Supplementary Information

Facile aerobic photooxidative oxylactonization of oxocarboxylic acids in fluorous solvents

Norihiro Tada, Lei Cui, Takafumi Ishigami, Kazunori Ban, Tsuyoshi Miura, Bunji Uno and Akichika Itoh*

Gifu Pharmaceutical University, 1-25-4 Daigaku-nishi, Gifu 501-1196, Japan

E-mail: itoha@gifu-pu.ac.jp

1.	General Information	SI-2			
2.	Aerobic Photooxidative Syntheses of Oxolactones in the Presence of				
	Trifluoroacetic Anhydride				
2.1	Optimization of the Reaction Conditions (Supplemental data for Table 1)	SI-2			
2.2	Measurement of Peroxide by Iodometry	SI-3			
2.3	General Procedure	SI-3			
3.	Products data	SI-4			
4.	Reference	SI-6			
Apper	ndix: ¹ H and ¹³ C NMR spectra	SI-7			

1. General Information.

All dry solvents were obtained from Kanto Kagaku Co., Ltd. Other chemicals used were of reagent grade and were obtained from Aldrich Chemical Co., Tokyo Kasei Kogyo Co., Ltd. and Wako Pure Chemical Industries, Ltd. ¹H NMR and ¹³C NMR spectra were obtained on a JEOL ECA 500 spectrometer or JEOL AL 400 spectrometer (500 or 400 MHz for ¹H NMR and 125 or 100 MHz for ¹³C NMR). Chemical shifts (δ) are reported in parts per million (ppm) downfield from internal Me₄Si. Mass spectra (MS) were obtained on a JEOL JMS-T100TD instrument. Preparative thin-layer chromatography (TLC) was carried out on precoated plates of silica gel (MERCK, silica gel F-254).

2. Aerobic Photooxidative Syntheses of Oxolactones in the Presence of Trifluoroacetic Anhydride 2.1. Optimization of the Reaction Conditions (Supplemental data for Table 1)

Table S1 Study of solvents ^a									
Ph C	$\begin{array}{c} O_2, h_V \text{ (flucture})\\ O_2, h_V \text{ (flucture})\\ OH & \text{Solve} \end{array}$	lorescent lamp) A (3 equiv) rent, 15 h Ph ∕		ph 0 0					
1a			2a	3a					
entry	solvent		yield ^b						
	Solvent	2a	3a	1a					
1	AcOEt	17	24	20					
2	CH ₃ CN	32	17	5					
3	THF	trace	38	28					
4	CH_2CI_2	58	0	0					
5	Acetone	11	trace	23					
6	CHCI ₃	53	trace	9					
7	cyclohexane	e 47	16	14					
8	hexane	43	10	13					
9	HFE-7200 ^c	39	11	5					
10	FC-77	40	0	33					
11	FC-72	71	0	trace					
12	neat	19	35	22					

^a Reaction conditions: **1a** (0.3 mmol), TFAA (3 equiv), solvent (5 mL) with O_2 balloon irradiation with two of 22-W fluorescent lamps for 15 h.

^{b 1}H NMR yields.

 $^{\rm c}$ HFE-7200 is nonafluorobutyl ethyl ether (C_4F_9OC_2H_5)

Table S2 Study of additives ^a										
Ph	о –	O ₂ , <i>hv</i> (fluorescent lamp) additive FC-72, 15 h	→ Ph							
1a				2a	3a					
entry	addit	additive (equiv)	yield ^b							
			2a	3a	1a					
1	TFAA	x (3)	71	0	0					
2	TFA	(3)	0	0	0					
3	(CH ₃	CO) ₂ O (3)	0	0	0					
4	CH ₃ C	CH ₃ CO ₂ H (3)		0	0					
5	BF ₃ -I	BF ₃ ∙Et ₂ O (3)		0	0					
6	male	c anhydride (3)	0	0	0					
7	NaOl	H (3)	0	0	0					
8	AICI ₃	(3)	0	0	0					
9	K ₂ CC	D ₃ (3)	0	0	0					
10	<i>t</i> -BuC	DK (3)	0	0	0					
11	Tf ₂ O	(3)	0	0	0					
12	TFAA	x (2)	43	0	25					
13	TFAA	x (1)	32	0	45					
14	TFAA	x (0.5)	15	0	69					

 a Reaction conditions: 1a (0.3 mmol), additive, FC-72 (5 mL) with $\rm O_2$ balloon irradiation with two of 22-W fluorescent lamps for 15 h.

^{b 1}H NMR yields.

