Available online at www.sciencedirect.com
SCIENCE DIRECT®
Bioorganic & Medicinal Chemistry 13 (2005) 5154–5158
Bioorganic & Medicinal Chemistry

Catalytic Pictet–Spengler reactions using $Yb(OTf)_3$

Kei Manabe, Daisuke Nobutou and Shū Kobayashi*

Graduate School of Pharmaceutical Sciences, The University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

Received 25 April 2005; revised 9 May 2005; accepted 9 May 2005
Available online 21 June 2005

Abstract—The catalytic Pictet–Spengler reactions proceeded in high yields with high regioselectivity in the presence of a catalytic amount of $Yb(OTf)_3$ and a dehydrating agent at room temperature. High regioselectivities were obtained in these reactions, and it is suggested that the reactions proceeded under kinetic control.

1. Introduction

Pictet–Spengler reaction has been known for almost 100 years.[1] However, it is still a powerful methodology to synthesize 1,2,3,4-tetrahydroisoquinoline or β-carboline derivatives effectively.[2] A lot of natural and unnatural biologically important alkaloids have been synthesized utilizing this reaction as one of key steps;[3] however, there is certainly room for improvement of the reaction. For instance, Pictet–Spengler reaction requires heating and large excess amounts of strong Brønsted acids for unreactive substrates to obtain satisfactory levels of conversions,[4] while reactive ones do not necessarily need harsh reaction conditions.[5] In addition, it has not been fully investigated with respect to what kinds of activators in small amounts are the most effective to catalyze Pictet–Spengler reaction even for reactive substrates.[6] Furthermore, there have been very few reports on catalysts which could control regioselectivity or enantioselectivity of the Pictet–Spengler reaction.[5,7] Based on this background, we have screened several catalyst systems for Pictet–Spengler reaction, and now report that $Yb(OTf)_3$ gives promising results.

2. Results and discussion

We chose benzaldehyde and reactive *m*-tyramine as model substrates,[5a,b] and searched for activators in this reaction (Table 1). First, several basic conditions were examined to activate the phenolic moiety of *m*-tyramine. It was revealed that an aqueous 1 M NaOH solution (50 mol%) accelerated the reaction in MeOH at room temperature for 24 h to afford the desired product in 39% yield (**1**/**2** = 3/97, not shown in the table). However, the yield was not further improved even after examination of several reaction conditions. Moreover, metal acetates such as NaOAc, $Ni(OAc)_2$, and $Zn(OAc)_2$ were not effective. Then, several Lewis acids and Brønsted acids were tested as catalysts. It was found that, among them, several water-compatible Lewis acids gave promising results (entries 2–11).[8] In particular, $Yb(OTf)_3$ was found to be the most effective catalyst (entry 11).[9] On the other hand, Brønsted acids such as trifluoromethanesulfonic acid, acetic acid, and trifluoroacetic acid were not effective (entries 12–14).

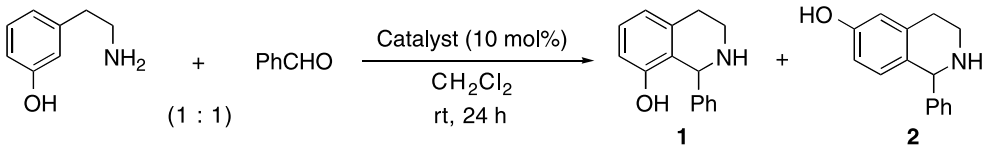
An imine intermediate and water formed at the initial stage of this reaction, and we thought that this water might disturb a further reaction. Thus, we then added various dehydrating agents to improve the yield further. As shown in Table 2, we tested three kinds of molecular sieves and Drierite, and in all cases these dehydrating agents increased both yields and regioselectivities (entries 1–5). On the other hand, the desired reactions proceeded only sluggishly without $Yb(OTf)_3$ even if MS 3A was added (entries 6 and 7). Finally, the amount of $Yb(OTf)_3$ could be reduced to 1 mol% combined with MS 3A (entry 8).

