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Synthesis of 1,5-Bifunctionalized Optically Active 3-Pentanol as a Reversible Chiral Building Block. Asymmetric Reduction of 4-(1,3-Dithian-2-yl)-3-oxobutanoates with Fermenting Bakers' Yeast

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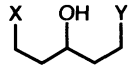
Bakers' yeast reduction of a homologous series of 4-(1,3-dithian-2-yl)-3-oxobutanoates to the corresponding chiral 4-(1,3-dithian-2-yl)-3-hydroxybutanoates was investigated. A shift in enantiomeric excess, stereochemistry, and chemical yield of the reduction product was observed as the size of the ester alkoxyl group was changed. The kind of bakers' yeast (raw or dry) and reaction conditions also affected the optical purity and chemical yield of the product. These studies showed that the reduction of methyl 4-(1,3-dithian-2-yl)-3-oxobutanoate with the raw yeast in the absence of additives was most efficient, giving methyl (*S*)-4-(1,3-dithian-2-yl)-3-hydroxybutanoate with 77% ee in 37% yield.

The synthetic utility of microorganisms and enzymes as organic reagents has recently been demonstrated by their numerous applications to the synthesis of valuable chiral building blocks of high optical purity.[1] Among these bioorganic transformations, the synthesis of optically active and symmetrically functionalized secondary alcohol such as 1,5-bifunctionalized 3-pentanol, symbolized as **1**, is of importance and has received significant attention in recent years.[2,3] Recent studies in this field have made it possible to obtain this type of bifunctional chiral alcohol with varying degree of enantiomeric selectivity.[2,3] We considered, however, that (*S*)- or (*R*)-4-(1,3-dithian-2-yl)-3-hydroxybutanoate **3** could be an excellent candidate as such type of chiral building block for the synthesis of a variety of natural products (e.g., polyoxygenated compounds) because not only for its ease of functional convertibility but its utility as two configurational antipodes (reversible) by synthetic chemical distinguishing between the potentially equivalent two (dithianyl and ester) functional groups. We now wish to report the synthesis of a novel 1,5-bifunctional 3-pentanol **3** as a reversible chiral building block by employing the asymmetric reduction of 4-(1,3-dithian-2-yl)-3-oxobutanoates **2** with fermenting bakers' yeast (*Saccharomyces Cerevisiae*).



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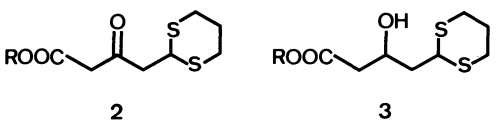
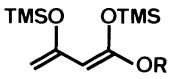


2 3

a : R = CH_3
b : R = C_2H_5
c : R = n-C_8H_{17}
d : R = K

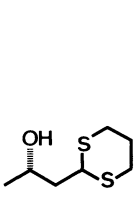
Results and Discussion

Methyl and ethyl esters **2a,b** were prepared by alkylation of dienol silyl ethers **4a,b** of the corresponding 3-oxobutanoates with 1,3-dithienium tetrafluoro-



4a : R = CH_3
b : R = C_2H_5

borate. Octyl ester **2c** was obtained by the ester-exchange reaction of **2a** with 1-octanol in the presence of *p*-toluenesulfonic acid (*p*-TsOH). Potassium carboxylate **2d** was prepared by the hydrolysis of **2a** in ethanol with 1 M KOH (1 M=1 mol dm^{-3}) and used directly for the subsequent yeast reduction. The reduction of a homologous series of 1,3-dithianyl-3-oxobutanoates **2a—d** with raw bakers' yeast under standard conditions provided the corresponding β-hydroxy esters **3a—c** together with optically pure (*S*)-1-(1,3-dithian-2-yl)-2-propanol (**5**). The latter compound was produced by the yeast reduction of the initially formed decarboxylation product **6**.[4] The results are summarized in Table 1. Optical purity of the β-hydroxy esters obtained was determined by 400 MHz ^1H NMR analyses of the respective (+)-α-methoxy-α-(trifluoromethyl)phenylacetic acid ((+)-MTPA) ester derivatives **7a—c** and the (+)-MTPA esters of the respective racemic form as references obtained by the reduction of **2a,c** with $Zn(BH_4)_2$ and of **2b** with $NaBH_4$.[5]



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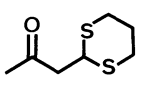

