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Catalytic oxidations of enolizable ketones using 2-alkylidene-4-oxothiazolidine vinyl bromide

Marija Baranac-Stojanović [a,b,*], Rade Marković [a,b], Milovan Stojanović [b]

[a] Faculty of Chemistry, University of Belgrade, Studentski trg 16, P.O. Box 158, 11000 Belgrade, Serbia
[b] Center for Chemistry ICTM, P.O. Box 473, 11000 Belgrade, Serbia

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ABSTRACT

Direct oxidation of enolizable ketones to α-hydroxy derivatives, vicinal dicarbonyls or tricarbonyl compounds has been achieved by a catalytic amount of 2-alkylidene-4-oxothiazolidine vinyl bromide in DMSO as a solvent. The yields range from moderate to good.

1. Introduction

The oxidation of enolizable ketones is an important transformation leading to synthetic intermediates, such as α-diketones, glyoxals and α-hydroxyketones, which are of considerable significance in organic and medicinal chemistry.[1] A popular method for the preparation of α-diketones and glyoxals from methylene[2] and methyl ketones,[1e,3] respectively, is the oxidation with selenium dioxide. An alternative is DMSO-based oxidations. Conversion of α-bromoacetophenones to arylglyoxals through the agency of DMSO was reported by Kornblum et al.[4] and later improved by Floyd et al.[5] who showed that acetophenones can be directly oxidized to arylglyoxals with an excess of 48% aq HBr in DMSO. The latter procedure was also applied for the oxidation of α-methylene ketones to the corresponding α-diketones.[6] An attempted catalytic oxidation of acetophenone by 48% aq HBr in DMSO, however, resulted in low yield of the product (10%).[7] Other oxidation methods for the formation of α-diketones involve oxidation of various substrates: (i) olefins with selenium dioxide[8] or potassium permanganate,[9] (ii) acetylenes with potassium permanganate,[10] $PdCl_2$/DMSO,[11] NBS/DMSO,[12] or HCO_2H/$MeSO_3H$/HBr/DMSO,[13] (iii) α-hydroxyketones or the corresponding tautomeric 1,2-dihydroxyethenes with iodine,[14] atmospheric oxygen,[15] sodium hypobromite,[16] bismuth nitrate–copper(II) acetate,[17] or a catalytic amount of trichlorooxovanadium.[18] The routes to α-hydroxyketones include the reaction of enolates[19] or silyl enol ethers[20] with sources of electrophilic oxygen, or direct hydroxylations by iodine[21] or hypervalent iodine reagents.[22] Catalytic α-hydroxylations are multistep syntheses involving the preformation of pure enol ethers,[23] though the direct proline-catalyzed α-oxyamination,[23] iodobenzene-catalyzed α-acetoxylation,[24] alanine-[23] or metal-catalyzed hydroxylations with molecular oxygen have also been reported.[25] The formation of tertiary alcohols from β-dicarbonyl compounds is usually accomplished by metal-catalyzed α-hydroxylation with O_2[26] or dimethyl dioxirane (DMDO).[27] The use of a slight excess of 2-iodoxybenzoic acid (IBX) for the α-hydroxylation of β-dicarbonyl compounds has also been reported.[28] Hydroxyketones are also accessible by ketohydroxylation of alkenes,[23,29] or by partial reduction of α-diketones.[30]

In the course of our studies on reactivity of push–pull 2-alkylidene-4-oxothiazolidines **1** we have found that vinyl bromides **2**, easily prepared by bromination of **1**,[31] can undergo an easy cleavage of the C–Br bond in the presence of a nucleophile.[31,32] Depending on the type of nucleophile used, this cleavage can end up in reductive dehalogenation (path A, Scheme 1), bromine substitution (path B) or bromine migration to the C(5) position of the ring (path C). This last path is the basis for the C(5) functionalization of *N*-unsubstituted 2-alkylidene-4-oxothiazolidines.[31,32b]

In DMSO, the C–Br dissociation is spontaneous and the bromonium ion, released into the solution, is trapped by the C(5) of another vinyl bromide **2** yielding dibromide **3** (Scheme 2). Subsequent hydrolysis gives the alcohols **4** and liberates HBr.[33]

* Corresponding author. Tel.: +381 11 3336740; fax: +381 11 2636061; e-mail address: mbaranac@chem.bg.ac.rs (M. Baranac-Stojanović).

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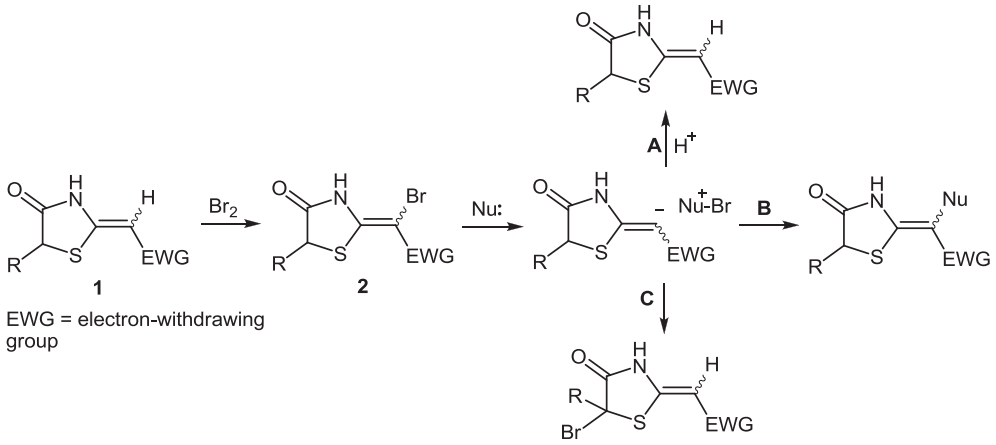
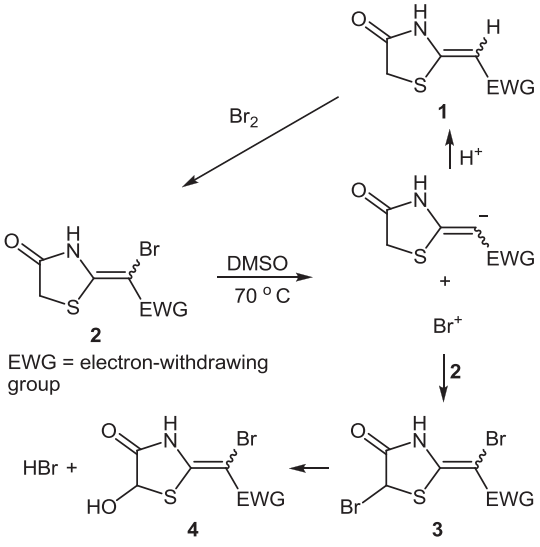


Scheme 1.

Oxidation of HBr by DMSO (Scheme 3)[34] results in the formation of molecular bromine, which reacts with **1** (Scheme 2), thus regenerating the starting vinyl bromide **2**. Now, **2** can enter the reaction cycle again giving the products **4** in moderate to good yields (55–72%).[33]

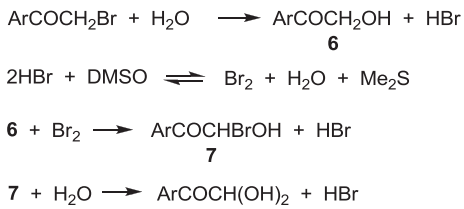


Scheme 2.

Scheme 3.

We saw a possible synthetic application of this reaction in the presence of a second component, which could be brominated and further oxidized by DMSO, as described by Kornblum et al.[4] and Floyd et al.[5] In fact, two mechanisms were proposed for this oxidation. According to the first, the DMSO–adduct **5**, formed from DMSO and α-bromoketone, is decomposed to glyoxal and dimethyl sulfide (Scheme 4).[35]

The second mechanism was suggested by Floyd et al.,[5] based on their experimental observations (Scheme 5). It involves the hydrolysis of α-bromoacetophenone to α-hydroxyketone **6**. Molecular bromine, formed by the oxidation of liberated HBr by DMSO, then reacts with **6** to give the intermediate **7**, which is rapidly hydrolyzed to glyoxal **8**.