Under optimized conditions, substrate scope of the catalytic Pictet–Spengler reaction was examined (Table 3). A substituted aromatic aldehyde gave the desired product in high yield with excellent regioselectivity (entry 1). The reactions proceeded in good yields with high

Keywords: Catalytic reaction; Lewis acid; Pictet–Spengler reaction; Ytterbium triflate.
* Corresponding author. Tel: +81 3 5841 4790; fax: +81 3 5684 0634; e-mail: skobayas@mol.f.u-tokyo.ac.jp

0968-0896/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.bmc.2005.05.018

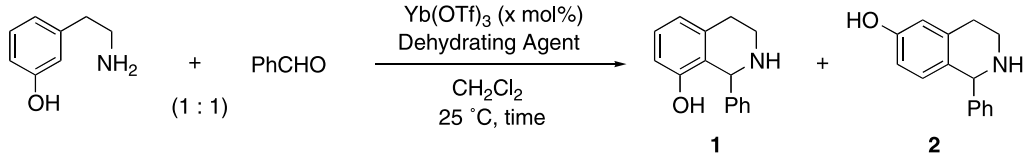
Table 1. Effect of metal catalysts



Entry	Catalyst	Yield (%)[a]	1/2
1	None	22	9/91
2	$Zn(OTf)_2$	22	16/84
3	$ln(OTf)_3$	40	11/89
4	$Bi(OTf)_3$	39	9/91
5	$Sm(OTf)_3$	24	15/85
6	$Eu(OTf)_3$	20	12/88
7	$Tb(OTf)_3$	19	12/88
8	$Dy(OTf)_3$	17	13/87
9	$Er(OTf)_3$	21	14/86
10	$Lu(OTf)_3$	33	11/89
11	$Yb(OTf)_3$	59	15/85
12	CF_3SO_3H	25	10/90
13	AcOH	15	13/87
14	CF_3COOH	34	12/88

[a] Combined NMR yield of **1** and **2**.

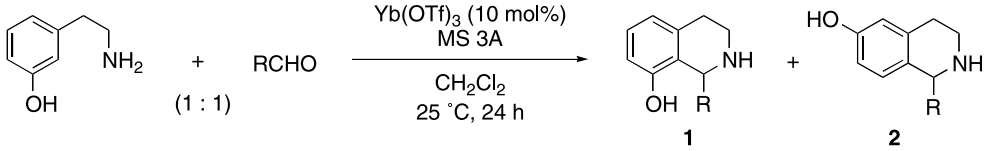
Table 2. Effect of dehydrating agents



Entry	x	Time (h)	Dehydrating agent	Yield (%)[a]	1/2
1	10	24	None	53	11/89
2[b]	10	24	MS 3A	94	3/97
3[b]	10	24	MS 4A	90	4/96
4[b]	10	24	MS 5A	94	2/98
5	10	24	Drierite	97	8/92
6[b,c]	—	8	MS 3A	22	7/93
7[b]	10	8	MS 3A	82	3/97
8[b]	1	24	MS 3A	92	5/95

[a] Combined NMR yield of **1** and **2**.
[b] Molecular sieves of powder form were used.
[c] Without $Yb(OTf)_3$.

Table 3. Substrate scope of the catalytic Pictet–Spengler reactions

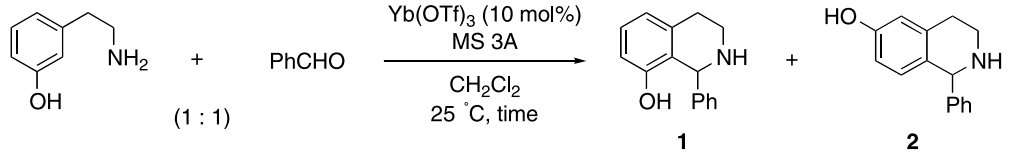


Entry	R	Yield (%)[a]	1/2
1	4-*t*-BuC_6H_4	98	1/99
2	2-Pyridyl	60	7/93
3	*i*-Bu	55	10/90
4	PhCH=CH (*trans*)	Complex mixture	—

