SELECTIVE TRANSFORMATION OF 3-ACETYL-5-ARYL-2-METHYLFURANS USING PHOTOOXYGENATION

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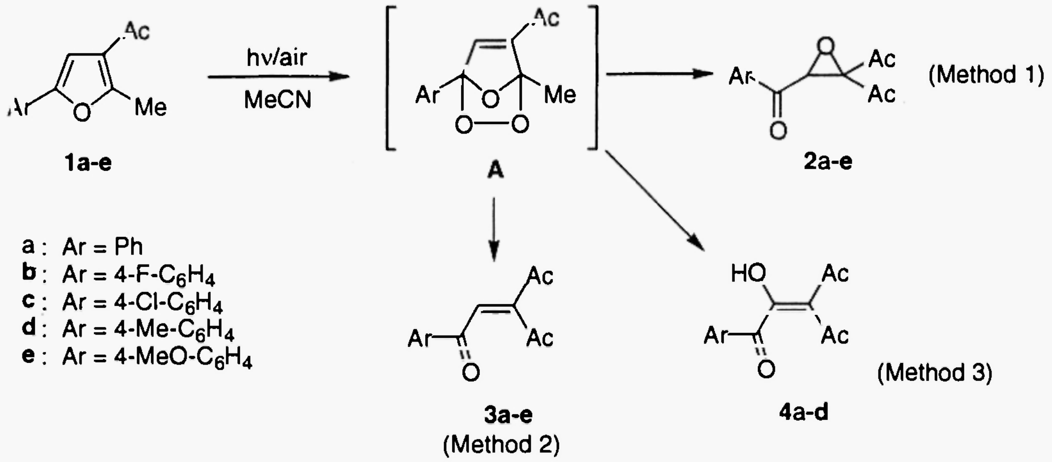
Abstract: The photooxygenation of 3-acetyl-5-aryl-2-methylfurans was carried out in acetonitrile through a dry air stream in the presence of Rose Bengal to give 2,2-diacetyl-3-aroyloxiranes *via* the corresponding *endo*-peroxide intermediate, while the 3-acetyl-1-aryl-2-pentene-1,4-diones were formed when the reaction mixture was poured into water after the photooxygenation. The direct irradiation of 3-acetyl-5-aryl-2-methylfurans using UV light through a dry air stream afforded the 3-acetyl-1-aryl-2-hydroxy-2-pentene-1,4-diones.

Recently, we reported that the photo-induced reaction of 5,5-diaryl-4,5-dihydrofurans gave substituted naphthalenes (1). The photoreaction was so efficient and convenient that it prompted us to investigate the irradiation of 3-acetyl-5-aryl-2-methylfurans **1a-e** which were readily obtained by the acid-catalyzed decomposition of the corresponding 6,6-diaryl-1,2-dioxan-3-ols (2). The photoreaction of 3-acetyl-5-phenyl-2-methylfuran **1a** was carried out expecting benzannulation or [2+2]cycloaddition to occur. However, it was found that **1a** was quite sensitive toward singlet oxygen and 2,2-diacetyl-3-benzoyloxirane **2a** was obtained in a good yield (3). Although the photooxygenation of substituted furans is well documented and characterized because of their sensitivity toward singlet oxygen (4) and the importance for the synthesis of industrial and pharmaceutical materials (5), it seems that quite attractive reactions of furan derivatives still remain.

In order to fully understand the photochemistry of substituted furans, we examined in detail the photooxygenation of 3-acetyl-5-aryl-2-methylfurans **1a-e**. Typically, 3-acetyl-2-methyl-5-phenylfuran **1a** (0.5 mmol) was dissolved in acetonitrile (10 mL) in a quartz cell containing Rose Bengal (5 mg) of which the quantum yield for singlet oxygen is larger than that of methylene blue, and the mixture was irradiated at 23 °C for 5 min using a



Scheme 1

Method 1: Visible light, Rose Bengal, irradiated for 5 min at 23 °C, then kept at 23 °C for 12 h
Method 2: Visible light, Rose Bengal, irradiated for 5 min at 0 °C, then poured into water
Method 3: UV light, irradiated for 90 min at 0 °C

Table 1. Photooxygenation of 3-Acetyl-5-aryl-2-methylfurans **1a-e** in Acetonitrile[a]

