Allylation of Aldehydes with Allyltin Compounds in Acidic Aqueous Media-A Catalytic Version

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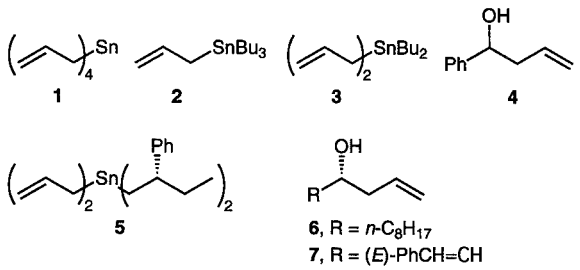
Abstract: Allylation reaction of aldehydes with allyltributyltin was achieved using Sn catalysts in acidic aqueous media. Exclusive aldehyde selectivity was observed for competitive reactions of aldehydes and ketones with allyltributyltin in the presence of 5 mol% of tetraallyltin or $SnCl_4$ in a mixture of aqueous HCl solution and THF.

Previous studies in our laboratory have resulted in new methodology for chemoselective allylation of carbonyl compounds using tetraallyltin (**1**) in acidic aqueous media.[1] This paper concerns the development of the catalytic process. Tetraallyltin (**1**) exists stably in a neutral or basic aqueous solution and reacts very slowly with carbonyl compounds under such reaction conditions.[2,3] However, this tin compound gradually decomposes in acidic aqueous solutions and four of the allyl groups rapidly react with carbonyl compounds in the presence of only 1 equiv of hydrochloric acid.[4,5] In contrast, allyltributyltin (**2**), which is commonly employed for Lewis acid-promoted carbonyl allylation,[6] does not react in the presence of HCl.[7,8] For example, only 3% yield of the product was obtained by its reaction with nonanal at room temperature for 24 h under the influence of a stoichiometric amount of HCl. This striking difference in reactivity between these allyltin reagents prompted us to further investigate the Brønsted acid-promoted allylation reaction. The number of allyl groups of tin reagents is crucial to the conduct of the carbonyl addition reaction. For example, reaction of diallyldibutyltin (**3**, 1 equiv)[9] with benzaldehyde (1 equiv) in a mixture of 2 N HCl (2 equiv) and THF at 20 °C afforded the homoallylic alcohol **4** in 74% yield, whereas no reaction was observed in the absence of the acid. This suggests that $(allyl)_nSnBu_{4-n}$ (n = 2 ~ 4) has a certain interaction with HCl and/or carbonyl compound.



Attempts to perform the catalytic allylation process in acidic aqueous media were successful with use of allyltributyltin (**2**) as an allyl source (eq 1). Selected results are summarized in Table 1. Treatment of 0.05 equiv of tetraallyltin (**1**) with benzaldehyde (1 equiv) in a 1:1 mixture of 2 N HCl (1 equiv) and THF at 20 °C for 40 min followed by addition of allyltributyltin (**2**, 1 equiv) and subsequent stirring for 4 h provided the allylated product **4** in 97% yield (entry 2).[10] Use of less than 0.01 equiv of the catalyst resulted in a lower yield and longer reaction times were required to obtain high yields (entries 3-5). Parallel experiments with aliphatic and α,β-unsaturated aldehydes gave similar results (entries 6 and 7). In the reaction with (*E*)-cinnamaldehyde, an exclusive 1,2-addition took place. Diallyldibutyltin (**3**) showed a similar catalytic activity (entries 8 and 9). Furthermore, tin(IV) oxide and tin(IV) halides were also found to promote the catalytic allylation (entries 10-14), with $SnCl_4$ exhibiting the highest reactivity among them (entries 13 and 14). In contrast, the reaction did not proceed catalytically using a typical Lewis acid, BF_3•OEt_2 (entry 15).