[a] Combined NMR yield of **1** and **2**.

regioselectivity when heteroaromatic and aliphatic aldehydes were used (entries 2 and 3). However, an α,β-unsaturated aldehyde caused severe side reactions, and the desired product could not be obtained when *trans*-cinnamaldehyde was used (entry 4). When less reactive β-phenethylamine derivatives than *m*-tyramine (e.g,

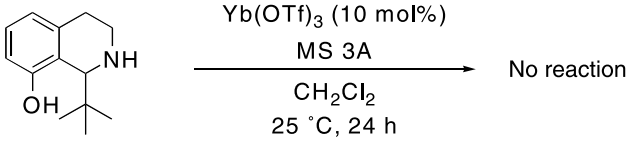
Table 4. Kinetic versus thermodynamic control



Entry	Time (h)	Yield (%)[a]	1/12
1	0.5	7	**2** alone
2	8	82	3/97
3	16	90	3/97
4	24	94	3/97
5[b]	24	6	**2** alone

[a] Combined NMR yield of **1** and **2**.
[b] At 0 °C.

3-methoxy-β-phenethylamine, 3,5-dimethoxy-β-phenethylamine, and 4-hydroxy-β-phenethylamine) were tried, the reactions stopped at the formation of imine intermediates, and no cyclized products were obtained. In entries 1–3, regioisomers were formed, and we next tried to confirm whether the regioselectivity of the reaction was controlled kinetically or thermodynamically. Thus, we checked the regioisomer ratio during the reaction course (Table 4). As a result, the ratio hardly changed within 24 h, and the product **2** cyclized at the *para* position to the phenolic hydroxyl group was always obtained as a major isomer. In addition, the cyclized product **2** was also produced as a predominant isomer when the reaction temperature was decreased from 25 to 0 °C (entry 5). These results suggest that the regioisomer ratio was determined kinetically rather than thermodynamically. When the *ortho* cyclized product **1** corresponding to entry 1 in Table 3 was exposed to the same reaction conditions as those in Table 3, the same *ortho* cyclized product **1** was recovered and no *para* cyclized product was observed (Eq. 1). This result also suggests that the regioselectivity of the reaction was determined under kinetic control.



(1)

3. Conclusion

We investigated effective catalyst systems for Pictet–Spengler reaction where benzaldehyde and *m*-tyramine were used as model substrates. After screening of various activators, $Yb(OTf)_3$ was found to be the most effective catalyst. With the help of some dehydrating agents,[10] both yield and regioselectivity were improved, and catalytic Pictet–Spengler reaction proceeded smoothly under mild reaction conditions in high yield with high regioselectivity. In addition, it was demonstrated that cyclization reactions occurred at the *para* position to the phenolic hydroxyl group preferentially to the *ortho* position when *m*-tyramine and various aldehydes were condensed. These results suggest that regioselectivity of the Pictet–Spengler reaction was determined by kinetic, rather than thermodynamic control. Further investigations to develop catalytic enantioselective Pictet–Spengler reactions are now in progress.

4. Experimental

4.1. General

Infrared (IR) spectra were recorded on a JASCO FT/IR-610 spectrometer. Nuclear magnetic resonance (NMR) spectra were recorded on a JEOL JNM-LA300 or JNM-LA400 spectrometer in CD_3OD or DMSO-d_6. The peaks derived from the deuterated solvents were used as internal standards for ^1H NMR (δ: 3.30 for CD_3OD and δ: 2.49 for DMSO-d_6) and ^{13}C NMR (δ: 49.0 for CD_3OD and δ: 39.5 for DMSO-d_6). Mass spectra were measured with a Bruker BIO TOF-II spectrometer. Preparative thin-layer chromatography (TLC) was carried out using Wakogel B-5F. All other reagents were purified based on standard procedures unless otherwise noted. Starting materials are commercially available or were synthesized by the reported procedure.[11]