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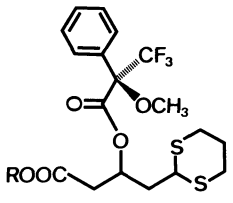

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As shown in Table 1, a shift in the enantiomeric

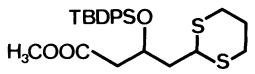
Table 1. Reduction of 4-(1,3-Dithian-2-yl)-3-oxobutanoates **2** with Raw Bakers' Yeast under Standard Conditions[a]

Entry	Substrate	Time/day	Product yields/%[b]		ee of **3**/%[d]	Absolute config.[d]
			3	**5**[c]		
1	**2a**	7	16	26	74	*S*
2	**2b**	10	14	13	50	*S*
3	**2c**	10	15	21	14	*R*
4	**2d**	3	3[e]	8	86	*S*

a) The reaction conditions were described in the Experimental section. b) Yields of pure products separated by MPLC. c) In all cases, the optical purity was determined to be >98% ee. d) See text. e) Isolated as the corresponding methyl ester after work-up with diazomethane.

excess and stereochemistry of the product **3** were observed as a function of the size of the ester alkoxyl group transformed. Methyl and ethyl esters **2a,b** were reduced by bakers' yeast to (*S*)-**3a,b** preferentially in 74% and 50% ee, respectively (Entries 1,2). On the other hand, the yeast reduction of potassium salt **2d** also gave (*S*)-**3a** after work-up with diazomethane with the highest optical purity (86% ee), but the chemical yield was too low to be synthetically useful (Entry 4). However, the reduction of octyl ester **2c** preferentially formed (*R*)-**3c** in 14% ee (Entry 3). Recently, Zhou et al. have closely examined the Prelog rule, which has been used to predict the stereochemistry of yeast reductions of acyclic ketones, on the yeast reduction of 4-chloro-3-oxobutanoates.[6] They showed that the esters having a very small alkoxyl group and a very large one were reduced to the (*S*)- and (*R*)-isomer, respectively, and the ee-value consecutively dropped as the size of the ester alkoxyl group draw near to medium. Our results on stereoselectivity and trend toward the ee-value shift are explicable based on the Prelog rule in analogy to the results of Zhou et al. However, the enantiomeric excess in the reduction of methyl ester **2a** was higher than that (ca. 65% ee) of methyl 4-chloro-3-oxopropanoate while the reduction of octyl ester **2c** showed lower stereoselectivity than that (ca. 97% ee) of octyl 4-chloro-3-oxopropanoate. Since the stereochemical course and enantioselectivity of the bakers' yeast reduction of β-keto esters should be mainly determined by the relative balance in steric bulk derived from the carbonyl substituents, the aforementioned fact is most likely due to the relative bulkiness of the dithianyl moiety when compared with the chloromethyl moiety (i.e., the relatively small difference in size between the dithianyl and ester moieties in **2**).

The absolute configuration of the hydroxy esters obtained in the present bakers' yeast reduction was determined by transforming **3a** into known lactone **11** as follows. Hydrolysis of the dithioacetal group of compound **8** obtained by the silylation of the β-hydroxy ester **3a** with *t*-butyldiphenylsilyl chloride (TBDPS-Cl) and imidazole in DMF provided the aldehyde **9**. The aldehyde **9** was reduced to **10** with $Zn(BH_4)_2$ in ether and the subsequent lactonization of **10** with *p*-TsOH in benzene gave the 3-hydroxyvalerolactone derivative **11**, $[\alpha]_D^{24}$ +7.0° (*c* 0.26, $CHCl_3$). Since the specific rotation of (*R*)-**11** with 80% ee is previously reported in the literature to be $[\alpha]_D$ +9.2° (*c* 7.7, $CHCl_3$),[3] the absolute configuration of the major isomer of **3a** was thus established to be *S*. The absolute configurations of **3b** and **3c** were determined by a similar comparison of $[\alpha]_D$ after respective conversion into the corresponding methyl ester by the ester-exchange reaction with *p*-TsOH in benzene.