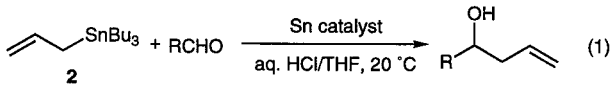


Table 1. Catalytic allylation of aldehydes with allyltributyltin (**2**)[a]

Entry	Catalyst (equiv)	Aldehyde	Time, h	Yield (%)[b]
1[c]	—	PhCHO	4	<1
2	**1** (0.05)	PhCHO	4	97
3	**1** (0.01)	PhCHO	4	59
4	**1** (0.01)	PhCHO	22	86
5	**1** (0.001)	PhCHO	61	70
6	**1** (0.01)	*n*-C_8H_{17}CHO	22	60
7	**1** (0.01)	(*E*)-PhCH=CHCHO	22	67
8	**3** (0.05)	PhCHO	4	83
9[d]	**3** (0.001)	PhCHO	47	30
10	Bu_2SnO (0.05)	PhCHO	24	40
11	Bu_2SnCl_2 (0.05)	*n*-C_8H_{17}CHO	24	60
12	Bu_2SnBr_2 (0.05)	*n*-C_8H_{17}CHO	24	55
13[e]	$SnCl_4$ (0.05)	PhCHO	4	71
14[f]	$SnCl_4$ (0.05)	PhCHO	14	90
15[e]	BF_3·OEt_2 (0.05)	PhCHO	4	3

[a] Unless otherwise noted, the reaction was carried out using catalyst (0.05 ~ 0.001 equiv), allyltributyltin (**2**, 1 equiv), and aldehyde (1 equiv) in a 1:1 mixture of 2 *N* HCl (1 equiv) and THF at 20 °C. [b] Isolated yield. [c] The reaction was performed in a 1:8 mixture of 2 *N* HCl (1 equiv) and THF. [d] The reaction was performed in a 3:5 mixture of 2 *N* HCl (1 equiv) and THF. [e] The reaction was performed in a 1:5 mixture of 2 *N* HCl (1 equiv) and THF. [f] The reaction was performed in a 1:2 mixture of 2 *N* HCl (1 equiv) and THF

The present catalytic allylation exhibited a high chemoselectivity towards aldehydes and some examples are shown in Table 2. For instance, in the reaction of benzaldehyde (1 equiv) and acetophenone (1 equiv) with allyltributyltin (1 equiv) in the presence of tetraallyltin (**1**, 0.05 equiv) in a mixture of 2 N HCl (1 equiv) and THF, only the aldehyde adduct was obtained in 97% yield (entry 3). Use of $SnCl_4$ as a catalyst resulted in a similar chemoselectivity and satisfactory yield (entry 4). Exclusive aldehyde selectivities were also observed for the competitive reaction of aliphatic aldehydes and ketones (entries 1, 2, 5, and 6).

Figure 1 provides a proposed mechanism of the catalytic reaction pathway of allyltributyltin (**2**) with aldehydes in the presence of a catalytic amount of tetraallyltin (**1**) or diallyldibutyltin (**3**). First, the tin catalyst reacts with 2 equiv of HCl to generate a tin dichloride **A**. Subsequent allyl group transfer from allyltributyltin (**2**) to **A** gives a diorganoallyltin chloride **B** which would have a moderate Lewis acidity. Coordination of aldehyde to **B** followed by allyl group migration of the resulting pentacoordinated tin compound **C** via a six-membered cyclic transition structure **D** produces a tin alkoxide of homoallylic alcohol **E**. Finally, the reaction of **E** with HCl regenerates the tin dichloride **A**. The allyltin chloride **B** is regarded as a key intermediate for catalytic and stoichiometric carbonyl addition reactions with allyltin reagents in acidic aqueous media.[11]

Table 2. Catalytic chemoselective allylation of aldehydes with allyltributyltin (**2**)[a]

Entry	Sn catalyst	Carbonyl compounds	Yield (%)[b]	Ratio[c]
1[d]	**1**	n-$C_7H_{15}CHO$ + n-$C_5H_{11}COCH_3$	57	>99:1
2[d]	$SnCl_4$	n-$C_7H_{15}CHO$ + n-$C_5H_{11}COCH_3$	73	>99:1
3[e]	**1**	PhCHO + $PhCOCH_3$	97	>99:1
4	$SnCl_4$	PhCHO + $PhCOCH_3$	77	>99:1
5	$SnCl_4$	t-BuCHO + n-$C_5H_{11}COCH_3$	40	>99:1
6[d]	$SnCl_4$	n-$C_7H_{15}CHO$ + 	87	98:2
7	$SnCl_4$	PhCHO + 	85	>99:1

