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Aerobic photo-decarboxylation of α-hydroxy carboxylic acid derivatives under visible light irradiation in the presence of catalytic iodine

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Abstract

A catalytic amount of iodine enables us to carry out aerobic photo-decarboxylation of α-hydroxy carboxylic acid derivatives to the corresponding carboxylic acids or ketones selectively in high yields under irradiation of vis. This new oxidation is interesting in keeping with the notion of Green Chemistry due to the non-use of heavy metals and halogenated solvents, waste reduction, and the use of molecular oxygen.

Keywords: Aerobic; α-Hydroxy carboxylic acid; Iodine; Photo-decarboxylation; Visible light

The notion of Green Chemistry is becoming well established, and the development of environmentally benign processes is the goal of various research projects. The method using molecular oxygen which possesses a high atom effect as an oxidant is a way consistent with this notion. In this background in mind, we have studied aerobic photo-oxidation, and found several reactions in the presence of some catalysts.[1] Among them, oxidative photo-decarboxylation of α-hydroxy carboxylic acids,[1o] phenyl acetic acids[1o] and N-protected α-amino acids[1m] to afford the corresponding carbonyl compounds in the presence of FSM-16,[2] a mesoporous silica, is environmentally more benign than the previous methods, which involve the use of heavy metals and large quantities of complex organic reagents,[3] due to its metal free and usage of recyclable FSM-16. Although this reaction has the advantages of both acquisition of safe reagents and easy work-up, UV, which is irradiated by an expensive high-pressure mercury lamp and has harmful effect on the human body, is needed to proceed. As mentioned above, this reaction becomes safe, economical and steady, and the equipment is more easily installed, if visible light (vis) from a fluorescent lamp is applicable instead of the high-pressure mercury lamp; however, unfortunately, among our study, only a trace amount of the oxidative product was obtained with FSM-16 mentioned above under irradiation of vis by a general-purpose fluorescent lamp. This is the driving force of our continued wide-ranging studies on this oxidation, and we have found that iodine is suitable for this purpose. The effective use of vis is a most important research topic at this time of hoped-for the development of new energy conversion and energy-using technology, and our new oxidation method is interesting since there have been few reports about the application of photo-oxidation with vis by a general-purpose fluorescent lamp to fine chemistry.[1a–c,g] We now report our detailed study for visible light oxidative photo-decarboxylation of α-hydroxy carboxylic acids in the presence of catalytic iodine.

Table 1 shows the results of study of reaction conditions for the aerobic photo-decarboxylation conducted with mandelic acid (**1**, 0.3 mmol) as test substrate in the presence of catalysts in typical solvents equipped with an oxygen balloon under irradiation with 500 W xenon-lamp through the filter, which absorbs the UV of wavelength less than

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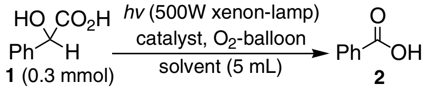
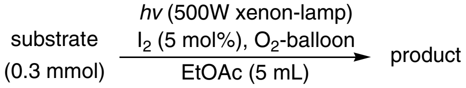
Table 1
Study of reaction conditions of aerobic photo-decarboxylation

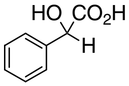
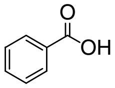
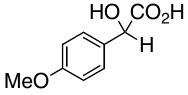
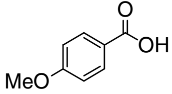
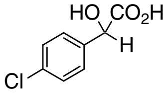
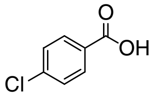
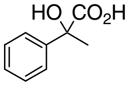
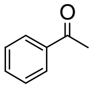
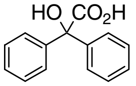
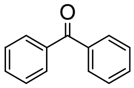
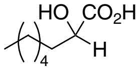


Entry	Solvent	Catalyst (mol %)	Time (h)	Yield[a] (%)
1	Acetone	I_2 (5)	5	38
2	MeCN	I_2 (5)	5	35
3	Hexane	I_2 (5)	5	0
4	MeOH	I_2 (5)	5	Trace
5	CH_2Cl_2	I_2 (5)	5	0
6	EtOAc	I_2 (5)	5	70
7	EtOAc	I_2 (5)	5	65[b]
8	EtOAc	I_2 (5)	5	34[c]
9	EtOAc	I_2 (5)	10	77
10	EtOAc	I_2 (5)	15	82
11	EtOAc	I_2 (1)	5	62
12	EtOAc	I_2 (10)	5	59
13	EtOAc	I_2 —	15	6
14	EtOAc	I_2 (5)	15	0[d]
15	EtOAc	I_2 (5)	15	3[e]
16	EtOAc	CI_4 (5)	5	52
17	EtOAc	NIS (5)	5	55
18	EtOAc	LiI (5)	5	70
19	EtOAc	NaI (5)	5	3
20	EtOAc	KI (5)	5	25
21	EtOAc	CsI (5)	5	24
22	EtOAc	CaI_2 (5)	5	68
23	EtOAc	Br_2 (5)	5	57

[a] All yields were for pure, isolated products.
[b] The reaction was carried out under the irradiation of 400 W Hg-lamp.
[c] The reaction was carried out under the irradiation of fluorescent lamp.
[d] The reaction was carried out in the dark.
[e] The reaction was carried out under Ar.