Entry	Furan	Additive	Light[b]	Temperature °C	Irradiation time min	Product Yield/%[c]	
1[d]	**1a**	none	visible	23	15	n.r.[e]	
2[f]	**1a**	Methylene Blue	visible	23	5	**2a** (55)	**3a** (17)
3[f]	**1a**	Rose Bengal	visible	23	5	**2a** (63)	**3a** (9)
4[f]	**1b**	Rose Bengal	visible	23	5	**2b** (57)	**3b** (14)
5[f]	**1c**	Rose Bengal	visible	23	5	**2c** (56)	**3c** (9)
6[f]	**1d**	Rose Bengal	visible	23	5	**2d** (71)	**3d** (10)
7[f]	**1e**	Rose Bengal	visible	23	5	**2e** (77)	**3e** (12)
8[g]	**1a**	Rose Bengal	visible	0	5	**3a** (68)	
9[g]	**1b**	Rose Bengal	visible	0	5	**3b** (62)	
10[g]	**1c**	Rose Bengal	visible	0	5	**3c** (68)	
11[g]	**1d**	Rose Bengal	visible	0	5	**3d** (69)	
12[g]	**1e**	Rose Bengal	visible	0	5	**3e** (67)	
13[d]	**1a**	none	UV	23	15	n.r.[e]	
14	**1a**	none	UV	0	90	**4a** (60)	
15	**1b**	none	UV	0	90	**4b** (32)	
16	**1c**	none	UV	0	90	**4c** (21)	
17	**1d**	none	UV	0	90	**4d** (23)	

[a] The photooxygenation of **1** (0.5 mmol) was carried out in acetonitrile (10 mL) under a dry air stream (blow rate: 120 dm^3 min^{-1}). [b] Visible and UV lights were generated by a 250-W halogen and a 100-W mercury lamp, respectively. [c] Isolated yield based on the amount of the furan **1** used. [d] The reaction was carried out under an argon atmosphere. [e] No reaction. [f] The reaction mixture was kept at 23 °C for 12 h after the irradiation (method 1). [g] The reaction mixture was poured into water (30 mL) after the irradiation (method 2).

250-W halogen lamp through a dry air stream (flow rate: 120 dm^3 min^{-1}). After standing for 12 h at room temperature, the reaction mixture was separated by silica gel TLC using hexane/ethyl acetate (1:1 v/v), giving 2,2-

diacetyl-3-benzoyloxirane **2a** (63% yield) together with a small amount of unstable 3-acetyl-1-phenyl-2-pentene-1,4-dione **3a** (9% yield) (Table 1, entry 3). The existence of the corresponding *endo*-peroxide intermediate **A** was confirmed by the ^{1}H NMR spectrum of the reaction mixture just after irradiation (6,7). The photooxygenation of other furans **1b-e** also gave the corresponding 2,2-diacetyl-3-aroyloxiranes **2b-e** in good yields along with a small amount of 2-pentene-1,4-diones **3b-e** (Table 1, entries 4-7) (8). The unstable by-products **3a-e** were quite interesting because of the considerable electron-deficient alkene and mechanistic reason for their production (9). Therefore, in order to improve the yield of **3a-e**, the reaction conditions were explored and we found that treatment of the reaction mixture with water after the irradiation led to the improvement of the yield of **3a-e** (62-69%) (10). When the reaction mixture was poured into water, the evolution of some gas, which seemed to be molecular oxygen, was observed. This provided proof that the *endo*-peroxide intermediate **A** should immediately rearrange to the corresponding carbonyl oxide and the 2-pentene-1,4-dione **3** was subsequently formed along with extrusion of molecular oxygen *via* the bimolecular reaction of the carbonyl oxide (11). Although it was reported that the *endo*-peroxide intermediate **A** was reduced by diethyl sulfide to give the corresponding 2-pentene-1,4-dione (3,6b), the present reaction is much simpler and more convenient because such a reductant is not used. Simple heating at 80 °C of the reaction mixture for 10 min after the irradiation of **1a** resulted in a decreased yield of **3a** (31%), however, 3-acetyl-2-hydroxy-1-phenyl-2-pentene-1,4-dione **4a** was newly obtained in 12% yield (12). The 2-hydroxy-2-pentene-1,4-dione **4a** was also interesting because of the ambiguous formation mechanism. Refluxing **2a** and **3a** in aqueous acetonitrile for 2 h did not give **4a**, and **2a** and **3a** were recovered. Accordingly, it appeared that the homolytic fission of the *endo*-peroxide intermediate **A** and subsequent rearrangement might yield **4a** during the heating. Since it is known that heteroaromatic compounds such as furans also work as photosensitizers of singlet oxygen, the direct UV irradiation of the furans **1a-d** was examined. As a result, 2-hydroxy-2-pentene-1,4-diones **4a-d** which would be produced by the homolytic fission of the intermediate **A** induced by the UV light were exclusively obtained (Table 1, entries 14-17) (13).

In summary, all of the trisubstituted furans **1a-e** were reactive toward singlet oxygen and could be selectively transformed into oxiranes **2**, 2-pentene-1,4-diones **3** or **4** in good yields depending on the reaction conditions and the work-up procedure.

References and Notes

(1) Nishino, H.; Kajikawa, S.; Hamada, Y.; Kurosawa K. *Tetrahedron Lett.* **1995**, *36*, 5753.

(2) Qian, C.-Y.; Hirose, J.; Nishino, H.; Kurosawa, K. *J. Heterocycl. Chem.* **1994**, *31*, 1219.

(3) Graziano, M. L.; Iesce, M. R.; Scarpati, R. *Synthesis*, **1984**, 66.