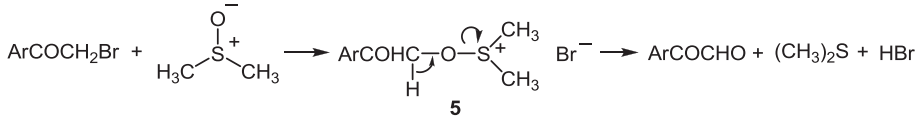


Scheme 5.

According to both mechanisms HBr is liberated. Since its oxidation (Scheme 3) can regenerate the source of electrophilic bromine (Br_2 or vinyl bromide **2**), we reasoned that a catalytic amount of **2** would be enough for the reaction. In addition, dimethyl sulfide is also formed in the oxidation step (Scheme 3). As its accumulation can lead to formation of by-products[5] and depletion of bromine,[13] it should be removed from the reaction mixture. In this paper, we report on the catalytic oxidation of various enolizable ketones and β-dicarbonyl compounds by vinyl bromide **2** in DMSO.

2. Results and discussion

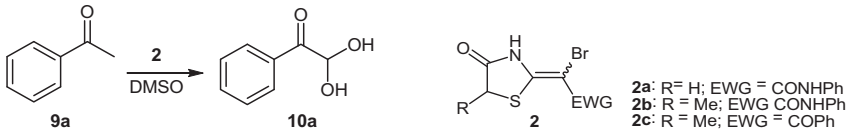
Our investigation began with the oxidation of acetophenone **9a** (Table 1). Thus, a mixture of the substrate **9a**/vinyl bromide **2a**/DMSO in a molar ratio 1:0.1:13 was heated in an open flask,[36] at the temperature of an oil bath of 80 °C (entry 1). The oxidation did occur, though in low yield. Since the catalyst **2a** can react with bromine according to the Scheme 2,[37] two other 5-substituted bromides **2b** and **2c** (Table 1), not undergoing C(5) bromination, were also tried as catalysts (entries 2 and 3). Although the



Scheme 4.

conversion of **9a** to phenylglyoxal hydrate **10a** occurred in similar yields, the reaction time was almost triple than that with **2a**. For this reason all other reactions were performed with the bromide **2a**. The dilution of the reaction mixture by increasing the amount of the solvent, DMSO, increased the yield from 36% to 57% (compare entries 1 and 4–6). The best molar ratio was 1:0.1:26 and further dilution did not have an effect on the reaction time and yield of the product (entries 5 and 6). We were intrigued to see if even lower quantity of the catalyst could affect the transformation with similar outcome. With one molar percent of catalyst the reaction was extremely slow and after 5 days there was still appreciable amount of unreacted substrate **9a** (not shown in the Table). Five molar percent of the catalyst under the same conditions gave lower yield of the product (entry 7), while in a more concentrated solution the yield was even lower (entry 8).

Table 1
Oxidation of acetophenone **9a** under different conditions[a]



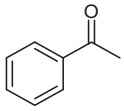
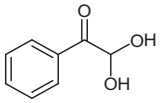
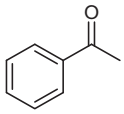
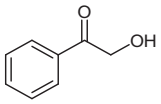
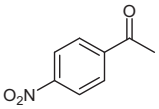
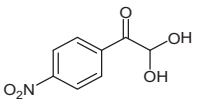
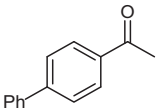
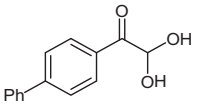
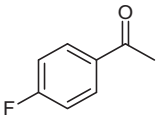
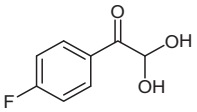
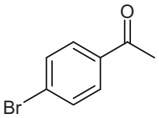
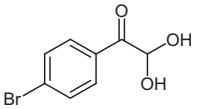
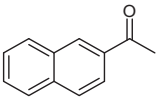
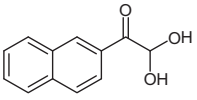
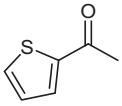
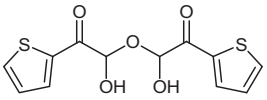
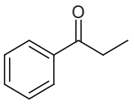
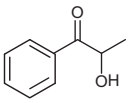
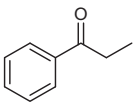
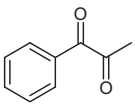
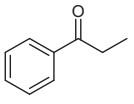
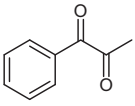
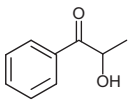
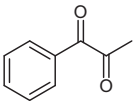
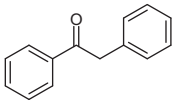
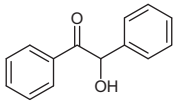
Entry	Catalyst	Molar ratio Substrate/catalyst/DMSO	Time (h)	Yield[b] of **10a** (%)
1	**2a**	1:0.1:13	12	36
2	**2b**	1:0.1:13	34	30
3	**2c**	1:0.1:13	34	38
4	**2a**	1:0.1:19	48	36
5	**2a**	1:0.1:26	47	57
6	**2a**	1:0.1:52	48	57
7	**2a**	1:0.05:26	48	35
8	**2a**	1:0.05:13	48	22

[a] All reactions were heated at the temperature of an oil bath of 80 °C in an open flask in order to remove dimethyl sulfide.
[b] Isolated yield after column chromatography.

Thus we chose the conditions as presented in Table 1, entry 5, and attempted to oxidize a series of methyl ketones **9b**–**g**, as shown in Table 2 (entries 3–8). All substrates **9b**–**f** underwent oxidation to the corresponding arylglyoxal hydrates **10b**–**f** under the selected reaction conditions, in moderate yields. In the case of 2-acetylthiophene **9g** only hemiacetal dimer **10g** was isolated. By comparison, the use of 0.1 equiv of HBr (as 48% aq HBr) for the oxidation of **9a** and **9b** under analogous reaction conditions afforded products **10a** and **10b** in 37% and 33% yields, respectively. Increasing the reaction temperature resulted in shortening of the reaction time with the same product yield in the case of **9e** as a substrate (entry 6). Unfortunately, higher reaction temperature was not suitable for the conversion of other substrates to arylglyoxals due to increased rate of decomposition/by-products formation.[38]

