	 **2f**	10	90
7	 **1g**	 **2g**	8	80
8	 **1h**	 **2h**	12	76
9	 **1i**	 **2i**	12	29
10	 **1j**	 **1j**	20	49
11	 **1k**	 **2k**	12	62
12	 **1l**	 **2l**	12	59
13	 **1m**	 **2m**	30	64
14	 **1n**	 **2n**	30	0

[a]Reactions were carried out in 0·2 mmol scale in 0·5 mL DMSO using 0·1 mmol I_2 (50 mol%) under microwave irradiation

[b]Isolated yield

afforded 1,2-diphenyl-ethane-1,2-dione only 19% yield (table 1, entry 1). The amount of I_2 increased to 20 mol%, resulted in slightly increased yields (table 1, entry 2). When the amount of I_2 increased from 30 mol% to 40 mol%, moderate yields were obtained (table 1, entries 3–4). By further increasing the amount of I_2 to 50 mol% (table 1, entry 5), the excellent yields were obtained (up to 95%).

Under the optimum reaction conditions, We synthesized a range of 1,2-diaryldiketones using 50% amount I_2 in DMSO under microwave irradiation. It has been found that arylalkynes with electron-donating groups (table 2, entries 1–6) gave 1, 2-diaryldiketones in high yields (from 81% to 95%) within shorter reaction time, even if another electron-withdrawing group on the other benzene ring of the substrates (entry 7 and 8) also gave the corresponding products in good yields. However, the substrates only with electron-withdrawing groups such as NO_2, Cl gave moderate yields (table 2, entries 9–12). Under the same conditions, we have also found that 1,4-*bis*(phenylethynyl)benzene could be oxidized to 2,2′-(1,4-phenylene)*bis*(1-phenylethane-1,2-dione) in 64% yields (table 2, entry 13). But the 2-(phenylethynyl)thiophene could not be oxidized by this method (table 2, entry 14).

4. Conclusions

In summary, we have developed a microwave-enhanced, simple, and efficient process for synthesis of *a*-diketones using DMSO/I_2. The most attractive features of this method was the short reaction times, good yields, low cost and easy preparation. It has been found that the amount of I_2 played an important role on this system. The electron-donating substitutents (entries 1–6) on the benzene ring of arylalkynes gave 1,2-diaryldiketones in high yields (from 81 to 95%) within shorter reaction time. The 1,2-diaryldiketones can be safely and beneficially reproduced by this method. Further studies on expanding the scope of those reactions and their mechanistic aspects are currently underway in our laboratory.

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