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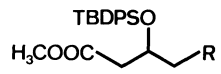
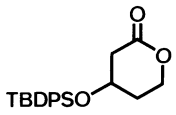


9 : R = CHO
10 : R = CH_2OH



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It is indicated from recent results appeared in the literature that the optical purity of the yeast reduction of β-keto esters depends on substrate concentration, the kind of commercially available forms of bakers' yeast (raw cake or dried granules), and the concentration of sugars.[7] Thus, we evaluated these effects on the reduction of **2a**, with an aim of possible improvement in the chemical yield and optical purity of **3a**. The results are summarized in Table 2. When dry yeast was used in place of raw yeast under the standard conditions, the enantiomeric excess dropped from 74% to 61% (Entry 4). However, considerable improvement in both chemical yield and optical purity could be achieved by the reduction using raw yeast without sugar, giving **3a** in 37% yield with 77% ee (Entry 2). The reduction without additives under low substrate concentration did not further influence the ee-value of **3a** in spite of the significant improvement in decarboxylation of **2a** (Entry 3). Accordingly, the

Table 2. Bakers' Yeast Reduction of **2a** under Several Conditions

Entry	Reaction conditions[a,b]			Chemical yield/%[e]		ee of **3a**/%[f]
	Yeast	Initial concn of **2a**	Additives[c]	**3a**	**5**	
1	Raw	7.7×10^{-2} M	S/N/M	16	26	74
2	Raw	7.7×10^{-2} M	None	37	45	77
3	Raw	3.8×10^{-2} M	None	28	7	78
4	Dry[d]	7.7×10^{-2} M	S/N/M	31	27	61

a) All the reactions were carried out with the 1-mmol scale of the substrate **2a** according to the standard procedure (see Experimental section). b) Reaction time: 7 days for Entry 1; 5 days for Entries 2 and 3; 4 days for Entry 4. c) S=sucrose, N=$Na_4P_2O_7$, M=$MgSO_4$. d) Half amount of raw yeast was used. e) Yields of pure products separated by MPLC. f) In all cases, absolute configuration of the major product was determined to be S.

useful chiral building block, methyl (*S*)-4-(1,3-dithian-2-yl)-3-hydroxybutanoates **3a**, is now available in 37% chemical yield and in 77% optical purity.

Experimental

Melting points were recorded on a Yanagimoto micro melting point apparatus and are uncorrected. Optical rotations were determined with a Union Digital PM-101 polarimeter. IR spectra were obtained on a Perkin Elmer Model 1660 FT-IR spectrophotometer. ^{1}H NMR spectra were measured with a JEOL JNM-GX400 spectrometer at 400 MHz with tetramethylsilane as an internal reference. Silica gel (Merck silica gel 60, 230—400 mesh ASTM) was used for medium-pressure liquid chromatography (MPLC). Analytical and preparative TLC were carried out on Merck precoated silica gel plates (Merck silica gel 60 F_{254}).

Materials. Raw bakers' yeast (Oriental Yeast Co.) and Dry granular yeast (Oriental Yeast Co.) were commercially available. 1,3-Bis(trimethylsiloxy)-1-methoxy-1,3-butadiene (**4a**) and 1,3-bis(trimethylsiloxy)-1-ethoxy-1,3-butadiene (**4b**) were prepared according to reported methods.[8] 1,3-Dithienium tetrafluoroborate was prepared according to the method of Corey et al.[9] Zinc borohydride was prepared from sodium borohydride and zinc chloride as a 0.3 M ethereal solution.[10] The other reagents were supplied as high grade commercial products and used without further purification.

Methyl 4-(1,3-Dithian-2-yl)-3-oxobutanoate (2a). A solution of 1,3-dithienium tetrafluoroborate (9.02 g, 44 mmol) in dry nitromethane (93 ml) was cooled to −40 °C under nitrogen and a solution of dienol silyl ether **4a** (26 g, 100 mmol) in dry dichloromethane (93 ml) was then added dropwise. After stirring for 30 min at −40 °C, the mixture was allowed to slowly warm to room temperature and the stirring was continued for 19 h under nitrogen. 2 M HCl (20 ml) was added to the mixture and the solution was stirred for 30 min. The aqueous mixture was extracted with ether and the extract was washed with saturated aqueous $NaHCO_3$ solution and water. The organic layer was dried with $MgSO_4$ and concentrated under reduced pressure to give crude crystalline product. Recrystallization from methanol afforded pure **2a** as colorless needles (8.06 g, 78%); mp 70—70.2 °C; IR (KBr) 2976, 2956, 2904, 1737, 1714, 1434, 1416, 1404, 1356, 1321, 1275, 1247, 1196, 1172, 1132, 1116, 1085, 1046, 1016, 1000, 966, 910, and 576 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.88 (m, 1H), 2.11 (m, 1H), 2.88 (m, 4H), 2.98 (d, 2H, J=6.8 Hz), 3.51 (s, 2H), 3.75 (s, 3H), and 4.49 (t, 1H, J=6.8 Hz). Calcd for $C_9H_{14}O_3S_2$: C, 46.13; H, 6.02%. Found: C, 46.75; H, 5.92%.