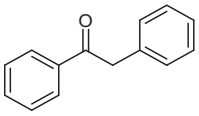
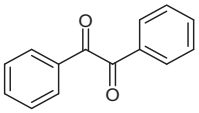
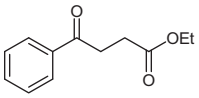
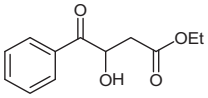
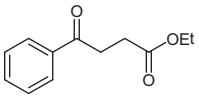
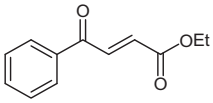
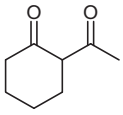
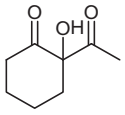
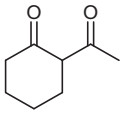
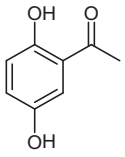
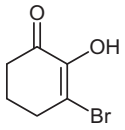
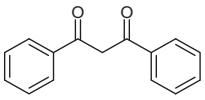
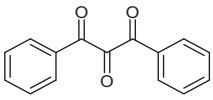
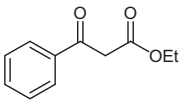
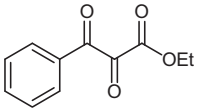
The vinyl bromide-catalyzed oxidation is not confined to methyl ketones. Under analogous conditions (substrate/**2a**/DMSO 1:0.1:26) α-methylene ketones were oxidized to the corresponding α-hydroxyketones and α-diketones. A judicious choice of the reaction conditions allows one to obtain one or another product. Thus, heating of propiophenone **12a** with 0.1 equiv of **2a** in DMSO at the temperature of 115 °C for 2 h yielded the α-hydroxyketone **13a** as the main product (entry 9). Prolongation of the reaction time or higher temperature resulted in further oxidation to the α-diketone **14a** (entries 10 and 11). It should be noted that the purity of **14a** obtained by direct oxidation of propiophenone **12a** was 90–95%, since the conversion of the starting material was never complete and the similarity in structures did not allow separation of **12a** and **14a** by column chromatography. The pure **14a** could be obtained starting from the α-hydroxyketone **13a** (entry 12). In fact, this oxidation required higher reaction temperature: increasing the temperature from 110 °C to 145 °C resulted in increase in the yield of **14a** from 12% to 38%. By contrast, the more activated methylene group in **12b** was oxidized under milder conditions and in higher yield (entries 13 and 14). Thus, heating of deoxybenzoin **12b** at the temperature of 85–90 °C for 12 h resulted in the formation of α-hydroxy compound **13b** (entry 13), which was further oxidized to **14b** in good yield by simple prolongation of the reaction time (entry 14). Raising the temperature increases the yield of **14b** and reduces the reaction time (entry 14). Vinyl bromide-catalyzed reaction also enabled the introduction of α-hydroxy group in the substrates **12c** and **12d**, the structure of which is such that an easy dehydrogenation would be expected. The secondary and tertiary alcohols **13c** and **13d** were obtained under standard reaction conditions, albeit in reduced yields (entries 15 and 17), as both reactions were accompanied by concomitant dehydrogenation. In the case of **12c**, under the conditions specified (entry 15), the alkene **15** was isolated in 13% yield, resulting in total conversion of 58%. With **12d** as the substrate, the dehydrogenation ended in the formation of 2,5-dihydroxyacetophenone **16** in 12% yield, making an overall conversion of 42% (entry 17). It is assumed that the formation of **16** comes from an allylic bromination of primarily formed α,β-unsaturated compound, followed by hydrolysis and subsequent aromatization, via α-keto bromination and dehydrobromination. Raising the reaction temperature increased the yield of dehydrogenated products **15** and **16** from 13% to 33% and 12% to 19%, respectively (entries 16 and 18), though in the latter case the improvement was only slight. In both reactions the secondary and tertiary alcohols **13c** and **13d** were also isolated and the total conversion of the substrates **12c** and **12d**, under the conditions specified in entries 16 and 18, was 59% and 42%, respectively. An attempted oxidation of cyclohexanone **12e** gave only the brominated product **17** (entry 19), obviously by a primary oxidation to enolized α-diketone, which was then quickly brominated. Oxidation of β-dicarbonyl compounds **18a** and **18b** proceeded smoothly at somewhat elevated temperature to give the vicinal tricarbonyl compounds **19a** and **19b** (entries 20 and 21), which were isolated as a mixture of keto and hydrated form. Since most established synthetic routes to this preparatively useful class of compounds involve oxidation of preformed α-substituted derivatives,[39] this

Table 2
Oxidation of enolizable ketones and dicarbonyl compounds with a catalytic amount of vinyl bromide **2a** in DMSO[a]

Entry		Substrate		Product	Reaction conditions Temperature (°C)/Time (h)	Yield[b] (%)
1	**9a**		**10a**		80/47	57
2	**9a**		**11**		80/11	8
3	**9b**		**10b**		80/36	52
4	**9c**		**10c**		80/48	65
5	**9d**		**10d**		80/48	65
6	**9e**		**10e**		80/24; 110/4	65; 66
7	**9f**		**10f**		80/48	61
8	**9g**		**10g**		95–100/27	43
9	**12a**		**13a**		115/2	60
10	**12a**		**14a**		115/25	39[c]
11	**12a**		**14a**		135/24	46[c]
12	**13a**		**14a**		145/2	38
13	**12b**		**13b**		85–90/12	65

(*continued on next page*)

Table 2 (*continued*)

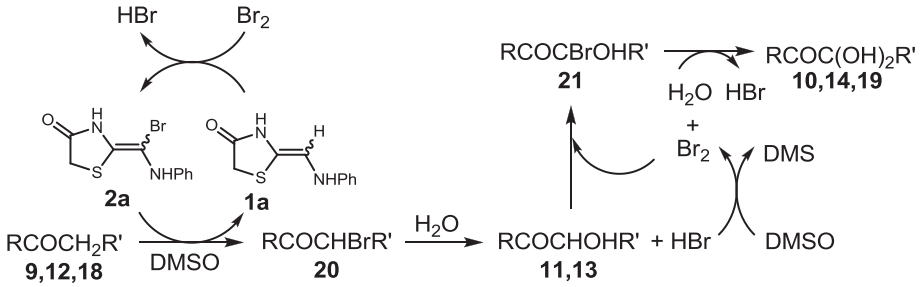
Entry		Substrate		Product	Reaction conditions Temperature (°C)/Time (h)	Yield[b] (%)
14	**12b**		**14b**		85–90/36; 135/7	71; 85
15	**12c**		**13c**		80/28	45 (58)[d]
16	**12c**		**15**		140/1.5	33 (59)[e]
17	**12d**		**13d**		110–115/7.5	30 (42)[f]
18	**12d**		**16**		130–135/3	19 (42)[g]
19	**12e**		**17**		80/14[h]	7[i]/68[j]
20	**18a**		**19a**		130–135/2	55
21	**18b**		**19b**		120/4	59

[a] The reactions were performed using substrate/catalyst/DMSO 1:0.1:26 molar ratio.
[b] Isolated yield after column chromatography.
[c] The purity ranges from 90% to 95%.
[d] Total conversion of the substrate **12c** into α-hydroxy derivative **13c** and alkene **15**, which was obtained in 13% yield under the specified conditions.
[e] Total conversion of the substrate **12c** into alkene **15** and α-hydroxy derivative **13c**, which was obtained in 26% yield under the specified conditions.
[f] Total conversion of the substrate **12d** into tertiary alcohol **13d** and **16**, which was obtained in 12% yield under the specified conditions.
[g] Total conversion of the substrate **12d** into **16** and tertiary alcohol **13d**, which was obtained in 23% yield under the specified conditions.
[h] The reaction concentration was doubled.
[i] Yield based on cyclohexanone.
[j] Yield based on the available bromine, i.e., vinyl bromide.

direct oxidation of readily available β-dicarbonyl compounds should be of particular interest.

From a mechanistic point of view, the first step in the oxidation reactions is α-bromination to **20** by electrophilic bromine released from the vinyl bromide **2a** (Scheme 6). Two mechanisms have been suggested for the oxidation of α-bromoketones by DMSO, as depicted in Schemes 4 and 5. The isolation of α-hydroxy derivatives **13** goes in favour of the second mechanism proposed by Floyd et al.[5] In addition, the α-hydroxyacetophenone **11** was isolated as the intermediate in the oxidation of acetophenone (Table 2, entry 2). The water necessary for this hydrolytic step was present in small amount in DMSO, as we used the commercially obtained solvent without any further purification.[40] Water is also produced during the oxidation of the liberated HBr by DMSO (Schemes 3 and 6). Molecular bromine, formed in the same step, may react with the α-hydroxy compounds **11** and **13** to give the unobservable α-hydroxy-α-bromo intermediates **21** or with the parent 4-oxothiazolidine **1a**, thus regenerating the catalyst **2a**. The last step is the rapid hydrolysis of **21** to products **10**, **14** and **19**. All α-keto aldehydes (arylglyoxals) were isolated as hydrates, tricarbonyl compounds as a mixture of hydrate and keto form, and α-diketones in the keto form. Finally, the catalyst **2a** is turned into the 5-hydroxy derivative **4** (Scheme 2), which needs to be removed by aq Na_2CO_3 only before the purification of arylglyoxals **10** by

column chromatography (see Experimental section). The fact that the analogous HBr-catalyzed oxidations of **9a** and **9b** proceeded in lower yields (37% and 33%, respectively, see Results and discussion section) may be rationalized by drop in the equilibrium concentration of bromine (Scheme 3) due to the increased amount of water, added as 48% aq HBr.



Scheme 6.

3. Conclusion

We have presented a novel, catalytic method for the direct oxidation of enolizable ketones that allows the introduction of a secondary or tertiary hydroxy group, or creation of vicinal dicarbonyl and tricarbonyl structural unit. The catalyst is non-toxic and readily obtainable. The method is operationally simple and reaction conditions are neutral. This procedure has circumvented the use of stoichiometric amounts of oxidants, or toxic transition-metal catalysts. It has also avoided highly acidic reaction medium as in the HBr–DMSO oxidations, or selenium-containing contaminants, which often accompany products of selenium dioxide oxidations.

