

Catalytic Allylation of Hydrates of α -Keto Aldehydes and Glyoxylates with Allyltrimethylsilane Using Non-Fluorine-Containing Sulfonic Acids as Catalysts*

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Received 5 March 2001; revised 3 April 2001

ABSTRACT: *Methanesulfonic acid, aromatic sulfonic acids, and 10-camphorsulfonic acid have been used as catalysts in allylation of hydrates of α -keto aldehydes **1a–d** and glyoxylates **1e–f** with allyltrimethylsilane **2** to afford the corresponding homoallylic alcohols **4a–e** in good yields. Two plausible mechanisms of sulfonic acid-catalyzed allylation reactions with an allylsilane are discussed. © 2001 John Wiley & Sons, Inc. Heteroatom Chem 12:534–538, 2001*

INTRODUCTION

The allylation of carbonyl compounds with an allylsilane under Lewis acid conditions (the Hosomi-Sakurai reaction [1]) has been extensively used for the formation of carbon–carbon bonds in organic synthesis [2]. This reaction can be promoted by stoichiometric amounts of a conventional Lewis acid such as TiCl_4 , SnCl_4 , and AlCl_3 and catalyzed by various species, such as fluoride ions [3], lanthanide

triflate [4], trimethylsilyl triflate (TMSOTf) [5], a superacid $\text{TfOH}_2^+ \text{B}(\text{OTf})_4^-$ (prepared from BBr_3 and TfOH) [6], and a Brønsted acid $\text{HN}(\text{SO}_2\text{F})_2$ [7]. The strong electron-withdrawing fluorine atom contained in these catalysts appears to be very important for the catalytic capability. A question arises whether reagents without a fluorine substituent could also catalyze the Hosomi-Sakurai reaction. On the other hand, since allyltrimethylsilane is likely hydrolyzed under acidic conditions [8], a Brønsted acid has been used only a few times as a catalyst for the addition of allylsilane to carbonyl compounds [7]. Herein, we wish to report the results on the allylation of aldehydes with allyltrimethylsilane (Hosomi-Sakurai reaction) catalyzed by non-fluorine-containing sulfonic acids, including methanesulfonic acid, aromatic sulfonic acids, and 10-camphorsulfonic acid.

RESULTS AND DISCUSSION

Methanesulfonic Acid as a Catalyst

The allylation reactions of hydrates of α -keto aldehydes (**1b–d**) and glyoxylates (**1e–f**) with allyltrimethylsilane **2** in the presence of a catalytic amount (10 mol %) of methanesulfonic acid (**MsOH**) (**3**) were carried out in dichloromethane (Scheme 1) at room temperature for a given time to afford the corresponding α -keto (**4a–c**) and α -ester (**4d,e**) homoallylic alcohols