2.2. Measurement of Peroxide by Iodometry

Typical procedure is as follows; A solution of 4-benzoylbutyric acid (**4a**: 0.3 mmol), TFAA (3 equiv) in FC-72 (5 mL) in a Pyrex test tube with O_2 balloon is stirred and irradiated externally with two 22-W fluorescent lamps for 15 h. The residue is mixed with saturated aq. KI (3 mL), AcOH (1 mL) and *i*-PrOH (10 mL), and warmed at 100°C for 5 min. The resulting solution is titrated by 0.1 M aq. Na₂S₂O₃, and the volumes of required 0.1 M aq. Na₂S₂O₃ are 0.6 mL. These results correspond to 0.015 mmol of peroxides respectively after subtracting the required volume of 0.1 M aq. Na₂S₂O₃ for blank experiment.

2.3. General Procedure

A solution of substrate (0.3 mmol), TFAA (3 equiv) in FC-72 (5 mL) in a Pyrex test tube with O_2 balloon is stirred and irradiated externally with two of 22-W fluorescent lamps for indicated time. Then the solution is basified with sat. NaHCO₃ and the product is extracted with EtOAc. The product is purified by PTLC.

3. Products data

Me Me

4-(2,6-Dimethyl)benzoylbutyric acid (**1g**): colorless solid; m.p. 117-119 °C; ¹H NMR (500 MHz, CDCl₃) δ 7.59 (d, J = 8.1 Hz, 1H), 7.06 (m, 2H), 2.98 (t, J = 7.2 Hz, 2H), 2.49-2.46 (m, 5H), 2.35 (s, 3H), 2.05 (quint, J = 7.2Hz, 2H); ¹³C NMR (125 MHz, CDCl₃) δ 202.54, 178.76, 142.02, 138.73, 134.56, 132.93, 129.06, 126.31, 39.77, 33.03, 21.60, 21.33, 19.26; IR (KBr) 2980, 1711, 1682, 1609, 1563, 1450, 1403, 1373, 1302, 1198, 1070, 982, 907 cm⁻¹; Anal. calcd. for C₁₃H₁₆O₃: C, 70.89; H, 7.32. Found: C, 70.73; H, 7.34.



5-Benzoyldihydrofuran-2(3H)-one (2a)¹: colorless oil; ¹H NMR (400 MHz, CDCl₃) δ 7.98 (d, *J* = 9.8 Hz, 2H), 7.65 (t, *J* = 7.8 Hz, 1H), 7.52 (m, 2H), 5.86-5.77 (m, 1H), 2.65-2.44 (m, 4H); ¹³C NMR (100 MHz, CDCl₃) δ 194.31, 176.22, 134.27, 133.55, 128.98, 128.73, 78.21, 26.76, 24.95; CAS Registry Number: 35304-85-9.



5-(4-Fluorobenzoyl)dihydrofuran-2(3H)-one (2b): colorless solid; ¹H NMR (500 MHz, CDCl₃) δ 8.05-8.03 (m, 2H), 7.20 (t, *J* = 9.2 Hz, 2H), 5.75-5.73 (m, 1H), 2.63-2.50 (m, 4H); ¹³C NMR (125 MHz, CDCl₃) δ 192.72, 176.01, 166.33 (d, *J* = 256.3 Hz), 131.68 (d, *J* = 9.5 Hz), 130.14, 116.26 (d, *J* = 22.7 Hz), 78.23, 26.83, 24.63; CAS Registry Number: 1268103-05-4.



5-(4-Chlorobenzoyl)dihydrofuran-2(3H)-one (**2c**)²: colorless oil; ¹H NMR (500 MHz, CDCl₃) δ 7.94 (d, J = 8.6 Hz, 2H), 7.49 (d, J = 8.6 Hz, 2H), 5.74-5.73 (m, 1H), 2.66-2.44 (m, 4H); ¹³C NMR (125 MHz, CDCl₃) δ 193.20, 176.00, 140.86, 131.93, 130.22, 129.32, 78.21, 26.77, 24.62; CAS Registry Number: 172167-95-2.



5-(4-Methylbenzoyl)dihydrofuran-2(3H)-one (2d)²: colorless oil; ¹H NMR (500 MHz, CDCl₃) δ 7.88 (d, J = 8.1 Hz, 2H), 7.31 (d, J = 8.0 Hz, 2H), 5.81-5.78 (m, 1H), 2.62-2.43 (m, 7H); ¹³C NMR (125 MHz, CDCl₃) δ 193.88, 176.35, 145.40, 131.03, 129.66, 128.82, 78.15, 26.79, 25.06, 21.74; MS m/z 136 (M⁺), 118, 91; CAS Registry Number: 420119-86-4.