4. Experimental

4.1. General

Melting points were determined on a Stuart SMP10 apparatus and are uncorrected. The IR spectra were recorded on a Perkin–Elmer FT-IR 1725X spectrophotometer and are reported as wave numbers (cm^{-1}). The NMR spectra were recorded on a Varian Gemini 2000 spectrometer (^1H at 200 MHz, ^{13}C at 50.3 MHz) in DMSO-d_6 or $CDCl_3$. Chemical shifts are reported in parts per million (ppm) on the δ scale from TMS as an internal standard. HRMS was carried out on 6210 TOF LC/MS coupled with HPLC 1200 Series Agilent Technologies. Thin-layer chromatography (TLC) was carried out on Kieselgel G nach Stahl and spots were visualized by iodine or by 50% H_2SO_4. Column chromatography was carried out on SiO_2 (silica gel 60 Å, 12–26, ICN Biomedicals). Solvents used for column chromatography were distilled before use. All liquid substrates were distilled before use. DMSO was used without purification. Vinyl bromide **2a** was synthesized according to the published procedure.[31] It should be kept in a freezer.

4.2. General procedure for the oxidation

A mixture of a substrate (0.6 mmol), vinyl bromide **2a** (0.06 mmol) in DMSO (1.1 mL) was heated in an open flask (the temperature of an oil bath and the reaction time are specified in Table 2). After the completion of the reaction (checked by TLC), the reaction mixture was diluted with water (11 mL), saturated with NaCl and extracted with ethyl acetate (5×4 mL). Only in the case of the synthesis of arylglyoxals the organic layer was additionally washed with Na_2CO_3 (0.12 mmol in 2 mL of water), with saturated aq NaCl and dried with anhydrous Na_2SO_4. Column chromatography (eluent: gradient petrolether/ethyl acetate) of the extract gave the pure products. The products were characterized on the basis of spectral data and where possible by comparison with the literature data.

*4.2.1. Phenylglyoxal hydrate (**10a**).* Compound **10a** was obtained from **9a** (74.5 mg, 0.62 mmol) and **2a** (19.4 mg, 0.062 mmol) in DMSO (1.2 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 80:20) gave pure **10a** (53.9 mg, 57%) as a white solid, mp 72–74 °C (lit.[3c] 73–91 °C, depending on the degree of hydration); R_f=0.25 (petrolether/ethyl acetate 4:1); IR (KBr):[13] ν_{max} 3407, 1697, 1596, 1448, 1111, 714, 684 cm^{-1}; ^1H NMR[13] (200 MHz, DMSO-d_6, 25 °C): δ 5.71 (br s, 1H, CH), 6.77 (d, J=6.4 Hz, 2H, 2× OH), 7.46–7.68 (m, 3H, *m*- and *p*-Ph), 8.08 (d, J=6.8 Hz, 2H, *o*-Ph); ^{13}C NMR[13] (50.3 MHz, DMSO-d_6, 25 °C): δ 89.4, 128.7, 129.6, 133.6, 134.0, 196.5; HRMS calcd for $C_8H_7O_3$ $(M-H)^-$: 151.0401; found: 151.0411.

*4.2.2. 2-Hydroxyacetophenone (**11**).* Compound **11** was obtained from **9a** (70.6 mg, 0.59 mmol) and **2a** (18.4 mg, 0.059 mmol) in DMSO (1.1 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 80:20) gave pure **11** (6.5 mg, 8%) as a pale yellow solid, mp 81–82 °C (lit.[22b] 80–82 °C); R_f=0.35 (petrolether/ethyl acetate 4:1); IR (KBr):[22b] ν_{max} 3446, 1691, 1597, 1449, 1097, 1019, 757, 689 cm^{-1}; ^1H NMR[22b] (200 MHz, $CDCl_3$, 25 °C): δ 3.51 (t, J=4.2 Hz, 1H, OH), 4.89 (d, J=4.2 Hz, 2H, CH_2), 7.47–7.55 (m, 2H, *m*-Ph), 7.60–7.69 (m, 1H, *p*-Ph), 7.91–7.97 (m, 2H, *o*-Ph); ^{13}C NMR (50.3 MHz, $CDCl_3$, 25 °C): δ 65.4, 127.7, 129.0, 133.6, 134.3, 198.4; HRMS calcd for $C_8H_7O_2$ $(M-H)^-$: 135.0452; found: 135.0455.

*4.2.3. p-Nitrophenylglyoxal hydrate (**10b**).* Compound **10b** was obtained from **9b** (101.7 mg, 0.62 mmol) and **2a** (19.3 mg, 0.062 mmol) in DMSO (1.2 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 90:10 to 70:30) gave pure **10b** (63.0 mg, 52%) as a pale yellow solid, mp 90–91 °C (lit.[3a] 97–100 °C); R_f=0.22 (petrolether/ethyl acetate 7:3); IR (KBr): ν_{max} 3328, 1694, 1605, 1534, 1350, 1012, 855 cm^{-1}; ^1H NMR[41] (200 MHz, DMSO-d_6, 25 °C): δ 5.67 (t, J=6.2 Hz, 1H, CH), 7.07 (d, J=6.2 Hz, 2H, 2× OH), 8.26–8.37 (m, 4H, Ph); ^{13}C NMR[41] (50.3 MHz, DMSO-d_6, 25 °C): δ 90.3, 123.8, 131.1, 138.8, 150.1, 195.6; no molecular ion was detected by HRMS.

*4.2.4. (p-Phenyl)phenylglyoxal hydrate (**10c**).* Compound **10c** was obtained from **9c** (120.0 mg, 0.61 mmol) and **2a** (19.2 mg, 0.061 mmol) in DMSO (1.1 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 80:20) gave pure **10c** (91.2 mg, 65%) as a pale yellow solid, mp 109–110 °C (lit.[42] 113–117 °C); R_f=0.24 (petrolether/ethyl acetate 7:3); IR (KBr): ν_{max} 3436, 3376, 1694, 1603, 1449, 1126, 865, 752, 692 cm^{-1}; ^1H NMR (200 MHz, DMSO-d_6, 25 °C): δ 5.75 (br s, 1H, CH), 6.83 (br d, J=6.4 Hz, 2H, 2× OH), 7.42–7.55 (m, 3H, *m*- and

p-Ph), 7.23–7.84 (m, 4H, *o*- and *m*-Ph), 8.19 (d, *J*=8.4 Hz, 2H, *o*-Ph); ^{13}C NMR (50.3 MHz, DMSO-d_6, 25 °C): δ 89.6, 126.9, 127.3, 128.7, 129.4, 130.4, 132.7, 139.3, 144.9, 196.1; HRMS calcd for dehydrated form $C_{14}H_{11}O_2$ $(M+H)^+$: 211.0754; found: 211.0749.

*4.2.5. p-Fluorophenylglyoxal hydrate (**10d**).* Compound **10d** was obtained from **9d** (83.7 mg, 0.61 mmol) and **2a** (19.0 mg, 0.061 mmol) in DMSO (1.1 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 80:20) gave pure **10d** (66.5 mg, 65%) as a pale yellow solid, mp 80–81 °C (lit.[3b] 80–82 °C); R_f=0.26 (petrolether/ethyl acetate 7:3); IR (KBr): ν_{max} 3348, 1699, 1597, 1505, 1231, 1061, 804 cm^{-1}; ^{1}H NMR (200 MHz, DMSO-d_6, 25 °C): δ 5.65 (br s, 1H, CH), 6.84 (br s, 2H, 2× OH), 7.28–7.39 (m, 2H, *m*-Ph), 8.11–8.20 (m, 2H, *o*-Ph); ^{13}C NMR (50.3 MHz, DMSO-d_6, 25 °C): δ 89.9, 115.6, 116.0, 132.7, 132.9, 162.8, 167.8, 195.2; HRMS calcd for dehydrated form $C_8H_6FO_2$ $(M+H)^+$: 153.0346; found: 153.0342.