[a] Unless otherwise specified, the reaction was carried out using tetraallyltin (**1**, 0.05 equiv) or $SnCl_4$ (0.05 equiv), allyltributyltin (**2**, 1 equiv), and two carbonyl compounds (1 equiv, respectively) in a 1:5 mixture of 2 *N* HCl (1 equiv) and THF at 20 °C for 4 h. [b] Combined isolated yields of the allylation products. [c] Determined by ^1H NMR or GLC analysis. [d] The reaction was performed at 20 °C for 23 h. [e] The reaction was performed in a 1:3 mixture of 2 *N* HCl (1 equiv) and THF

With this mechanistic guidance it became of interest to evaluate appropriate chiral allyltin reagents which might deliver the allyl group enantioselectively to one face of an aldehyde, both as a test of the mechanistic hypothesis and a step toward more powerful synthetic methodology. Thus, (-)-diallylbis(2-phenylbutyl)tin (**5**, 98% ee, 0.05 equiv)[12] was employed as a catalyst for the condensation of nonanal (1 equiv) with allyltributyltin (**2**, 1 equiv) in a 1:1 mixture of 2 N HCl (1 equiv) and THF at 20 °C, and the (*S*)-enriched alcohol **6** was obtained in 83% yield with 11% ee.[13] In the reaction with cinnamaldehyde, the (*R*)-enriched alcohol **7** formed in 75% yield also indicated the same optical purity (11% ee).[14] Noteworthy was the fact that when these aldehydes were treated with an equimolar amount of the optically active diallyltin compound **5** under the influence of 4 equiv of 2 N HCl, similar levels of enantioselectivity (12 ~ 15% ee) were observed. These results imply that a common intermediate might participate in both the catalytic and stoichiometric allylations.

The reaction reported herein is a new class of highly chemoselective allylation of aldehydes with allyltributyltin using a catalytic amount of tin catalyst in acidic aqueous media.

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References and Notes

(1) Yanagisawa, A.; Inoue, H.; Morodome, M.; Yamamoto, H. *J. Am. Chem. Soc.* **1993**, *115*, 10356.

(2) Tetraallyltin reacted with benzaldehyde in an 8:1 mixture of THF and H_2O at 20 °C for 3 h to provide the homoallylic alcohol **4** in 8 % yield.

(3) Recently, Young et al. found that tetraallyltin shows unusually high reactivity in methanol and reacts with aldehydes in high yield without any catalyst: (a) Cokley, T. M.; Marshall, R. L.; McCluskey, A.; Young, D. J. *Tetrahedron Lett.* **1996**, *37*, 1905. (b) Cokley, T. M.; Harvey, P. J.; Marshall, R. L.; McCluskey, A.; Young, D. J. *J. Org. Chem.* **1997**, *62*, 1961. For the reaction with acetals, see: (c) McCluskey, A.; Mayer, D. M.; Young, D. J. *Tetrahedron Lett.* **1997**, *38*, 5217. The rate acceleration of the reaction of tetraallyltin in methanol has also been reported by Baba et al.: (d) Yasuda, M.; Fujibayashi, T.; Shibata, I.; Baba, A. 70th Annual Meeting of the Chemical Society of Japan, Tokyo, March 28, 1996; 1J226.

(4) Most of the allylation reactions of carbonyl compounds in aqueous media reported are the Barbier-type reactions, see reviews: (a) Li, C.-J. *Chem. Rev.* **1993**, *93*, 2023. (b) Lubineau, A.; Augé, J.; Queneau, Y. *Synthesis* **1994**, 741. (c) Li, C.-J. *Tetrahedron* **1996**, *52*, 5643.

(5) Kobayashi et al. reported $Sc(OTf)_3$ and $Yb(OTf)_3$-catalyzed allylation reactions of carbonyl compounds with tetraallyltin: (a) Hachiya, I.; Kobayashi, S. *J. Org. Chem.* **1993**, *58*, 6958. (b) Kobayashi, S.; Hachiya, I.; Yamanoi, Y. *Bull. Chem. Soc. Jpn.* **1994**, *67*, 2342. Polymer-supported Sc-catalyzed allylations: (c) Kobayashi, S.; Nagayama, S. *J. Org. Chem.* **1996**, *61*, 2256. $Sc(OTf)_3$-catalyzed allylations in micellar systems: (d) Kobayashi, S.; Wakabayashi, T.; Oyamada, H. *Chem. Lett.* **1997**, 831. Akiyama and Iwai showed that tetraallylgermane also reacts with carbonyl compounds in the presence of a catalytic amount of $Sc(OTf)_3$: (e) Akiyama, T.; Iwai, J. *Tetrahedron Lett.* **1997**, *38*, 853.