(4) Wasserman, H. H.; Ives, J. L. *Tetrahedron* **1981**, *37*, 1825 and references cited therein.

(5) a) Bosshard, P.; Eugster, C. H. *The Development of the Chemistry of Furans, 1952-1963* in *Advances in Heterocyclic Chemistry*; Vol. 7, Katritzky, A. R.; Boulton, A. J. Ed.; Academic: New York, 1966; pp 377-488. b) Livingstone, R. *Compounds Containing a Five-Membered Ring with One Hetero Atom of Group VI: Oxygen* in *Rodd's Chemistry of Carbon Compounds*; Vol. IV, Part A, Coffey, S. Ed.; Elsevier: Amsterdam, 1973; pp 83-217. c) Dean, F. M. *Recent Advances in Furan Chemistry, Part I* in *Advances in Heterocyclic Chemistry*; Vol. 30, Katritzky, A. R. Ed.; Academic: New York, 1982; pp 167-238. d) Acheson, R. M. *An Introduction to the Chemistry of Heterocyclic Compounds*; Wiley: Tronto, 1976.

(6) a) Lutz, R. E.; Welstead, Jr., W. J.; Bass, R. G.; Dale, J. I. *J. Org. Chem.* **1962**, *27*, 1111. b) Graziano, M. L.; Iesce, M. R.; Scarpati, R. *J. Chem. Soc., Perkin Trans. 1*, **1980**, 1955.

(7) The characteristic peak of the methyl group of the *endo*-peroxide **A** (Ar = Ph) showed at δ 2.05 in the ^{1}H NMR spectrum, while the methyl group of **1a** appeared at δ 2.61 in $CDCl_3$ (6b).

(8) 1,1-Diacetyl-2-(4-methylbenzoyl)oxirane **2d**: colorless needles (from methanol), mp 70.4 °C; IR ($CHCl_3$) ν 1712, 1690 (C=O); ^{1}H NMR ($CDCl_3$) δ 7.84 (2H, m, arom H), 7.30 (2H, m, arom H), 4.57 (1H, s, H-2), 2.43 (3H, s, Me), 2.34 (3H, s, Ac), 2.32 (3H, s, Ac); ^{13}C NMR ($CDCl_3$) δ 199.8, 199.2, 189.7 (C=O), 146.0, 132.4, 129.8, 128.7 (ArH), 69.3, 60.8 (>CH-O), 28.8, 26.1 (Ac), 21.9 (Me). Anal. Calcd for $C_{14}H_{14}O_4$: C, 68.28; H, 5.73. Found: C, 68.57; H, 5.80.

(9) Onitsuka, S.; Nishino, H.; Kurosawa, K. *Tetrahedron Lett.* **2000**, *41*, 3149.

(10) 3-Acetyl-1-(4-methylphenyl)-2-pentene-1,4-dione **3d**: yellow oil; IR ($CHCl_3$) ν 1701 (C=O), 1665 (O=C-C=C); ^{1}H NMR ($CDCl_3$) δ 7.86 (2H, m, arom H), 7.58 (1H, s, HC=), 7.30 (2H, m, arom H), 2.46 (3H, s, Me), 2.42 (6H, s, Ac); ^{13}C NMR ($CDCl_3$) δ 203.0, 196.3, 189.3 (C=O), 151.8 (>C=), 145.7, 133.8 (ArC), 130.2 (HC=), 129.8 (2C), 128.9 (2C) (ArH), 30.7, 27.3 (Ac), 21.8 (Me).

(11) a) Bunnelle, W. H. *Chem. Rev.* **1991**, *91*, 335. b) Iesce, M. R.; Cermola, F.; Graziano, M. L.; Scarpati, R. *J. Chem. Soc., Perkin Trans. 1*, **1994**, 147.

(12) 3-Acetyl-2-hydroxy-1-phenyl-2-pentene-1,4-dione **4a**: colorless needles (from benzene), 160 °C (decompd.), IR (KBr) ν 3400-2900 (OH), 1716 (C=O), 1640 (O=C-C=C); ^{1}H NMR (DMSO-d_6) δ 8.85 (1H, br. s, OH), 7.47-7.41 (5H, m, arom H), 2.72 (3H, s, Ac), 2.31 (3H, s, Ac); ^{13}C NMR (DMSO-d_6) δ 196.7, 195.8, 192.6 (C=O), 135.2, 129.4, 128.4 (2C), 125.5 (2C) (PhH), 112.4 (=C-OH), 106.1 (>C=), 29.4 (Ac), 18.2 (Ac). Anal. Calcd for $C_{13}H_{12}O_4$: C,67.23; H, 5.21. Found: C, 67.37; H, 5.29.

(13) A small amount of **2** and **3** which were detected by ^{1}H NMR spectra was simultaneously formed. However, the products **2** and **3** could not be isolated from the reaction mixture. Although the photolysis of **2a** and **3a** using the UV light was also examined, **2a** and **3a** completely decomposed after 4 h and an intractable mixture was obtained.

Received on July 28, 2000