*4.2.6. p-Bromophenylglyoxal hydrate (**10e**).* Compound **10e** was obtained from **9e** (110.0 mg, 0.55 mmol) and **2a** (17.3 mg, 0.055 mmol) in DMSO (1.0 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 80:20) gave pure **10e** (83.0 mg, 65%) as a pale yellow solid, mp 108–109 °C (lit.[43] 125 °C); R_f=0.32 (petrolether/ethyl acetate 7:3); IR (KBr): ν_{max} 3376, 1693, 1582, 1008, 806 cm^{-1}; ^{1}H NMR[1e] (200 MHz, DMSO-d_6, 25 °C): δ 5.63 (br s, 1H, CH), 6.87 (br s, 2H, 2× OH), 7.71–7.77 (m, 2H, *m*-Ph), 7.99–8.03 (m, 2H, *o*-Ph); ^{13}C NMR[1e] (50.3 MHz, DMSO-d_6, 25 °C): δ 89.9, 127.6, 131.7, 131.8, 132.9, 195.7; HRMS calcd for $C_8H_7BrClO_3$ $(M+Cl)^-$: 264.9273; found: 264.9289.

*4.2.7. Naphthalen-2-yl-oxoacetaldehyde hydrate (**10f**).* Compound **10f** was obtained from **9f** (90.1 mg, 0.53 mmol) and **2a** (16.6 mg, 0.053 mmol) in DMSO (1.0 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 80:20) gave pure **10f** (65.1 mg, 61%) as a white solid, mp 84–86 °C (lit.[1e] 108–111 °C); R_f=0.35 (petrolether/ethyl acetate 7:3); IR (KBr): ν_{max} 3406, 1685, 1624, 1095, 798, 746 cm^{-1}; ^{1}H NMR[1e] (200 MHz, DMSO-d_6, 25 °C): δ 5.83 (t, *J*=7.4 Hz, 1H, CH), 6.84 (d, *J*=7.4 Hz, 2H, 2× OH), 7.58–7.72 (m, 2H, arom.), 7.98–8.12 (m, 4H, arom.), 8.78 (s, 1H, arom.); ^{13}C NMR[1e] (50.3 MHz, DMSO-d_6, 25 °C): δ 89.5, 124.9, 127.2, 127.9, 128.3, 129.0, 129.9, 131.2, 131.7, 132.2, 135.3, 196.5; no molecular ion was detected by HRMS.

*4.2.8. Thiophen-2-yl-oxoacetaldehyde hemiacetal dimer (**10g**).* Compound **10g** was obtained from **9g** (74.3 mg, 0.59 mmol) and **2a** (18.5 mg, 0.059 mmol) in DMSO (1.1 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 90:10 to 60:40) gave pure **10g** (37.7 mg, 43%) as a pale yellow oil; R_f=0.15 (petrolether/ethyl acetate 7:3); IR (KBr): ν_{max} 3412, 1666, 1408, 1056, 729 cm^{-1}; ^{1}H NMR (200 MHz, DMSO-d_6, 25 °C): δ 5.88 (d, *J*=7.4 Hz, 1H, CH), 7.24–7.28 (m, 1H, arom.), 7.54 (d, *J*=7.4 Hz, 1H, OH), 8.03–8.09 (m, 2H, arom.); ^{13}C NMR (50.3 MHz, DMSO-d_6, 25 °C): δ 91.4, 129.1, 135.8, 136.1, 139.9, 187.5; HRMS calcd for $C_{12}H_{10}O_5S_2Na$ $(M+Na)^+$: 320.9862; found: 320.9856.

*4.2.9. 2-Hydroxy-1-phenyl-1-propanone (**13a**).* Compound **13a** was obtained from **12a** (69.7 mg, 0.52 mmol) and **2a** (16.3 mg, 0.052 mmol) in DMSO (1.0 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 90:10) gave pure **13a** (46.8 mg, 60%) as a pale yellow oil; R_f=0.24 (petrolether/ethyl acetate 9:1); IR (KBr): ν_{max} 3457, 1679, 1596, 1127, 968, 697 cm^{-1}; ^{1}H NMR[44] (200 MHz, $CDCl_3$, 25 °C): δ 1.46 (d, *J*=7.2 Hz, 3H, CH_3), 3.84 (br s, 1H. OH), 5.17 (q, *J*=7.2 Hz, 1H, CH), 7.46–7.67 (m, 3H, *m*- and *p*-Ph), 7.91–7.97 (m, 2H, *o*-Ph); ^{13}C NMR[44] (50.3 MHz, $CDCl_3$, 25 °C): δ 22.2, 69.2, 128.6, 128.8, 133.3, 134.0, 202.4; no molecular ion was detected by HRMS.

*4.2.10. 1-Phenylpropane-1,2-dione (**14a**).* Compound **14a** was obtained from **13a** (90.5 mg, 0.60 mmol) and **2a** (18.9 mg, 0.060 mmol) in DMSO (1.1 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 90:10) gave pure **14a** (34.1 mg, 38%) as a yellow oil; R_f=0.79 (petrolether/ethyl acetate 9:1); IR (KBr): ν_{max} 1711, 1671, 1596, 1159, 701 cm^{-1}; ^{1}H NMR[45] (200 MHz, $CDCl_3$, 25 °C): δ 2.53 (s, 3H, CH_3), 7.50 (t, *J*=7.4 Hz, 2H, *m*-Ph), 7.65 (t, *J*=7.4 Hz, 1H, *p*-Ph), 8.02 (d, *J*=7.4 Hz, 2H, *o*-Ph); ^{13}C NMR[45] (50.3 MHz, $CDCl_3$, 25 °C): 26.3, 128.9, 130.3, 131.8, 134.6, 191.4, 200.6; no molecular ion was detected by HRMS.

*4.2.11. 2-Hydroxy-1,2-diphenylethanone (benzoin, **13b**).* Compound **13b** was obtained from **12b** (110.0 mg, 0.56 mmol) and **2a** (17.6 mg, 0.056 mmol) in DMSO (1.1 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 90:10) gave pure **13b** (77.4 mg, 65%) as a pale yellow solid, mp 132–133 °C (lit.[22b] 126–128 °C); R_f=0.18 (petrolether/ethyl acetate 9:1); IR (KBr): ν_{max} 3413, 3378, 1679, 1595, 1449, 1068, 755, 701 cm^{-1}; ^{1}H NMR[22b] (200 MHz, $CDCl_3$, 25 °C): δ 4.57 (d, *J*=5.9 Hz, 1H, OH), 5.96 (d, *J*=5.9 Hz, 1H, CH), 7.25–7.56 (m, 8H, arom.), 7.89–7.94 (m, 2H, *o*-Ph); ^{13}C NMR (50.3 MHz, $CDCl_3$, 25 °C): δ 76.1, 127.7, 128.6, 128.7, 129.1, 133.4, 133.9, 139.0, 198.9; HRMS calcd for $C_{14}H_{12}O_2Na$ $(M+Na)^+$: 235.0730; found: 235.0727.

*4.2.12. 1,2-Diphenylethane-1,2-dione (benzil, **14b**).* Compound **14b** was obtained from **12b** (106.2 mg, 0.54 mmol) and **2a** (16.9 mg, 0.054 mmol) in DMSO (1.0 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 90:10) gave pure **14b** (96.9 mg, 85%) as a pale yellow solid, mp 93–94 °C (lit.[12] 94–95 °C); R_f=0.60 (petrolether/ethyl acetate 9:1); IR (KBr):[13] ν_{max} 1675, 1662, 1594, 1449, 1211, 720 cm^{-1}; ^{1}H NMR[13] (200 MHz, $CDCl_3$, 25 °C): δ 7.47–7.55 (m, 2H, *m*-Ph), 7.62–7.71 (m, 1H, *p*-Ph), 7.95–8.00 (m, 2H, *o*-Ph); ^{13}C NMR[13] (50.3 MHz, $CDCl_3$, 25 °C): δ 129.0, 129.9, 132.9, 134.9, 194.6; HRMS calcd for $C_{14}H_{11}O_2$ $(M+H)^+$: 211.0754; found: 211.0748.