Table 2
Aerobic photo-decarboxylation of various α-hydroxy carboxylic acid derivatives



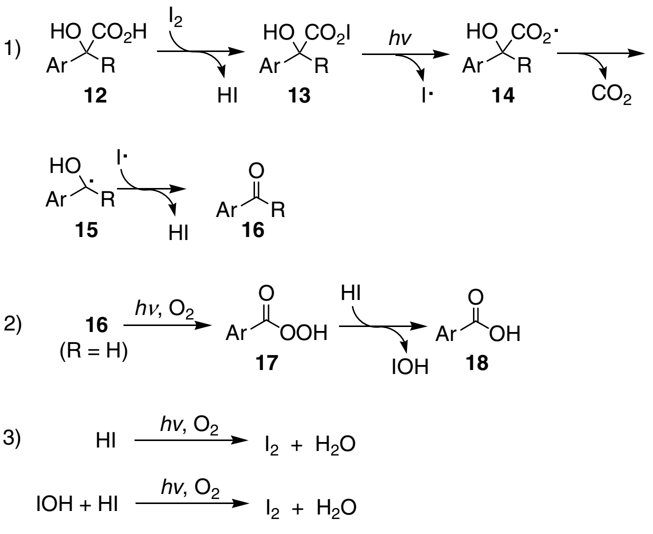
Entry	Substrate		Time (h)	Product		Yield[a] (%)
1		**1**	15		**2**	82
2		**3**	15		**4**	84
3		**5**	15		**6**	84
4		**7**	24		**8**	86[b]
5		**9**	24		**10**	86[b]
6		**11**	24	—		0

[a] All yields were for pure, isolated products.
[b] The reaction was carried out in the presence of 1 mol % of I_2.

370 nm.[4] Among the solvents and lamps examined, ethyl acetate and 500 W xenon-lamp were found to be most effective (entries 1–8). The yield of **2** was increased when the reaction time was extended up to 15 h (entry 10). Although 5 mol % of iodine was required to give **2** in high yield, an excess amount of iodine inhibited this oxidation (entries 6, 11 and 12). On the other hand, the result that, without iodine, irradiation or molecular oxygen, **2** was not obtained or was obtained only in low yield shows the necessity of all of the foregoing conditions for this reaction (entries 13–15). Although iodine, lithium iodide and calcium iodide were found to be superior to other catalysts we examined, we exclusively used iodine, which is metal-free and inexpensive, as an iodo source. On the other hand, product **2** was obtained only in moderate yield when using bromine (entries 6, 16–23).

Table 2 shows the results of this decarboxylation using several substrates under the reaction conditions mentioned above. Mandelic acid derivatives (**1**, **3** and **5**) produced to the corresponding benzoic acids (**2**, **4** and **6**), respectively, in high yields regardless of electron-donating group or electron-withdrawing group at aromatic nucleus (entries 1–3). Acetophenone (**8**) and benzophenone (**10**) were obtained in 86% yield when atrolactic acid (**7**) and benzilic acid (**9**) were used as substrates in the presence of 1 mol % of iodine for 24 h (entries 4 and 5). Unfortunately, 2-hydroxy-*n*-octanoic acid (**11**), an aliphatic substrate, was intact under this reaction condition (entry 6).

Scheme 1 shows a plausible path of this oxidation, which is postulated by considering the necessity of continuous irradiation, a catalytic amount of iodine and molecular oxygen in this reaction. α-Hydroxy carboxylic acid **12** initially reacts with iodine to generate **13**, which transforms



Scheme 1. Plausible path of the aerobic photo-decarboxylation.

to radical species **14** by irradiation with 500 W xenon-lamp. The corresponding carbonyl compound **16** is formed from **14** through decarboxylation and elimination of hydrogen iodide with iodo radical (Eq. 1). When **16** is aldehyde (R = H), further oxidation proceeds, and the corresponding carboxylic acid **18** is generated through peracid **17** (Eq. 2).[5,6] Iodine is regenerated by aerobic photo-oxidation of hydrogen iodide or hypoiodous acid (Eq. 3).

In conclusion, we have found the oxidative photo-decarboxylation of α-hydroxy carboxylic acid derivatives to the corresponding carboxylic acids or ketones selectively in high yields. This new oxidation is interesting in keeping with the notion of Green Chemistry due to the non-use of heavy metals and halogenated solvents, waste reduction, and the use of molecular oxygen.

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4. *A typical procedure follows*: A dry ethyl acetate solution (5 mL) of the mandelic acid (**1**, 0.3 mmol) and I_2 (0.015 mmol) in a pyrex test tube equipped with an O_2-balloon was irradiated without stirring condition for 15 h with a 500 W xenon-lamp through the filter which absorbs the UV of wavelength less than 370 nm, which was set from the test tube in the distance of 45 cm. The reaction mixture was concentrated under reduced pressure. The pure product was obtained by purification with preparative TLC.
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6. Although the corresponding carboxylic acid was obtained in 45% yield under the same reaction conditions when using benzaldehyde as a substrate, the yield was reduced to 22% yield without iodine. This suggests that hydrogen iodide, generated from iodine, promotes the transformation of **17** and **18**.