4.2. A typical experimental procedure for Pictet–Spengler reaction (Table 2, entry 2)

To a two-necked 10-mL flask, $Yb(OTf)_3$ (12.4 mg, 0.02 mmol) was added under an atmosphere of argon, and dried in vacuo at 200 °C for 2 h. After cooling the flask at room temperature, well-dried molecular sieves 3A (40.0 mg) was added under an atmosphere of argon. Then, 0.5 mL of dry CH_2C1_2, benzaldehyde (21.2 mg, 0.20 mmol), and *m*-tyramine (27.4 mg, 0.20 mmol) were added successively, and the reaction mixture was stirred at 25 °C. After 24 h, the reaction was quenched with an aqueous saturated sodium bicarbonate solution (3 mL), and organic compounds were extracted with ethyl acetate. The organic layer was dried over anhydrous sodium sulfate, and evaporated. To the crude reaction mixture, an appropriate amount of trimethylsilylpropanesulfonic acid sodium salt (10–20 mg) was added under an atmosphere of argon as an internal standard for the analysis of crude ^1H NMR spectra in DMSO-d_6.

4.3. A typical experimental procedure for the synthesis of 1-phenyl-1,2,3,4-tetrahydroisoquinoline derivatives[12]

To a one-necked 10-mL flask equipped with a reflux condenser, *m*-tyramine (52.3 mg, 0.38 mmol), benzaldehyde (53.8 mg, 0.51 mmol), and pyridine (1.0 mL) were added successively. The reaction mixture was stirred and refluxed for 2 h. After cooling the flask at room temperature, a 10% aqueous sodium hydroxide solution was added to basify the media, and the aqueous layer was washed with Et_2O. To the aqueous layer, 10% aqueous HCl was added to acidify the media and then, a 28% aqueous ammonia solution was added to basify the media again. The organic compounds were extracted with dichloromethane. The organic layer was dried over anhydrous sodium sulfate, and evaporated. Pyridine (1.0 mL) was added to the crude reaction mixture, and the solution was stirred at room temperature. Then, trifluoroacetic anhydride (0.5 mL, 9.0 equiv.) was added slowly, and the reaction mixture was stirred overnight. The reaction was stopped with 1 N aqueous HCl, and the organic compounds were extracted with ethyl acetate. The organic layer was washed with 1 N aqueous HCl, saturated aqueous sodium bicarbonate, and brine successively, dried over anhydrous sodium sulfate, and evaporated. Purification by silica gel chromatography gave the desired *N*-protected cyclized products (6-OH adduct: 45.7 mg, 37%, 8-OH adduct: 11.8 mg, 10%). To each protected isomer in methanol, an aqueous sodium hydroxide solution (10 equiv.) was added, and the reaction mixture was stirred overnight. The deprotection reactions proceeded quantitatively, and were stropped with 1 N aqueous HCl. A saturated aqueous sodium bicarbonate solution was then added to basify the media again. After extraction with ethyl acetate, followed by drying and concentration, the desired 1,2,3,4-tetrahydroisoquinoline derivatives were obtained in pure forms.

4.4. l-Phenyl-6-hydroxy-l,2,3,4-tetrahydroisoquinoline

^{1}H NMR (DMSO-d_6) δ: 9.14 (br s, 1H), 7.31–7.16 (m, 5H), 6.52–6.46 (m, 1H), 6.45–6.36 (m, 2H), 4.86 (s, 1H), 3.08–2.96 (m, 1H), 2.90–2.72 (m, 2H), 2.67–2.53 (m, 1H); ^{1}H NMR (CD_3OD): δ: 7.35–7.16 (m, 5H), 6.56 (d, 1H, J = 2.1 Hz), 6.48 (d, 1H, J = 8.6 Hz), 6.46 (dd, 1H, J = 2.1, 8.6 Hz), 4.98 (s, 1H), 3.21–3.11 (m, 1H), 3.02–2.89 (m, 2H), 2.83–2.69 (m, 1H); ^{13}C NMR (CD_3OD) δ: 156.94, 145.51, 137.47, 130.21, 130.21, 129.74, 129.45, 128.52, 115.80, 114.42, 62.42, 29.98; IR (KBr, cm^{-1}) 3438, 3281, 3034, 2955, 2932, 2790, 2656, 2551. HRMS calcd for $C_{15}H_{15}NO{\cdot}H^+$ ($M+H^+$) 226.1232. Found 226.1239.