(6) (a) Pereyre, M.; Quintard, J.-P.; Rahm, A. *Tin in Organic Synthesis*; Butterworths: London, 1987; p 216. (b) Nishigaichi, Y.; Takuwa, A.; Naruta, Y.; Maruyama, K. *Tetrahedron* **1993**, *49*, 7395. (c) Yamamoto, Y.; Asao, N. *Chem. Rev.* **1993**, *93*, 2207.

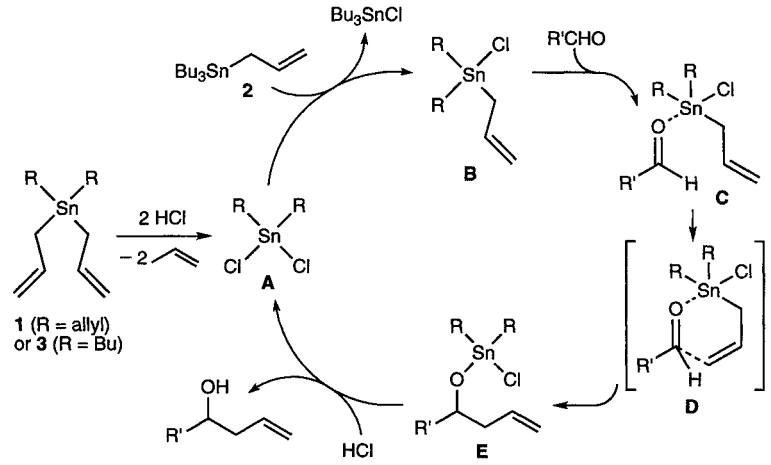

Figure 1. Proposed mechanism of the catalytic allylation

(7) Intramolecular allylic tributylstannane-aldehyde condensation reactions were accomplished by Brønsted acids: (a) Denmark, S. E.; Weber, E. J.; Wilson, T. M.; Willson, T. M. *Tetrahedron* **1989**, *45*, 1053. (b) Gevorgyan, V.; Kadota, I.; Yamamoto, Y. *Tetrahedron Lett.* **1993**, *34*, 1313.

(8) Reactions of allyl- and allenyltin chlorides with carbonyl compounds in water or acid media were reported: (a) Boaretto, A.; Marton, D.; Tagliavini, G.; Gambaro, A. *J. Organomet. Chem.* **1985**, *286*, 9. (b) Boaretto, A.; Marton, D.; Tagliavini, G. *J. Organomet. Chem.* **1985**, *297*, 149. (c) Furlani, D.; Marton, D.; Tagliavini, G.; Zordan, M. *J. Organomet. Chem.* **1988**, *341*, 345. (d) Marton, D.; Tagliavini, G.; Vanzan, N. *J. Organomet. Chem.* **1989**, *376*, 269.

(9) Preparation: (a) Jones, W. J.; Davies, W. C.; Bowden, S. T.; Edwards, C.; Davis, V. E.; Thomas, L. H. *J. Chem. Soc.* **1947**, 1446. (b) Dang, H.-S.; Davies, A. G. *J. Organomet. Chem.* **1992**, *430*, 287. (c) Carofiglio, T.; Marton, D.; Tagliavini, G. *Organometallics* **1992**, *11*, 2961.

(10) A representative experimental procedure (entry 2 in Table 1): To a solution of tetraallyltin (**1**, 57 mg, 0.2 mmol) and benzaldehyde (425 mg, 4 mmol) in THF (2 mL) was added at 20 °C an aqueous HCl solution (2 N, 2 mL, 4 mmol). After being stirred for 40 min, allyltributyltin (**2**, 1.32 g, 4 mmol) was added over a period of 30 min with a syringe pump and the mixture was stirred for another 4 h at this temperature. The reaction mixture was treated with a mixture of 2 N HCl (10 mL) and KF aqueous solution (ca.10 M, 5 mL) at ambient temperature for 30 min. The resulting precipitate was filtered off and ether (10 mL) was added to the filtrate. The organic extracts were washed with brine (10 mL), dried over anhydrous $MgSO_4$, and concentrated *in vacuo*. The crude product was purified by column chromatography on silica gel (10:1 to 5:1 hexane/ethyl acetate as the eluant) to afford the homoallylic alcohol **4** (576 mg, 97% yield) as a colorless oil: TLC R_f 0.34 (1:3 ethyl acetate/hexane); IR (neat) 3700-3120, 3077, 3031, 2907, 1642, 1603, 1493, 1455, 1316, 1198, 1115, 1076, 1048, 916, 870, 758, 700 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 2.01 (d, 1 H, J = 2.5 Hz, OH), 2.52 (m, 2 H, CH_2), 4.75 (dt, 1 H, J = 6.9, 2.5 Hz, CH), 5.14-5.20 (m, 2 H, 2 vinyls), 5.82 (m, 1 H, vinyl), 7.25-7.37 (m, 5 H, aromatic).