Ethyl 4-(1,3-Dithian-2-yl)-3-oxobutanoate (2b). Dienol silyl ether **4b** (11.5 g, 41.9 mmol) was reacted with 1,3-dithienium tetrafluoroborate (4.15 g, 20.2 mmol) by a method similar to the preparation of **2a**. Recrystallization of the crude product from ethanol afforded pure **2b** as colorless needles (3.22 g, 64%); mp 71.6—72 °C; IR (KBr) 2978, 1724, 1470, 1438, 1411, 1358, 1316, 1279, 1189, 1171, 1131, 1115, 1085, 1029, 1004, 947, 931, 908, 872, 809, 669, 654, 632, and 575 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=1.29 (t, 3H, J=7.1 Hz), 1.88 (m, 1H), 2.11 (m, 1H), 2.88 (m, 4H), 2.98 (d, 2H, J=6.8 Hz), 3.49 (s, 2H), 4.21 (q, 2H, J=7.1 Hz), and 4.50 (t, 1H, J=6.8 Hz). Calcd for $C_{10}H_{16}O_3S_2$: C, 48.36; H, 6.49%. Found: C, 48.44; H, 6.51%.

Octyl 4-(1,3-Dithian-2-yl)-3-oxobutanoate (2c). A mixture of **2a** (3.81 g, 16.2 mmol), 1-octanol (30 ml), and *p*-TsOH monohydrate (310 mg, 1.62 mmol) in benzene (60 ml) was refluxed for 20 h. The mixture was cooled to room temperature and washed with saturated aqueous $NaHCO_3$ solution and water and then dried with $MgSO_4$. After evaporation of benzene under reduced pressure, most of remained 1-octanol was removed by vacuum distillation. MPLC purification (benzene–ethyl acetate 25:1 v/v) of the residue gave pure **2c** as a colorless heavy oil (4.15 g, 77%); IR (KBr) 2931, 1744, 1716, 1474, 1456, 1438, 1408, 1394, 1357, 1319, 1271, 1189, 1175, 1132, 1116, 1085, 1045, 1025, 991, 966, 913, 812, 722, 633, and 577 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=0.89 (t, 3H, J=7.1 Hz), 1.28 (br, 10H), 1.71 (m, 2H), 1.95 (m, 1H), 2.06 (m, 1H), 2.78 (ddd, 2H, J=14.2, 9.8, 2.9 Hz), 2.94 (ddd, 2H, J=14.2, 6.8, 2.9 Hz), 3.36 (d, 2H, J=7.8 Hz), 3.69 (s, 2H), 3.76 (t, 2H, J=6.4 Hz), and 4.32 (t, 1H, J=7.8 Hz). Calcd for $C_{16}H_{28}O_3S_2$: C, 57.79; H, 8.49%. Found: C, 57.89; H, 8.44%.

Bakers' Yeast Reduction of 4-(1,3-Dithian-2-yl)-3-oxobutanoates; Representative Method. Raw bakers' yeast (112 g) was dispersed in a solution of sucrose (22.9 g), $Na_4P_2O_7$ (11.2 g), and $MgSO_4$ (250 mg) in distilled water (335 ml), and the mixture was then stirred for 30 min at 25 °C. To the fermenting mixture was added the β-keto ester **2** (25.6 mmol) and stirred at the same temperature for 7 days (an additional bakers' yeast (56 g), sucrose (11.5 g), $Na_4P_2O_7$ (5.6 g), $MgSO_4$ (125 mg), and distilled water (167 ml) were supplied every day). Ethyl acetate (634 ml) was added to the reaction mixture and the mixture was stirred for 16 h. After filtration through a Celite pad, the filtrate was extracted with ethyl acetate and the extract was dried with $MgSO_4$. The solvent was removed by evaporation under reduced pressure and the residue was diluted with dichloromethane. The solution was filtered through a silica-gel pad (Wakogel

C-300) and evaporated under reduced pressure. Purification of the residue by MPLC (**3a**, hexane–ethyl acetate 5:3 v/v; **3b** and **3c**, benzene–ethyl acetate 10:1 v/v) gave pure β-hydroxy ester **3** as a colorless oil. Spectroscopic and analytical data of the reduction products **3** are as follows:

3a: $[\alpha]_D^{25}$ +1.0° (*c* 1.56, $CHCl_3$) (74% ee); IR (neat) 3460, 2949, 2902, 2850, 1729, 1437, 1372, 1277, 1197, 1075, 1046, 1020, 910, 872, 849, 774, 715, and 665 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.79—2.00 (m, 3H), 2.13 (m, 1H), 2.47 (dd, 1H, *J*=16.6, 8.4 Hz), 2.54 (dd, 1H, *J*=16.6, 3.7 Hz), 2.87 (m, 4H), 3.14 (d, 1H, *J*=3.9 Hz), 3.72 (s, 3H), 4.29 (dd, 1H, *J*=9.6, 4.6 Hz), and 4.35 (m, 1H). Calcd for $C_9H_{16}O_3S_2$: C, 45.74; H, 6.82%. Found: C, 45.63; H, 6.89%.

3b: $[\alpha]_D^{33}$ +2.6° (*c* 2.83, $CHCl_3$) (50% ee); IR (neat) 3418, 2903, 1732, 1464, 1424, 1374, 1277, 1186, 1074, 1023, 943, 909, 874, 848, 773, and 665 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.28 (t, 3H, *J*=7.1 Hz), 1.79—2.00 (m, 3H), 2.13 (m, 1H), 2.45 (dd, 1H, *J*=16.6, 8.5 Hz), 2.52 (dd, 1H, *J*=16.6, 3.7 Hz), 2.88 (m, 4H), 3.21 (d, 1H, *J*=3.9 Hz), 4.18 (q, 2H, *J*=7.1 Hz), 4.30 (dd, 1H, *J*=9.8, 4.6 Hz), and 4.34 (m, 1H). Calcd for $C_{10}H_{18}O_3S_2$: C, 47.97; H, 7.25%. Found: C, 47.95; H, 7.36%.

3c: $[\alpha]_D^{22}$ +0.19° (*c* 2.11, $CHCl_3$) (14% ee); IR (neat) 3452, 2926, 2854, 1729, 1466, 1423, 1345, 1276, 1247, 1182, 1073, 1018, 910, 872, 853, 774, 723, and 666 cm^{-1}; ^1H NMR ($CDCl_3$) δ=0.88 (t, 3H, *J*=7.1 Hz), 1.28 (br, 10H), 1.63 (m, 2H), 1.79—2.00 (m, 3H), 2.13 (m, 1H), 2.45 (dd, 1H, *J*=16.6, 8.5 Hz), 2.53 (dd, 1H, *J*=16.6, 3.7 Hz), 2.89 (m, 4H), 3.18 (d, 1H, *J*=4.2 Hz), 4.11 (t, 2H, *J*=6.8 Hz), 4.30 (dd, 1H, *J*=9.8, 4.6 Hz), and 4.34 (m, 1H). Calcd for $C_{16}H_{30}O_3S_2$: C, 57.45; H, 9.04%. Found: C, 57.28; H, 8.97%.

Methyl (*S*)-3-(*t*-Butyldiphenylsiloxy)-4-(1,3-dithian-2-yl)-butanoate (8). To a stirred solution of **3a** (1.01 g, 4.2 mmol) in dry DMF (4.6 ml) was added TBDPS-Cl (1.70 g, 6.2 mmol) and imidazole (0.85 g, 12.4 mmol) at room temperature. After stirring for 2 h at room temperature, the solvent was removed in vacuo. The residue was extracted with ethyl acetate (30 ml) and 5% aqueous oxalic acid solution (8 ml×3). The organic layer was then successively washed with 5% aqueous oxalic acid solution (15 ml), saturated aqueous $NaHCO_3$ solution (15 ml), and water (15 ml). The solution was dried with $MgSO_4$ and evaporated under reduced pressure to give almost TLC-pure product. MPLC purification (benzene–ethyl acetate 25:1 v/v) of the crude product afforded pure **8** as a colorless oil (2.02 g, 99%); $[\alpha]_D^{24}$ −6.9° (*c* 2.28, $CHCl_3$); IR (neat) 3070, 3048, 3014, 2998, 2931, 2896, 2856, 1738, 1472, 1462, 1427, 1390, 1362, 1276, 1197, 1157, 1111, 998, 940, 858, 822, 741, 704, and 610 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.05 (s, 9H), 1.78 (m, 1H), 1.97 (m, 3H), 2.50 (dd, 2H, *J*=6.0, 2.2 Hz), 2.67 (m, 4H), 3.52 (s, 3H), 3.94 (dd, 1H, *J*=8.4, 6.1 Hz), 4.43 (m, 1H), 7.40 (m, 6H), and 7.69 (m, 4H).