4.5. l-Phenyl-8-hydroxy-l,2,3,4-tetrahydroisoquinoline

^{1}H NMR (DMSO-d_6) δ: 9.06 (br s, 1H), 7.34–7.02 (m, 5H), 6.99 (dd, 1H, J = 7.8 Hz), 6.61 (d, 1H, J = 7.8 Hz), 6.55 (d, 1H, J = 7.8 Hz), 5.10 (s, 1H), 2.87–2.52 (m, 4H); ^{1}H NMR (CD_3OD) δ: 7.32–7.15 (m, 3H), 7.10 (d, 2H, J = 7.8 Hz), 7.04 (dd, 1H, J = 7.8 Hz), 6.70 (d, 1H, J = 7.8 Hz), 6.55 (d, 1H, J = 7.8 Hz), 5.31 (s, 1H), 3.01–2.71 (m, 4H); ^{13}C NMR (CD_3OD) δ: 155.47, 144.48, 137.49, 129.57, 128.99, 128.64, 127.98, 124.11, 120.96, 113.27, 56.03, 38.23, 29.21; IR (KBr, cm^{-1}) 3417, 3287, 3032, 2925, 2856, 2635, 2379, 2328, 1729. HRMS calcd for $C_{19}H_{15}NO{\cdot}H^+$ ($M+H^+$) 226.1232. Found 226.1221.

4.6. l-(4-*tert*-Butyl-phenyl)-6-hydroxy-l,2,3,4-tetrahydroisoquinoline

^{1}H NMR (DMSO-d_6) δ: 9.09 (br s, 1H), 7.29 (d, 2H, J = 8.2Hz), 7.13 (d, 2H, J = 8.2Hz), 6.48 (s, 1H), 6.43–6.36 (m, 2H), 4.82 (s, 1H), 3.04–2.97 (m, 1H), 2.88–2.74 (m, 2H), 2.65–2.55 (m, 1H), 1.25 (s, 9H); ^{13}C NMR (DMSO-d_6) δ: 155.13, 148.95, 142.72, 136.36, 129.36, 128.56, 128.42, 124.64, 114.71, 112.88, 60.32, 41.55, 34.14, 31.21, 29.47; IR (KBr, cm^{-1}) 3429, 3276, 2964, 2875, 2801, 2667, 2600. HRMS calcd for $C_{19}H_{23}NO{\cdot}H^+$ ($M+H^+$) 282.1858. Found 282.1849.

4.7. l-(4-*tert*-Butyl-phenyl)-8-hydroxy-l,2,3,4-tetrahydroisoquinoline

^{1}H NMR (DMSO-d_6) δ: 9.04 (br s, 1H), 7.27–7.17 (m, 2H), 7.01–6.89 (m, 3H,), 6.59 (d, 1H, J = 7.4 Hz), 6.53 (d, 1H, J = 7.4 Hz), 5.04 (s, 1H), 2.82–2.52 (m, 4H), 1.24 (s, 9H); ^{13}C NMR(DMSO-d_6) δ: 153.81, 148.13, 141.84, 136.91, 127.81, 126.68, 124.58, 124.20, 119.50, 111.81, 53.70, 38.67, 37.21, 34.06, 31.23, 28.66; IR (KBr, cm^{-1}) 3395, 3284, 3028, 2957, 2873, 2719, 2622. HRMS calcd for $C_{19}H_{23}NO{\cdot}H^+$ ($M+H^+$) 282.1858. Found 282.1854.