*4.2.13. Ethyl 3-hydroxy-4-oxo-4-phenylbutanoate (**13c**).* Compound **13c** was obtained from **12c** (120.2 mg, 0.58 mmol) and **2a** (18.3 mg, 0.058 mmol) in DMSO (1.1 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 70:30) gave pure **13c** (58.7 mg, 45%) as a pale yellow oil; R_f=0.29 (petrolether/ethyl acetate 4:1); IR (KBr): ν_{max} 3439, 1730, 1684, 1596, 1164, 1097, 692 cm^{-1}; ^{1}H NMR[46] (200 MHz, $CDCl_3$, 25 °C): δ 1.25 (t, *J*=7.2 Hz, 3H, CH_3), 2.57–2.94 (m, 2H, CH_AH_B), 4.16 (q, *J*=7.2 Hz, 2H, CH_2O), 5.43 (dd, J_{AX}=7.9 Hz, J_{BX}=3.9 Hz, 1H, CH_X), 7.46–7.66 (m, 3H, *m*- and *p*-Ph), 7.92–7.97 (m, 2H, *o*-Ph); ^{13}C NMR (50.3 MHz, $CDCl_3$, 25 °C): δ 13.9, 40.2, 61.0, 70.1, 128.6, 128.9, 133.3, 134.0, 170.44, 199.9; HRMS calcd for $C_{12}H_{15}O_4$ $(M+H)^+$: 223.0965; found: 223.0955.

*4.2.14. Ethyl 4-oxo-4-phenylbut-2-enoate (**15**).* Compound **15** was obtained from **12c** (118.9 mg, 0.58 mmol) and **2a** (18.1 mg, 0.058 mmol) in DMSO (1.1 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 70:30) gave pure **15** (39.1 mg, 33%) as a light yellow oil; R_f=0.77 (petrolether/ethyl acetate 4:1); IR (KBr): ν_{max} 1720, 1670, 1295, 1165, 729, 688 cm^{-1}; ^{1}H NMR[47] (200 MHz, $CDCl_3$, 25 °C): δ 1.35 (t, *J*=7.2 Hz, 3H, CH_3), 4.31 (q, *J*=7.2 Hz, 2H, CH_2O), 6.89 (d, *J*=15.0 Hz, 1H, =CH), 7.47–7.67 (m, 3H, *m*- and *p*-Ph), 7.91 (d, *J*=15.0 Hz, 1H, CH=), 7.98–8.02 (m, 2H, *o*-Ph); ^{13}C NMR[47]

(50.3 MHz, $CDCl_3$, 25 °C): δ 14.1, 61.3, 128.9, 132.6, 133.9, 136.4, 137.0, 165.6, 189.6; no molecular ion was detected by HRMS.

*4.2.15. 2-Acetyl-2-hydroxycyclohexanone (**13d**).* Compound **13d** was obtained from **12d** (76.7 mg, 0.55 mmol) and **2a** (17.1 mg, 0.055 mmol) in DMSO (1.0 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 70:30) gave pure **13d** (25.5 mg, 30%) as a pale yellow oil; R_f=0.46 (petrolether/ethyl acetate 4:1); IR (KBr): ν_{max} 3450, 1707, 1355, 1122 cm^{-1}; ^1H NMR[28] (200 MHz, $CDCl_3$, 25 °C): δ 1.56–1.96 (m, 4H, CH_2CH_2), 2.00–2.17 (m, 1H, C*H*H), 2.24 (s, 3H, CH_3), 2.34–2.50 (m, 1H, CH*H*), 2.56–2.81 (m, 2H, CH_2), 4.63 (s, 1H, OH); ^{13}C NMR[28] (50.3 MHz, $CDCl_3$, 25 °C): δ 21.6, 25.5, 27.2, 38.4, 39.3, 85.3, 207.5, 209.0; HRMS calcd for $C_8H_{13}O_3$ $(M+H)^+$: 157.0859; found: 157.0877.

*4.2.16. 2,5-Dihydroxyacetophenone (**16**).* Compound **16** was obtained from **12d** (68.7 mg, 0.49 mmol) and **2a** (15.4 mg, 0.049 mmol) in DMSO (0.9 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 70:30) gave pure **16** (14.1 mg, 19%) as a yellow solid, mp 184–186 °C (lit.[48] 197–199 °C); R_f=0.20 (petrolether/ethyl acetate 4:1); IR (KBr):[48] ν_{max} 3385, 3269, 1643, 1619, 1581, 1499, 1305, 1214, 788, 713 cm^{-1}; ^1H NMR[48] (200 MHz, DMSO-d_6, 25 °C): δ 2.57 (s, 3H, CH_3), 6.79 (d, *J*=9.0 Hz, 1H, H(3)-Ph), 6.96–7.02 (dd, *J*=9.0, 3.4 Hz, 1H, H(4)-Ph), 7.17 (d, *J*=3.4 Hz, 1H, H(6)-Ph), 9.72 (s, 1H, OH), 11.3 (s, 1H, OH); ^{13}C NMR (50.3 MHz, DMSO-d_6, 25 °C): δ 28.0, 115.7, 118.6, 120.5, 124.8, 149.7, 154.1, 204.4; HRMS calcd for $C_8H_7O_3$ $(M-H)^-$: 151.0401; found: 151.0419.

*4.2.17. 3-Bromo-2-hydroxycyclohex-2-enone (**17**).* Compound **17** was obtained from **12e** (56.5 mg, 0.58 mmol) and **2a** (18.0 mg, 0.058 mmol) in DMSO (0.6 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 90:10 to 70:30) gave pure **17** (7.5 mg, 7% based on **12e**, 68% based on **2a**) as a white solid, mp 100–102 °C (lit.[49] 103–104 °C); R_f=0.62 (petrolether/ethyl acetate 7:3); IR (KBr): ν_{max} 3255, 1666, 1641, 1321, 1162 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$, 25 °C): δ 2.08 (quintet, *J*=6.4 Hz, 2H, CH_2), 2.57 (t, *J*=6.4 Hz, 2H, CH_2C=), 2.89 (t, *J*=6.4 Hz, 2H, CH_2C=O), 6.41 (s, 1H, OH); ^{13}C NMR (50.3 MHz, $CDCl_3$, 25 °C): δ 22.9, 34.4, 35.5, 119.4, 146.0, 209.6; HRMS calcd for $C_6H_7BrO_2Na$ $(M+Na)^+$: 212.9522; found: 212.9523.

*4.2.18. 1,3-Diphenylpropane-1,2,3-trione/hydrate (**19a**).* Compound **19a** was obtained from **18a** (115.8 mg, 0.52 mmol) and **2a** (16.2 mg, 0.052 mmol) in DMSO (1.0 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 80:20) gave pure **19a** (70.6 mg, 55%, ketone/hydrate 1:1.6 molar ratio) as a yellow solid, mp 62–63 °C (lit.[50] 66 °C); R_f=0.26 (petrolether/ethyl acetate 4:1); IR (KBr): ν_{max} 3395, 1680, 1596, 1449, 1117, 725, 686 cm^{-1}; ^1H NMR[28] (200 MHz, $CDCl_3$, 25 °C): 1,3-*Diphenylpropane*-1,2,3-*trione*: δ 7.51–7.59 (m, 2H, *m*-Ph), 7.67–7.76 (m, 1H, *p*-Ph), 8.06–8.10 (m, 2H, *o*-Ph), *Diphenylpropane*-1,2,3-*trione hydrate*: δ 5.93 (s, 2H, 2× OH), 7.31–7.39 (m, 2H, *m*-Ph), 7.47–7.56 (m, 1H, *p*-Ph), 7.92–7.96 (m, 2H, *o*-Ph); ^{13}C NMR[28] (50.3 MHz, $CDCl_3$, 25 °C): *Diphenylpropane*-1,2,3-*trione*: δ 129.1, 130.2, 132.1, 135.4, 188.2, 192.5, *Diphenylpropane*-1,2,3-*trione hydrate*: δ 94.0, 128.8, 130.2, 132.0, 134.7, 194.0; HRMS calcd for $C_{15}H_{11}O_4$ $(M-H)^-$: 255.0663; found: 255.0677.