Methyl (*R*)-3-(*t*-Butyldiphenylsiloxy)-5-oxopentanoate (9). To a solution of **8** (1.01 g, 2.13 mmol) in acetonitrile (11 ml) and water (0.38 ml) was added iodomethane (1.59 g, 11.2 mmol) and K_2CO_3 (196 mg, 1.41 mmol). The mixture was refluxed for 3 h and the solvent was then removed by evaporation under reduced pressure. The residue was extracted with dichloromethane and the extract was dried with $MgSO_4$. The residue obtained by evaporation of the solvent under reduced pressure was purified by MPLC (hexane–ethyl acetate 4:1 v/v) to give pure **9** as a pale yellow oil (231 mg, 28%); $[\alpha]_D^{19}$ −1.7° (*c* 2.56, $CHCl_3$); IR (neat) 3073, 2932, 2859, 1742, 1714, 1473, 1428, 1363, 1308, 1160, 1112, 786, 702, 668, 612, 518, and 512 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.03 (s, 9H), 2.62 (m, 4H), 3.57 (s, 3H), 4.62 (m, 1H), 7.42 (m, 6H), 7.66 (m, 4H), and 9.62 (t, 1H, *J*=2.2 Hz).

Methyl (*R*)-3-(*t*-Butyldiphenylsiloxy)-5-hydroxypentanoate (10). To an ethereal solution of $Zn(BH_4)_2$ (0.3 M, 6.9 ml) cooled to 0 °C was added dropwise a solution of **9** (310 mg, 0.84 mmol) in dry ether (7 ml) with stirring under nitrogen and stirring was then continued for 2 h at 0 °C. After the addition of water (6 ml), the aqueous mixture was filtered and extracted with ether. The organic layer was dried with $MgSO_4$ and concentrated under reduced pressure to give crude product. MPLC purification (benzene–ethyl acetate 4:1 v/v) afforded pure **10** as a colorless oil (160 mg, 49%); $[\alpha]_D^{23}$ −1.7° (*c* 0.92, $CHCl_3$); IR (neat) 2959, 2931, 2858, 1738, 1472, 1428, 1391, 1362, 1309, 1261, 1221, 1164, 1112, 1084, 1027, 1008, 998, 927, 823, 703, and 613 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.05 (s, 9H), 1.66 (brs, 1H), 1.76 (m, 2H), 2.54 (d, 2H, *J*=6.3 Hz), 3.53 (s, 3H), 3.63 (m, 2H), 4.37 (m, 1H), 7.40 (m, 6H), and 7.69 (m, 4H).

(*R*)-3-(*t*-Butyldiphenylsiloxy)-5-pentanolide (11). A mixture of **8** (144 mg, 0.37 mmol) and *p*-TsOH monohydrate (7 mg, 0.037 mmol) in benzene (3.4 ml) was refluxed for 1 h. After cooling to room temperature, saturated aqueous $NaHCO_3$ solution (10 ml) was added to the mixture and the aqueous mixture was then extracted with benzene. The organic layer was dried with $MgSO_4$ and concentrated under reduced pressure to give crude product. MPLC purification (benzene–ethyl acetate 4:1 v/v) afforded pure **11** as a colorless oil (57 mg, 44%): $[\alpha]_D^{24}$ +7.0° (*c* 0.26, $CHCl_3$) (lit,[3] $[\alpha]_D$ +9.2° (*c* 7.69, $CHCl_3$)); IR (neat) 3461, 3071, 3049, 2932, 2856, 1731, 1589, 1567, 1472, 1427, 1391, 1361, 1261, 1223, 1161, 1114, 928, 864, 822, 742, 701, and 610 cm^{-1}; ^1H NMR ($CDCl_3$) δ=1.07 (s, 9H), 1.84 (m, 2H), 2.58 (d, 2H, *J*=4.9 Hz), 4.22 (m, 2H), 4.62 (ddd, 1H, *J*=11.4, 8.8, 4.2 Hz), 7.42 (m, 6H), and 7.63 (m, 4H).

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