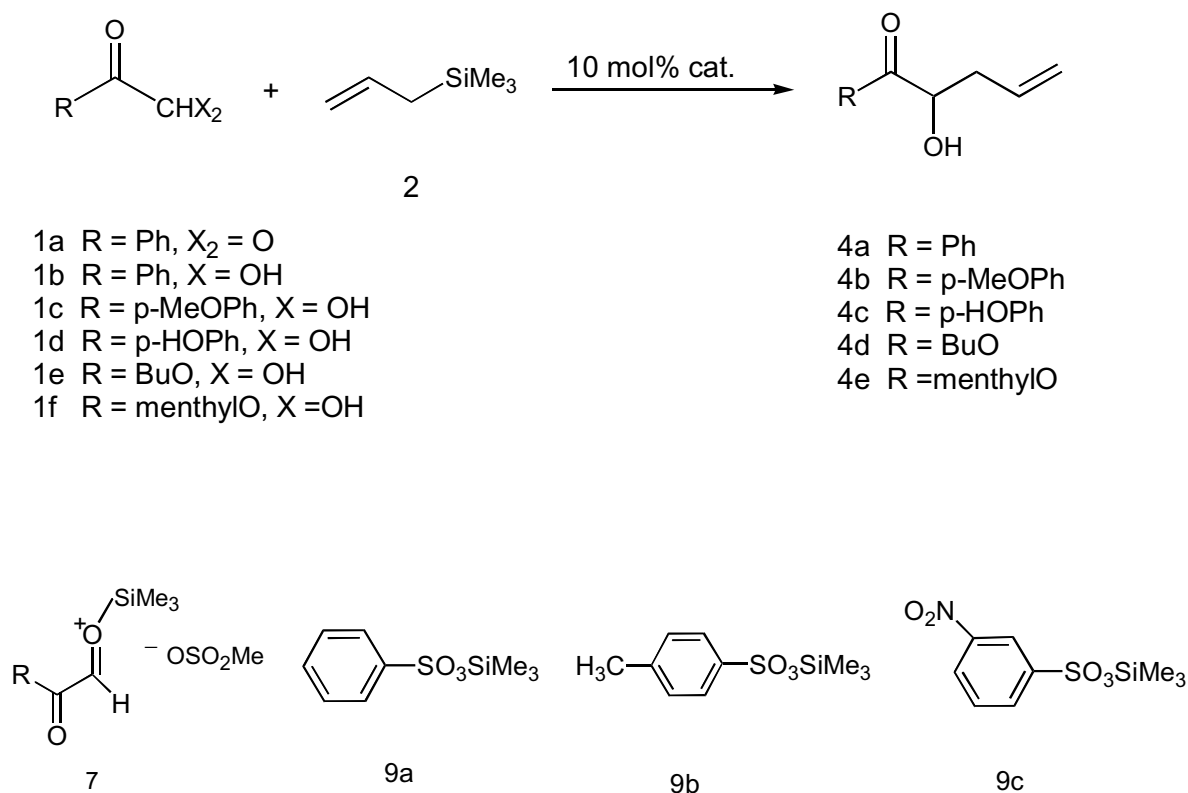
*For preliminary report, see: Wang, M. W.; Chen, Y. J.; Wang, D. Synlett 2000, 385–387.

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Contract Grant Sponsor: National Natural Science Foundation of China (298720041).

Contract Grant Sponsor: Chinese Academy of Sciences.

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SCHEME 1

in yields of 62–74% (Table 1). The reactions show very good chemoselectivity with the retention of keto and ester carbonyl groups. In the case of (–)-menthyl glyoxylate **1f** [9], the diastereomeric excess (de) of the product **4e** is 13%, determined by diastereomeric protons in ^1H NMR spectra.

With regard to the results of the MsOH-catalyzed Hosomi-Sakurai reaction, we became inquisitive as to whether MsOH would be an actual catalyst itself. When the reaction mixture of **2** and **3** is monitored by ^1H NMR spectroscopy, a new up-field peak at δ

0.38, assigned to silylmethyl protons of trimethylsilyl methanesulfonate (**5**, TMSOMs) ([10]; δ 0.4) appears soon, and this clearly supports the in situ formation of protodesilylation product **5** in the course of the reaction. Furthermore, the allylation reaction of **1b** with **2** using **5** as a catalyst, which was prepared by the reaction of **3** with chlorotrimethylsilane, gave **4a** in a comparable yield 65% (entry 2 vs. 1). It is interesting to note from the results that the in situ-generated TMSOMs from mixing **2** with **3** retains catalytic capability even in the case of the substrates

TABLE 1 Methanesulfonic Acid-Catalyzed Allylation of **1a–f**^a

Entry	Substrate	Catalyst	Amount of cat. (mol %)	Temp. (°C)	Time (h)	Product	Yield ^b (%)
1	1b	3	10	25	12	4a	66
2	1b	5	10	25	12	4a	65
3	1a	3	10	25	10	4a	62
4	1c	3	10	25	12	4b	63
5	1d	3	10	25	12	4c	70
6	1e	3	10	25	8	4d	74
7	1f	3	10	25	15	4e	72
8	1b	6	20	40	10	4a	54

^aSolvent: CH_2Cl_2 .