(11) Concerning the reactivity of allyltin chlorides, see: (a) Boaretto, A.; Marton, D.; Tagliavini, G.; Ganis, P. *J. Organomet. Chem.* **1987**, *321*, 199. See also ref.8. (b) Marshall, R. L.; Young, D. J. *Tetrahedron Lett.* **1992**, *33*, 2369. (c) Miyake, H.; Yamamura, K. *Chem. Lett.* **1992**, 1369. (d) Miyake, H.; Yamamura, K. *Chem. Lett.* **1992**, 2221. (e) Fouquet, E.; Gabriel, A.; Maillard, B.; Pereyre, M. *Bull. Soc. Chim. Fr.* **1995**, *132*, 590.

(12) Bp 198 °C (0.1 Torr); TLC R_f 0.59 (1:5 ethyl acetate/hexane); ^1H NMR (300 MHz, $CDCl_3$) δ 0.73 (t, 6 H, J = 7.3 Hz, 2 CH_3), 1.01-1.17 (m, 4 H, 2 CH_2), 1.28-1.43 (m, 4 H, 2 CH_2), 1.49-1.59 (m, 4 H, 2 CH_2), 2.47-2.57 (m, 2 H, 2 CH), 4.60 (d, 2 H, J = 10.0 Hz, 2 vinyls), 4.66 (d, 2 H, J = 16.9 Hz, 2 vinyls), 5.58-5.72 (m, 2 H, 2 vinyls), 7.08-7.30 (m, 10 H, aromatic); $[\alpha]^{22}_D$ -33.2° (*c* 1.0, benzene). (a) Otera, J.; Kawasaki, Y.; Mizuno, H.; Shimizu, Y. *Chem. Lett.* **1983**, 1529. (b) Otera, J.; Yoshinaga, Y.; Yamaji, T.; Yoshioka, T.; Kawasaki, Y. *Organometallics* **1985**, *4*, 1213.

(13) TLC R_f 0.30 (1:5 ethyl acetate/hexane); ^1H NMR (300 MHz, $CDCl_3$) δ 0.88 (t, 3 H, J = 7.2 Hz, CH_3), 1.19-1.58 (m, 15 H, 7 CH_2 and OH), 2.07-2.19 (m, 1 H, one proton of CH_2), 2.26-2.37 (m, 1 H, one proton of CH_2), 3.65 (m, 1 H, CH), 5.10-5.19 (m, 2 H, 2 vinyls), 5.83 (m, 1 H, vinyl); $[\alpha]^{21}_D$ -1.4° (*c* 2.5, CCl_4). The enantioselectivity was determined by ^1H NMR analysis of the MTPA ester.

(14) TLC R_f 0.28 (1:3 ethyl acetate/hexane); ^1H NMR (300 MHz, $CDCl_3$) δ 1.78 (br, 1 H, OH), 2.39 (m, 2 H, CH_2), 4.37 (dd, 1 H, J = 12.3, 6.1 Hz, CH_2), 5.16-5.22 (m, 2 H, 2 vinyls), 5.87 (m, 1 H, vinyl), 6.25 (dd, 1 H, J = 15.9, 6.3 Hz, vinyl), 6.62 (d, 1 H, J = 15.7 Hz, vinyl), 7.22-7.40 (m, 5 H, aromatic); $[\alpha]^{24}_D$ -1.5° (*c* 10.1, Et_2O). The enantioselectivity was determined by HPLC analysis (Chiralcel OD, Daicel Chemical Industries, Ltd.).