*4.2.19. Ethyl 2,3-dioxo-3-phenylpropanoate/hydrate (**19b**).* Compound **19b** was obtained from **18b** (96.8 mg, 0.50 mmol) and **2a** (15.8 mg, 0.050 mmol) in DMSO (1.0 mL) according to general procedure. Column chromatography (eluent: gradient petrolether/ethyl acetate 100:0 to 80:20) gave pure **19b** (65.8 mg, 59%, ketone/hydrate 1:5.7 molar ratio) as a yellow oil; R_f=0.23 (petrolether/ethyl acetate 4:1); IR (KBr): ν_{max} 3419, 1745, 1693, 1598, 1236, 1129, 1102, 687 cm^{-1}; ^1H NMR[28] (200 MHz, $CDCl_3$, 25 °C): *Ethyl* 2,3-*dioxo*-3-*phenylpropanoate*: δ 1.38 (t, *J*=7.4 Hz, 3H, CH_3), 4.42 (q, *J*=7.4 Hz, 2H, CH_2O), 7.43–7.75 (m, 3H, *m*- and *p*-Ph), 7.98–8.02 (m, 2H, *p*-Ph), *ethyl* 2,3-*dioxo*-3-*phenylpropanoate hydrate*: δ 1.07 (t, *J*=7.4 Hz, 3H, CH_3), 4.21 (q, *J*=7.4 Hz, 2H, CH_2O), 5.48 (br s, 2H, 2× OH), 7.43–7.75 (m, 3H, *m*- and *p*-Ph), 8.04–8.12 (m, 2H, *p*-Ph); ^{13}C NMR[28] (50.3 MHz, $CDCl_3$, 25 °C): *ethyl* 2,3-*dioxo*-3-*phenylpropanoate hydrate*: δ 13.5, 63.1, 91.7, 128.7, 130.1, 134.6, 135.5, 169.8, 191.6. HRMS calcd for *ketone* $C_{11}H_{11}O_4$ $(M+H)^+$: 207.0652; found: 207.0651; HRMS calcd for *hydrate* $C_{11}H_{12}O_5Na$ $(M+Na)^+$: 247.0577; found: 247.0578.

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References and notes

1. For α-dicarbonyl compounds, see: (a) Quiroga, J.; Acosta, P. A.; Cruz, S.; Abonia, R.; Insuasty, B.; Nogueras, M.; Cobo, J. *Tetrahedron Lett.* **2010**, *51*, 5443; (b) Lecinska, P.; Corres, N.; Moreno, D.; Garcia-Valverde, M.; Marcaccini, S.; Torroba, T. *Tetrahedron* **2010**, *66*, 6783; (c) Shibata, I.; Kojima, R.; Tsunoi, S.; Nozaki, T.; Watanabe, T.; Ninomiya, A.; Yasuda, M.; Baba, A. *Org. Biomol. Chem.* **2010**, *8*, 2009; (d) Sanudo, M.; Garcia-Valverde, M.; Marcaccini, S.; Delgado, J. J.; Rojo, J.; Torroba, T. *J. Org. Chem.* **2009**, *74*, 2189; (e) Reid, C. M.; Ebikeme, C.; Barrett, M. P.; Patzewitz, E.-M.; Müller, S.; Robins, D. J.; Sutherland, A. *Bioorg. Med. Chem. Lett.* **2008**, *18*, 2455; (f) Khalili, B.; Jajarmi, P.; Eftekhari-Sis, B.; Hashemi, M. M. *J. Org. Chem.* **2008**, *73*, 2090; (g) Arrault, A.; Dubuisson, M.; Gharbi, S.; Marchand, C.; Verbeuren, T.; Rupin, A.; Cordi, A.; Bouskela, E.; Rees, J.-F.; Marchand-Brynaert, J. *Bioorg. Med. Chem. Lett.* **2003**, *13*, 653 For α-hydroxyketones, see: (h) Mengel, A.; Reiser, O. *Chem. Rev.* **1999**, *99*, 1191; (i) Ghosh, A. K.; McKee, S. P.; Sanders, W. M. *Tetrahedron Lett.* **1991**, *32*, 711; (j) Roush, W.; Michaelides, M.; Tai, D.; Chong, W. *J. Am. Chem. Soc.* **1987**, *109*, 7575; (k) Lin, J.; Nikaido, M.; Clark, G. *J. Org. Chem.* **1987**, *52*, 3745; (l) Kido, F.; Kitahara, H.; Yoshikoshi, A. *J. Org. Chem.* **1986**, *51*, 1478; (m) Shono, T.; Matsamura, S.; Matsamura, Y.; Inoue, K.; Iwasaki, F. *J. Chem. Soc., Perkin Trans. 1* **1986**, 73.
2. (a) Chang, L. L.; Sidler, K. L.; Cascieri, M. A.; de Laszlo, S.; Koch, G.; Li, B.; MacCoss, M.; Mantlo, N.; O'Keefe, S.; Pang, M.; Rolando, A.; Hagmann, W. K. *Bioorg. Med. Chem. Lett.* **2001**, *11*, 2549; (b) Buehler, C. A.; Addleburg, J. W.; Glenn, D. M. *J. Org. Chem.* **1955**, *20*, 1350.
3. (a) Steinbach, L.; Becker, E. I. *J. Am. Chem. Soc.* **1954**, *76*, 5808; (b) Minor, J. T.; Vanderwerf, C. A. *J. Org. Chem.* **1952**, *17*, 1425; (c) Riley, H. A.; Grey, A. R. *Org. Synth.* **1947**, *II*, 509.
4. Kornblum, N.; Powers, J. W.; Anderson, G. J.; Jones, W. J.; Larson, H. O.; Levand, O.; Weaver, W. M. *J. Am. Chem. Soc.* **1957**, *79*, 6562.
5. Floyd, M. B.; Du, M. T.; Fabio, P. F.; Jacob, L. A.; Johnson, B. D. *J. Org. Chem.* **1985**, *50*, 5022.
6. (a) McKenna, J. M.; Halley, F.; Souness, J. E.; McLay, I. M.; Pickett, S. D.; Collis, A. J.; Page, K. M.; Ahmed, I. *J. Med. Chem.* **2002**, *45*, 2173; (b) Collis, A. J.; Foster, M. L.; Halley, F.; Maslen, C.; McLay, I. M.; Page, K. M.; Redford, E. J.; Souness, J. E.; Wilsher, N. E. *Bioorg. Med. Chem. Lett.* **2001**, *11*, 693.
7. Schipper, E.; Cinnamon, M.; Rascher, L.; Chiang, Y. H.; Oroshnik, W. *Tetrahedron Lett.* **1968**, 6201.
8. Buehler, C. A.; Harris, J. O.; Arendale, W. F. *J. Am. Chem. Soc.* **1950**, *72*, 4953.
9. Barta, T. E.; Stealey, M. A.; Collins, P. W.; Weier, R. M. *Bioorg. Med. Chem. Lett.* **1998**, *8*, 3443.
10. Walsh, C. J.; Mandal, B. K. *J. Org. Chem.* **1999**, *64*, 6102.
11. Yusubov, M. S.; Zholobova, G. A.; Vasilevsky, S. F.; Tretyakov, E. V.; Knight, D. W. *Tetrahedron* **2002**, *58*, 1607.
12. Wolfe, S.; Pilgrim, W. R.; Garrard, T. F.; Chamberlain, P. *Can. J. Chem.* **1971**, *49*, 1099.
13. Wan, Z.; Jones, C. D.; Mitchell, D.; Pu, J. Y.; Zhang, T. Y. *J. Org. Chem.* **2006**, *71*, 826.
14. (a) Heirtzler, F.; Neuburger, M.; Kulike, K. *J. Chem. Soc., Perkin Trans. 1* **2002**, 809; (b) Bark, T.; Weyhermüller, T.; Heirtzler, F. *Chem. Commun.* **1998**, 1475.
15. (a) Katritzky, A. R.; Lang, H.; Wang, Z.; Zhang, Z.; Song, H. *J. Org. Chem.* **1995**, *60*, 7619; (b) Buehler, C. A.; Harris, J. O. *J. Am. Chem. Soc.* **1950**, *72*, 5015.
16. Chang, H. S.; Woo, J. C.; Lee, K. M.; Ko, Y. K.; Moon, S.-S.; Kim, D.-W. *Synth. Commun.* **2002**, *32*, 31.
17. Tymonko, S. A.; Nattier, B. A.; Mohan, R. S. *Tetrahedron Lett.* **1999**, *40*, 7657.
18. Kirihara, M.; Ochiai, Y.; Takizawa, S.; Takahata, H.; Nemoto, H. *Chem. Commun.* **1999**, 1387.
19. (a) Mishra, J. K. *Synlett* **2005**, 543; (b) Crimmins, M. T.; Pace, J. M.; Nantermet, P. G.; Kim-Meade, A. S.; Thomas, J. B.; Watterson, S. H.; Wagman, A. S. *J. Am. Chem. Soc.* **2000**, *122*, 8453; (c) Ichinari, D.; Ueki, T.; Yoshihara, K.; Kinoshita, T. *Chem. Commun.* **1997**, 1743; (d) Davis, F. A.; Clark, C.; Kumar, A.; Chen, B. C. *J. Org. Chem.* **1994**, *59*, 1184; (e) Guertin, K. R.; Chan, T.-H. *Tetrahedron Lett.* **1991**, *32*, 715; (f) Reissig, H. U. *Org. Synth. Highlights* **1991**, 40; (g) Masui, M.; Ando, A.; Shiori, T.