^bIsolated yield.

bearing active protons of a hydroxyl group. However, decomposition or deactivation of the conventional moisture-sensitive Lewis acid catalysts might occur by using the same substrates. Corresponding to aldehyde hydrate **1b**, aldehyde **1a**, prepared by dehydration of **1b** by distillation under P_2O_5 , has similar reactivity in the methanesulfonic acid catalyzed allylation reactions (entry 3 vs. 1). In the reaction mixture of **1b** with **2**, the formation of **1a** was observed. It is suggested that there might be an equilibrium between **1a** and **1b** in the reaction media, and the formed **1a** is activated by in situ-generated TMSOMs and reacts with **2**, driving the equilibrium to the side of the aldehyde **1a**. Thus, similar to the plausible mechanism for the TMSOTf catalyzed reaction, suggested by Davis [6b], the catalyzed allylation reaction of aldehyde hydrates with **2** in the presence of **3** could be assumed to involve the in situ generation of the oxonium cation **7** with counterion MsO^- . The catalytic function of $MsOH$ **3** performs by producing an actual catalyst, TMSOMs.

In comparison, a catalytic amount of trifluoromethanesulfonic acid ($TfOH$), (**6**) [11] was used as a catalyst in the reaction of **1b** with **2**. It was found that stronger reaction conditions (reaction temperature $40^\circ C$; 20 mol % of catalyst) were required, and a relatively low yield of product (45%) was obtained.

Aromatic Sulfonic Acids as Catalysts

The reactions of α -keto aldehyde hydrate **1b** with **2** in the presence of aromatic sulfonic acids, including benzenesulfonic acid **8a**, *p*-toluenesulfonic acid **8b**, and *m*-nitrobenzenesulfonic acid **8c** were examined (Table 2). It was found that the aromatic sulfonic acids **8a–c** have a lower catalytic ability than $MsOH$ **3** under the same reaction conditions. A higher reaction temperature ($40^\circ C$) and more catalyst (20 mol %) are required. The substituents on the benzene ring, either methyl or the nitro group, do not influence the catalytic ability in the allylation reaction. Similarly, the new up-field peaks of tetramethylsilane (TMS) in the 1H NMR spectra of the mixtures

of **8a**, **8b**, or **8c** respectively with **2** were observed. The chemical shift at δ 0.36 is assigned to the TMS proton of trimethylsilyl benzenesulfonate **9a** ([12]: δ 0.39), that at δ 0.37 is assigned to trimethylsilyl *p*-toluenesulfonate **9b** ([12]: δ 0.38), and that at δ 0.44 is assigned to trimethylsilyl *m*-nitrobenzenesulfonate **9c**. By using **9a** as a catalyst, the allylation of **1b** proceeds smoothly giving the corresponding homoallylic alcohol **4a** in 69% yield. However, other types of organic acids, such as benzoic acid and heptanoic acid, were not effective in this reaction at all, with starting materials being recovered. The aromatic sulfonic acid-catalyzed allylation of aldehydes with **2** also seemed to be effected by the protodesilylation intermediates of **2** with sulfonic acid.

10-Camphorsulfonic Acid as a Catalyst

10-Camphorsulfonic acid (CSA), (**10**) has been used extensively in synthetic organic chemistry as an acid catalyst [13]. By using a catalytic amount of **10** (10 mol %), the reactions of **1b–f** with **2** in acetonitrile at room temperature proceeded smoothly to afford the products **4a–e** in yields of 64–78% (Table 3). The allylation of aldehyde hydrate **1a**, catalyzed by **10**, also gave **4a** in good yield (68%) (entry 1). The hydroxyl group in each substrate does not need to be protected. Even in the presence of traces of water, (CH_3CN/H_2O [50:1 to 20:1]), the CSA-catalyzed allylation reactions still proceeded smoothly (entries 3, 7, and 8). In order to examine the mechanism of the CSA-catalyzed allylation reaction, the following experiments were carried out: (1) after stirring of the mixture of **10** with **2** for 6 hours, no 1H NMR peak of the corresponding TMS proton was detected, and the starting material **10** was recovered; (2) in the presence of 2,6-di-*tert*-butyl-4-methylpyridine (15 mol %) [14], a known proton scavenger, the CSA-catalyzed allylation reaction does not proceed at all; (3) the reaction of **10** with chlorotrimethylsilane gave complicated products, but no formation of the corresponding TMSOCSA compound was detected. It is

TABLE 2 Aromatic Sulfonic Acid-Catalysed Allylation of **1b**^a

Entry	Catalyst	Amount of cat. (mol %)	Temp. ($^\circ C$)	Time (h)	Product	Yield ^b (%)
1	8a	20	40	10	3a	45
2	8b	20	40	10	3a	40
3	8c	20	40	10	3a	57
4	9a	20	40	12	3a	64

^aSolvent: CH_3CN .