4.8. l-iso-Butyl-6-hydroxy-l,2,3,4-tetrahydroisoquinoline

^{1}H NMR (CD_3OD) δ: 6.92 (d, 1H, J = 8.4 Hz), 6.58 (dd, 1H, J = 8.4, 2.3 Hz), 6.49 (d, 1H, J = 2.3 Hz), 3.97–3.83 (m, 1H), 3.21–3.08 (m, 1H), 2.93–2.63 (m, 3H), 1.92–1.77 (m, 1H), 1.67–1.55 (m, 2H), 1.00 (d, 3H, J = 6.4 Hz), 0.97 (d, 3H, J = 6.9 Hz); ^{13}C NMR (CD_3OD) δ: 184.52, 164.82, 159.27, 156.25, 144.03, 142.48, 82.09, 75.05, 69.39, 58.10, 53.63, 52.34, 49.76; IR (KBr, cm^{-1}) 3379, 3308, 2958, 2679, 2603, 2377. HRMS calcd for $C_{13}H_{19}NO{\cdot}H^+$ ($M+H^+$) 206.1545. Found 206.1543.

4.9. 1-iso-Butyl-8-hydroxy-1,2,3,4-tetrahydroisoquinoline

^{1}H NMR (CD_3OD) δ: 6.93 (dd, 1H, J = 7.7, 8.0 Hz), 6.57 (d, 1H, J = 7.7 Hz), 6.56 (d, 1H, J = 8.0 Hz), 4.30–4.22 (m, 1H), 3.23–3.12 (m, 1H), 3.00–2.80 (m, 2H), 2.76–2.64 (m, 1H), 1.91–1.80 (m, 1H), 1.69–1.58 (m, 2H), 1.04 (d, 3H, J = 6.9 Hz), 0.96 (d, 3H, J = 6.9 Hz); ^{13}C NMR (CD_3OD) δ: 150.00, 136.25, 127.78, 127.13, 1201.04, 113.30, 49.91, 42.73, 38.33, 29.26, 25.93, 24.56, 21.40; IR (KBr, cm^{-1}) 3410, 3041, 2959, 2864, 2722, 2378, 2338, 1729, 1681. HRMS calcd for $C_{13}H_{19}NO{\cdot}H^+$ ($M+H^+$) 206.1545. Found 206.1543.

4.10. 1-(2-Pyridyl)-6-hydroxy-1,2,3,4-tetrahydroisoquinoline

^{1}H NMR (CD_3OD) δ: 8.56–8.44 (m, 1H), 7.82–7.68 (m, 1H), 7.37–7.27 (m, 1H), 7.26–7.19 (m, 1H), 6.60 (d, 1H, J = 2.4 Hz), 6.55 (d, 1H, J = 8.6 Hz), 6.50 (d, 1H,

J = 2.4, 8.6 Hz), 5.10 (s, 1H), 3.20–3.07 (m, 1H), 3.03–2.71 (m, 3H); ^{13}C NMR (CD_3OD) δ: 164.13, 157.27, 149.96, 138.54, 137.67, 129.84, 128.10, 125.01, 124.03, 116.24, 114.60, 62.95, 42.10, 30.00; IR (KBr, cm^{-1}) 3267, 3052, 3014, 2925, 2817, 2706, 2603, 1882, 1681. HRMS calcd for $C_{14}H_{14}N_2O{\cdot}H^+$ ($M+H^+$) 227.1184. Found 227.1195.

4.11. 1-(2-Pyridyl)-8-hydroxy-1,2,3,4-tetrahydroisoquinoline

^{1}H NMR (CD_3OD) δ: 8.59–8.54 (m, 1H), 7.71–7.65 (m, 1H), 7.30–7.24 (m, 1H), 7.07 (dd, 1H, J = 7.9, 7.9 Hz), 6.96 (d, 1H, J = 7.9 Hz), 6.71 (d, 1H, J = 7.9 Hz), 6.59 (d, 1H, J = 7.9 Hz), 5.30 (s, 1H), 3.02–2.70 (m, 4H); ^{13}C NMR (CD_3OD) δ: 163.67, 155.86, 149.77, 137.99, 137.94, 128.97, 124.17, 123.49, 123.04, 121.20, 113.31, 57.54, 39.10, 29.54; IR (KBr, cm^{-1}) 3409, 3276, 3056, 2925, 2855, 2374, 1679. HRMS calcd for $C_{14}H_{14}N_2O{\cdot}H^+$ ($M+H^+$) 227.1184. Found 227.1171.