Tetrahedron Lett. **1988**, *29*, 2835; (h) Gardner, J. N.; Carlon, F. E.; Gnoj, O. J. *J. Org. Chem.* **1968**, *33*, 3294.
20. (a) Allen, J. G.; Danishefsky, S. J. *J. Am. Chem. Soc.* **2001**, *123*, 351; (b) Dayan, S.; Bareket, Y.; Rozen, S. *Tetrahedron* **1999**, *55*, 3657; (c) Horiguchi, Y.; Nakamura, E.; Kuwajima, I. *Tetrahedron Lett.* **1989**, *30*, 3323; (d) Andriamialisoa, R. Z.; Langlois, N.; Langlois, Y. *Tetrahedron Lett.* **1985**, *26*, 3563; (e) Lee, T. V.; Tockzek, J. *Tetrahedron Lett.* **1982**, *23*, 2917.
21. Zacuto, M. J.; Cai, D. *Tetrahedron Lett.* **2005**, *46*, 447.
22. (a) Moriarty, R. M. *J. Org. Chem.* **2005**, *70*, 2893; (b) Xie, Y.-Y.; Chen, Z.-C. *Synth. Commun.* **2002**, *32*, 1875; (c) Ley, S. V.; Thomas, A. W.; Finch, H. *J. Chem. Soc., Perkin Trans. 1* **1999**, 669; (d) Moriarty, R. M.; Berglund, B. A.; Penmasta, R. *Tetrahedron Lett.* **1992**, *33*, 6065; (e) Moriarty, R. M.; Hu, H.; Gupta, S. C. *Tetrahedron Lett.* **1981**, *22*, 1283.
23. Plietker, B. *Tetrahedron: Asymmetry* **2005**, *16*, 3453 and references cited therein.
24. Ochiai, M.; Takeuchi, Y.; Katayama, T.; Sueda, T.; Miyamoto, K. *J. Am. Chem. Soc.* **2005**, *127*, 12244.
25. Chuang, G. J.; Wang, W.; Lee, E.; Ritter, T. *J. Am. Chem. Soc.* **2011**, *133*, 1760.
26. (a) Christoffers, J.; Kauf, T.; Werner, T.; Rössle, M. *Eur. J. Org. Chem.* **2006**, 2601; (b) Christoffers, J.; Werner, T.; Frey, W.; Baro, A. *Chem.—Eur. J.* **2004**, *10*, 1042; (c) Christoffers, J.; Werner, T.; Unger, S.; Frey, W. *Eur. J. Org. Chem.* **2003**, 425 and references cited therein.
27. Adam, W.; Smerz, A. K. *Tetrahedron* **1996**, *52*, 5799.
28. Duschek, A.; Kirsch, S. F. *Chem.—Eur. J.* **2009**, *15*, 10713.
29. Plietker, B. *Synthesis* **2005**, 2453 and references cited therein.
30. Ho, T.-L.; Olah, G. A. *Synthesis* **1976**, 815.
31. (a) Baranac-Stojanović, M.; Tatar, J.; Stojanović, M.; Marković, R. *Tetrahedron* **2010**, *66*, 6873.
32. (a) Baranac-Stojanović, M.; Tatar, J.; Kleinpeter, E.; Marković, R. *Synthesis* **2008**, 2117; (b) Baranac-Stojanović, M.; Marković, R. *Synlett* **2006**, 729; (c) Marković, R.; Pavlovich, J. G.; Baranac, M. *Phosphorus, Sulfur Silicon Relat. Elem.* **2005**, *180*, 1411.
33. Baranac-Stojanović, M.; Marković, R. *Tetrahedron Lett.* **2007**, *48*, 1695.
34. (a) Dickman, D. A.; Chemburkar, S.; Konopacki, D. B.; Elisseon, E. M. *Synthesis* **1993**, 573; (b) Aida, T.; Akasaka, T.; Furukawa, N.; Oae, S. *Bull. Chem. Soc. Jpn.* **1976**, *49*, 1117; (c) Zoretic, P. A. *J. Org. Chem.* **1975**, *40*, 1867; (d) Aida, T.; Furukawa, N.; Oae, S. *Tetrahedron Lett.* **1973**, 3853.
35. (a) Torssell, K. *Acta Chem. Scand.* **1967**, *21*, 1; (b) Nace, H. R.; Monagle, J. J. *J. Org. Chem.* **1959**, *24*, 1792.
36. The reactions were heated in an open flask in order to remove dimethyl sulfide. When working with larger quantities dimethyl sulfide should be distilled off.
37. The alcohol **4** is not as effective in donating electrophilic bromine as is bromide **2**.
38. One of by-products formed at elevated temperatures was alkene ArCOC(SMe)=CHCOAr. For the synthesis of this type of alkenes from aryl methyl ketones, see: Yin, G.; Zhou, B.; Meng, X.; Wu, A.; Pan, Y. *Org. Lett.* **2006**, *8*, 2245.
39. (a) Wasserman, H. H.; Parr, J. *Acc. Chem. Res.* **2004**, *37*, 687; (b) Rubin, M. B.; Gleiter, R. *Chem. Rev.* **2000**, *100*, 1121.
40. DMSO is highly hygroscopic liquid. If not purified and kept over molecular sieves it contains a certain amount of water.
41. Karlsson, I.; Hillerström, L.; Stenfeldt, A.-L.; Mårtenson, J.; Börje, A. *Chem. Res. Toxicol.* **2009**, *22*, 1881.
42. Gunn, V. E.; Anselme, J. P. *J. Org. Chem.* **1977**, *42*, 754.
43. Karrer, P.; Musante, C. *Helv. Chim. Acta* **1935**, *18*, 1140.
44. Chai, V.; Takeda, A.; Hara, M.; Ji, S.-J.; Horiuchi, A. *Tetrahedron* **2005**, *61*, 2453.
45. Lourenço, E.; Rodrigues, J. A. R.; Moran, P. J. S. *J. Mol. Catal. B: Enzym.* **2004**, *29*, 37.
46. El-Seedi, H. R.; Jensen, H. M.; Kure, N.; Thomsen, I.; Torssell, K. B. G. *Acta Chem. Scand.* **1993**, *47*, 1004.
47. Bhella, S. S.; Elango, M.; Ishar, M. P. S. *Tetrahedron* **2009**, *65*, 240.
48. Naeimi, H.; Moradi, L. *J. Mol. Catal. A: Chem.* **2006**, *256*, 242.
49. Sato, K.; Suzuki, S.; Kojima, Y. *J. Org. Chem.* **1967**, *32*, 339.
50. Schank, K.; Lick, C. *Synthesis* **1983**, 392.