^bIsolated yield.

TABLE 3 CSA-Catalyzed Allylation of **1a–g**^a

Entry	Substrate	Solvent ^b	Temp. (°C)	Time (h)	Product	Yield ^c (%)
1	1a	A	25	10	4a	68
2	1b	A	25	10	4a	66
3	1a	B	25	10	4a	52
4	1c	A	25	10	4b	64
5	1d	A	25	10	4c	70
6	1e	A	25	6	4d	78
7	1e	B	25	6	4d	72
8	1e	C	40	6	4d	50
9	1f	A	25	8	4e	61

^aCatalytic loading: 10 mol %.^bA: CH₃CN, B: CH₃CN/H₂O (50:1); C: CH₃CN/H₂O (20:1).^cIsolated yield.

confirmed that CSA does not cause protodesilylation of allylsilane to give TMSOCSA in the course of the reaction. Based on these results, the CSA-catalyzed allylation reaction seems to be through an H⁺-catalysis cycle suggested by Davis [6b], and CSA functions as a Brönsted acid catalyst for the addition of allylsilane to carbonyl compounds. On the other hand, by use of (+)-**10** as a catalyst, the product of the allylation is racemic (enantiomeric excess [ee] = 0%), while for chiral glyoxylate, **1f**, the de of product **4e** is 11% in spite of a good yield 61% (entry 9). The low diastereoselectivity is reasonable with respect to the suggested H⁺-catalysis mechanism.

It can be concluded from the previously mentioned investigations that the non-fluorine-containing sulfonic acids also can play a catalytic role in some Lewis acid-catalyzed reaction systems, while the presence of the strong electron-withdrawing fluorine atom is not an essential ingredient [15]. The sulfonic acids able to be employed in the catalytic Hosomi-Sakurai reaction are extremely cheap and easy to handle and may possibly be applied to other types of Lewis acid-catalyzed reactions.

EXPERIMENTAL

All the chemicals used were reagent grade. IR spectra were recorded by a Perkin-Elmer 782 spectrophotometer. ¹H and ¹³C NMR spectra were recorded with a Varian XL-300 spectrometer. NMR spectra are reported in ppm with respect to TMS. Mass spectra were taken at 60 eV with an AEI MS-50/PS-30 instrument. Microanalysis was performed on a Calro 1102 Element Analysis instrument. Oxidation of the substituted acetophenones with selenium dioxide gave the hydrates of α -keto aldehydes **1b–d** [16]. The hydrate of glyoxylate **1e** was prepared according to Ref.

[17], while (–)-menthyl glyoxylate **1f** was prepared according to Kornblum's method [9].

General Procedure

MsOH-Catalyzed Allylation Reaction. To a solution of **2** (1 mmol) in 1 mL of CH₂Cl₂, MsOH (0.05 mmol) was added at room temperature. After the mixture had been stirred for 1 hour, the aldehyde hydrate (0.5 mmol) was added. The mixture was stirred for a given reaction time at a given temperature, treated with brine, and extracted with ether. The organic layer was dried over anhydrous Na₂SO₄. The crude product was purified by flash chromatography on silica gel to give the corresponding homoallylic alcohol.

Aromatic Sulfonic Acid-Catalyzed Allylation Reaction. To a solution of **2** (1 mmol) in 1 mL of CH₃CN, an aromatic sulfonic acid (0.05 mmol) was added at room temperature. After the mixture had been stirred for 1 hour, aldehyde hydrate (0.5 mmol) was added. The mixture was stirred for a given reaction time at a given temperature, treated with brine, and extracted with ether. The organic layer was dried over anhydrous Na₂SO₄. The crude product was purified by flash chromatography on silica gel to give the corresponding homoallylic alcohol.