5-(4-tert-Butylbenzoyl)dihydrofuran-2(3H)-one (2e): colorless oil; ¹H NMR (500 MHz, CDCl₃) δ 7.92 (d, *J* = 8.6 Hz, 2H), 7.53 (d, *J* = 8.6 Hz, 2H), 5.81-5.79 (m, 1H), 2.63-2.42 (m, 4H), 1.35 (s, 9H); ¹³C NMR (125 MHz, CDCl₃) δ 193.90, 176.33, 158. 30, 130.96, 128.75, 125.97, 78.22, 35.27, 30.97, 26.82, 25.05; CAS Registry Number: 1268048-66-3.



5-(4-Methoxybenzoyl)dihydrofuran-2(3H)-one (2f)²: colorless oil; ¹H NMR (500 MHz, CDCl₃) δ 7.97 (d, *J* = 8.9 Hz , 2H), 6.98 (d, *J* = 8.9 Hz, 2H), 5.77-5.74 (m, 1H), 3.90 (s, 3H), 2.62-2.47 (m, 4H); ¹³C NMR (125 MHz, acetone-*d*₆) δ 192.68, 176.38, 164.38, 131.20, 126.58, 114.21, 78.09, 55.59, 26.90, 25.01; CAS Registry Number: 24962-85-4.



5-(2,6-Dimethylbenzoyl)dihydrofuran-2(3H)-one (2g): colorless oil; ¹H NMR (500 MHz, CDCl₃) δ 7.59 (d, *J* = 8.1 Hz, 1H) , 7.12 (m, 2H), 5.73-5.71 (m, 1H), 2.62-2.52 (m, 6H), 2.38-2.34 (m, 4H); ¹³C NMR (125 MHz, CDCl₃) δ 196.85, 176.42, 143.58, 140.47, 133.34, 130.61, 129.42, 126.53, 79.04, 26.84, 25.23, 21.58, 21.44; IR (neat) 2965, 2926, 1785, 1689, 1612, 1566, 1451, 1380, 1165, 1143, 1064, 977, 906 cm⁻¹; Anal. calcd. for C₁₃H₁₄O₃: C, 71.54; H, 6.47. Found: C, 70.90; H, 6.50; HRMS (EI⁺) m/z calcd for C₁₃H₁₄O₃ [M⁺+1]: 218.0943, found 218.0901.



5-(2,5-Dimethylbenzoyl)dihydrofuran-2(3H)-one (**2h**)²: colorless oil; ¹H NMR (500 MHz, CDCl₃) δ 7.44 (s, 1H), 7.26 (d, *J* = 8.0 Hz, 1H), 7.19 (d, *J* = 8.0 Hz, 1H), 5.71-5.69 (m, 1H), 2.64-2.36 (m, 10H); ¹³C NMR (125 MHz, CDCl₃) δ 197.92, 176.34, 136.71, 135.50, 133.68, 133.36, 132.29, 129.43, 79.20, 26.86, 25.10, 20.91, 20.87; CAS Registry Number: 851682-33-2.



5-(2-Naphthoyl)dihydrofuran-2(3H)-one (2i)¹: yellow solid; ¹H NMR (500 MHz, CDCl₃) δ 8.51 (s, 1H), 8.02 (d, *J* = 8.6 Hz, 1H), 7.99 (d, *J* = 8.6 Hz, 1H), 7.94 (d, *J* = 8.6 Hz, 1H), 7.90 (d, *J* = 8.6 Hz, 1H), 7.65 (m, 1H), 7.59 (m, 1H), 5.97-5.94 (m, 1H), 2.68-2.48 (m, 4H); ¹³C NMR (125 MHz, CDCl₃) δ 194.20, 176.27, 136.00, 132.34, 130.96, 129.73, 129.23, 128.99, 127.87, 127.17, 123.83, 78.25, 26.88, 25.04; CAS Registry Number: 1186412-83-8.



5-Acetyldihydrofuran-2(3H)-one (2j)¹: colorless oil; ¹H NMR (400 MHz, CDCl₃) δ 4.81-4.80 (m, 1H), 2.62-2.51 (m, 3H), 2.34-2.29 (m, 4H); ¹³C NMR (100 MHz, CDCl₃) δ 205.69, 175.85, 82.00, 27.39, 26.32, 24.46; CAS Registry Number: 29393-32-6.

Reference

- (1) M. Uyanik, D. Suzuki, T. Yasui, K. Ishihara, Angew. Chem. Int. Ed., 2011, 50, 5331-5334.
- (2) R.-S. Hou, H.-M. Wang, Y.-C. Lin, L.-C. Chen, Heterocycles, 2005, 65, 649-656.







NI J





















~ . . .





~. . .







~- - -





~+ ---







8