Acknowledgments

This work was partially supported by ERATO, Japan Science and Technology Corporation (JST), and a Grant-in-Aid for Scientific Research from Japan Society of the Promotion of Science (JSPS).

References and notes

1. Pictet, A.; Spengler, T. *Ber. Dtsch. Chem. Ges.* **1911**, *44*, 2030.
2. (a) For recent reviews, see: Bringmann, G.; Ewers, C. L. J.; Walter, R. In Trost, B. M., Ed.; *Comprehensive Organic Synthesis*; Pergamon Press: Oxford; Vol. 6, chapter 4.2; (b) Chrzanowska, M.; Rozwadowska, M. D. *Chem. Rev* **2004**, *104*, 3341.
3. Cox, E. D.; Cook, J. M. *Chem. Rev.* **1995**, *95*, 1797.
4. (a) Whaley, W. M.; Govindachari, T. R. *Org. React.* **1951**, *6*, 151; for superacids approach, see: (b) Yokoyama, A.; Ohwada, T.; Shudo, K. *J. Org. Chem.* **1999**, *64*, 611.
5. (a) Kametani, T.; Fukumoto, K.; Agui, H.; Yagi, H.; Kigasawa, K.; Sugahara, H.; Hiiragi, M.; Hayasaka, T.; Ishimaru, H. *J. Chem. Soc. (C)* **1968**, 112; (b) Kametani, T.; Fukumoto, K. *Heterocycles* **1975**, *3*, 311; (c) Bates, H. A. *J. Org. Chem.* **1981**, *46*, 4931.
6. For Lewis acid catalysis, see: Srinivasan, N.; Ganesan, A. *Chem. Commun.* **2003**, 916.
7. (a) Yamada, H.; Kawate, T.; Matsumizu, M.; Nishida, A.; Yamaguchi, K.; Nakagawa, M. *J. Org. Chem.* **1998**, *63*, 6348; (b) Taylor, M. S.; Jacobsen, E. N. *J. Am. Chem. Soc.* **2004**, *126*, 10558; for diastereoselective approaches using chiral auxiliaries, see: (c) Waldmann, H.; Schmidt, G.; Henke, H.; Burkard, M. *Angew. Chem. Int. Ed. Engl.* **1995**, *34*, 2402; (d) Gremmen, C.; Wanner, M. J.; Koomen, G.-J. *Tetrahedron Lett.* **2001**, *42*, 8885.
8. Kobayashi, S.; Nagayama, S.; Busujima, T. *J. Am. Chem. Soc.* **1998**, *120*, 8287.
9. (a) Kobayashi, S. *Synlett* **1994**, 689; (b) Kobayashi, S.; Sugiura, M.; Kitagawa, H.; Lam, W. W.-L. *Chem. Rev.* **2002**, *102*, 2227, we also tested a wide variety of Lewis acids in a THF/water mixed solvent, but all attempts resulted in low yields.
10. (a) For the same catalyst system, see: Kobayashi, S.; Hachiya, I. *J. Org. Chem.* **1994**, *59*, 3590; for the $Yb(OTf)_3$ and TMSC1 system, see: (b) Tsuji, R.; Nakagawa, M.; Nishida, A. *Tetrahedron: Asymmetry* **2003**, *14*, 177; (c) Tsuji, R.; Yamanaka, M.; Nishida, A.; Nakagawa, M. *Chem. Lett.* **2002**, 428.
11. Hashima, H.; Hayashi, M.; Kamano, Y.; Sato, N. *Bioorg. Med. Chem.* **2000**, *8*, 1757.
12. Kametani, T.; Kigasawa, K.; Hiiragi, M.; Ishimaru, H. *J. Chem. Soc. (C)* **1971**, 2632.