CSA-Catalyzed Allylation Reaction. To a solution of **2** (1 mmol) and aldehyde hydrate (0.5 mmol) in 1 mL of CH₃CN, CSA (0.05 mmol) was added, followed by stirring for a given reaction time at a given temperature. The reaction mixture was treated with brine and extracted with ether. The organic layer was dried over anhydrous Na₂SO₄. The crude product was purified by flash chromatography on silica gel to give the corresponding homoallylic alcohol.

Compound **4a** [18]: colorless oil, IR: $\nu = 3442$, 2900, 1670, 1588, 1440 cm^{-1} . ^1H NMR $\delta = 2.34\text{--}2.43$ (m, 1H), 2.68–2.74 (m, 1H), 5.02–5.20 (m, 3H), 5.76–5.87 (m, 1H), 7.51–7.95 (m, 5H). m/z 176 (M^+ , 1.0), 135 ($\text{M}^+ - 41$, 10.7), 105 (100).

Compound **4b** [4a]: colorless oil, IR: $\nu = 3470$, 2940, 1670, 1570, 1260, 965 cm^{-1} . ^1H NMR $\delta = 2.33\text{--}2.38$ (m, 1H), 2.63–2.65 (m, 1H), 3.90 (s, 3H), 5.00–5.12 (m, 2H), 5.72–5.85 (m, 1H), 6.98 (d, 2H, $J = 9$ Hz), 7.91 (d, 2H, $J = 9$ Hz). m/z 206 (M^+ , 2.5), 135 (100).

Compound **4c** [4a]: colorless oil, IR: $\nu = 3430$, 2950, 1660, 1510, 1280, 1070, 960 cm^{-1} . ^1H NMR $\delta = 2.29\text{--}2.42$ (m, 1H), 4.99–5.16 (m, 2H), 5.74–5.82 (m, 1H), 6.50 (s, 1H), 6.92 (d, 2H, $J = 9.0$ Hz), 7.88 (d, 2H, $J = 9.0$ Hz).

Compound **4d**: Colorless oil. IR: $\nu = 3480$, 3070, 1760, 1635, 1460, 910 cm^{-1} . ^1H NMR $\delta = 0.87$ (t, 3H, $J = 7.3$ Hz, CH_3), 1.20–1.50 (m, 2H, CH_2), 1.55–1.70 (m, 2H, CH_2), 2.18 (s, 1H, OH), 2.35–2.80 (m, 2H, CH_2), 4.12 (dt, 2H, $J = 2.0$, 6.6 Hz), 4.19 (dd, 1H, $J = 4.8$, 6.4 Hz), 5.05–5.22 (m, 2H, $=\text{CH}_2$), 5.7–5.9 (m, 1H, $=\text{CH}$). ^{13}C NMR $\delta = 13.57$, 19.01, 30.57, 38.69, 65.52, 69.92, 118.58, 132.48, 174.48. Anal calcd for $\text{C}_9\text{H}_{16}\text{O}_3$: C, 62.76; H, 9.36. Found: C, 62.65; H, 9.27.

Compound **4e**: Colorless oil. IR: $\nu = 3450$ (OH), 2900, 1720 ($\text{C}=\text{O}$), 1620, 1210 cm^{-1} . ^1H NMR $\delta = 0.71\text{--}0.78$ (2d, 3H, CH_3), 0.80–0.95 (m, 6H), 0.95–2.10 (m, 9H), 2.30–2.64 (m, 2H), 4.24 (dd, 1H, $J = 2.0$, 6.4 Hz, CH), 4.80 (dt, 1H, $J = 4.6$, 6.4 Hz, CH), 5.10–5.25 (m, 2H, $=\text{CH}_2$), 5.70–5.90 (m, 1H, $=\text{CH}$); ^{13}C NMR $\delta = (15.7, 16.2)$, (20.6, 20.8), 21.9, (22.8, 23.3), (25.8, 26.2), 31.3, 34.0, (38.6, 38.7), (40.6, 40.8), (46.8, 46.9), (69.6, 70.0), (75.9, 76.1), (118.6, 118.7), (132.3, 132.4), 174.0. The data in parentheses are from two diastereoisomers. Anal. Calcd. for $\text{C}_{15}\text{H}_{26}\text{O}_3$: C, 70.83; H, 10.30. Found: C, 70.76; H, 10.28.

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