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Diastereoselective Reduction of Chiral 2-(1-Alkenoyl)- and 2-(1-Alkynoyl)-1,3-Oxathiane 3-Oxides Derived from (1*R*)-(+)-Camphor

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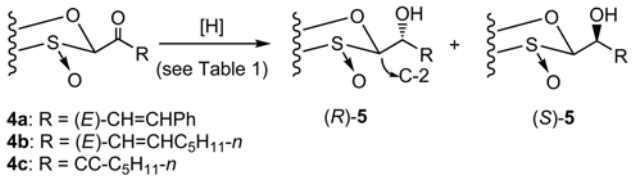
The diastereoselective addition of nucleophilic reagents to ketones having a chiral auxiliary is a useful method for obtaining optically active alcohols.[1] Chiral auxiliaries used for this purpose include enantiomerically pure amino alcohols derived from norephedrine,[2] (+)-pulegone,[3] amino acids[4], D-glucose,[5] or (1*R*)-(+)-camphor,[6] 3-hydroxythiols derived from (+)-pulegone,[7] (−)-myrtenal[8] or (1*R*)-(+)-camphor,[9] and 1,3-diols.[10]

We previously reported highly diastereoselective reduction of chiral 2-acyl-1,3-oxathiane sulfoxides **4** (R = phenyl, *n*-hexyl) derived from (1*R*)-(+)-camphor.[9] The high diastereoselectivity observed in the reduction with chelating reducing agents such as L-Selectride® (lithium tri-*sec*-butylborohydride) has been explained by invoking a chelate model, where the sulfoxide oxygen and the carbonyl oxygen take part in the chelation with metal cation. On the contrary, diisobutylaluminum hydride (DIBAL-H), a non-chelating agent, has been suggested to react according to a Solladié model, [11] giving the same epimeric carbinols.

As an extension of our previous work, we wish to report a highly diastereoselective reduction of **4** where R is 1-alkenyl or 1-alkynyl group and a determination of absolute configuration of newly formed stereocenter.

1,3-Oxathiane oxides **4** were prepared starting from the known oxathiane **1**,[12] according to Scheme 1. Thus, **1** was lithiated with *n*-BuLi in the presence of *N*,*N*,*N*′,*N*′-tetramethylethylenediamine (TMEDA) and then treated with cinnamaldehyde, (*E*)-2-octenal or 2-octynal to give the corresponding alcohols **2** as epimeric mixtures. Oxidation of **3** with PDC[13] in CH_2Cl_2 followed by treatment with *m*-CPBA gave the sulfoxides **4** (see below for the determination of equatorial position of oxygen in **4a**).



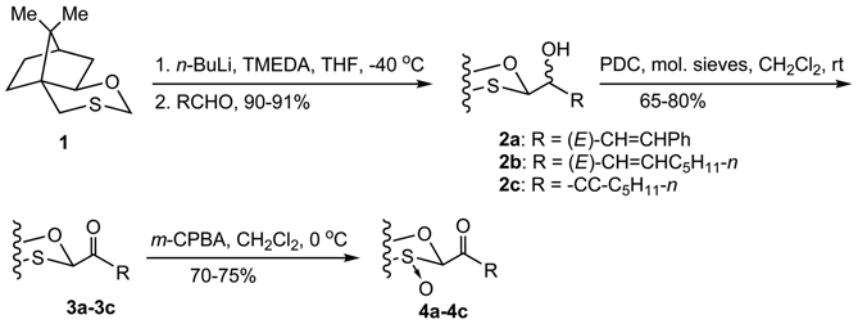
Scheme 2. Diastereoselective reduction of 2-acyl-1,3-oxathiane 3-oxides **4**.

Then, we studied reduction of ketones **4**, as shown in Table 1 (Scheme 2).

Diastereoselectivity could be easily determined by ^{1}H NMR spectroscopy. For example, in entry 1, C-2 proton of the major product **5a** appeared as a doublet at δ 4.14 (J = 2.2 Hz) and that of the minor one appeared as a doublet at δ 4.41 (J = 4.3 Hz).

In all cases, (*R*)-**5** (see below for the determination of the absolute configuration) was obtained as the major product, irrespective of the chelating nature of reducing agents. Generally, diastereoselectivity was higher when chelating reducing agents (entries 1-5) rather than nonchelating agents (entries 6-7) were used. High selectivity (> 98%) favoring the (*R*)-alcohol was observed when LiAlH(O-*t*-Bu)$_3$ or L-Selectride® was used (entries 4-5).

Next, we undertook the cleavage of **5** to determine the absolute configuration of the newly formed carbinol carbon and thereby the approaching preference of the nucleophile to the carbonyl faces. Thus, alcohol **5a** obtained from LiAlH(O-*t*-Bu)$_3$ reduction (entry 5b) was converted to diol **6a**, $[\alpha]_D^{20}$ −29.3 (c = 1.01, $CHCl_3$)[14] using acidic hydrolysis[15]

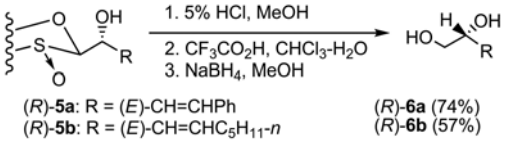


Scheme 1. Preparation of 2-acyl-1,3-oxathiane 3-sulfoxides **4**.

Table 1. Diastereoselectivity in the reduction of 2-acyl-1,3-oxathiane 3-oxides **4**[a]

Entry	Reagent	Solvent	Temp. (°C)	de (%)[b] **4a**/**4b**/**4c**
1	$NaBH_4$	EtOH	0	40/56/74
2	$LiBH_4$	THF	−70	50/60/56
3a	$LiAlH_4$	THF	−70	74/56/68
3b	$LiAlH_4$	Et_2O	−70	66/82/92
4a	L-Selectride®	Et_2O	−70	98/98/98
4b	L-Selectride®	THF	−70	98/98/98
5a	$LiAlH(O\text{-}t\text{-}Bu)_3$	THF	−70	66/82/98
5b	$LiAlH(O\text{-}t\text{-}Bu)_3$	Et_2O	−70	98/84/98
5c	$LiAlH(O\text{-}t\text{-}Bu)_3$/ 12-crown-4[c]	Et_2O	−70	98/86/98
6a	DIBAL-H	toluene	−70	38/40/16
6b	DIBAL-H	hexanes	−70	56/30/18
7	$n\text{-}Bu_4NBH_4$	CH_2Cl_2	20	50/38/62

[a]Determined by ^{1}H NMR on the crude products obtained from 0.1 mmol of ketones. [b]In all cases, the (*R*)-epimer was the major product. [c]The molar ratio of **4**, reagent, and crown ether = 1:3:5.



Scheme 3. Preparation of diols **6** by acidic hydrolysis of **5** followed by reduction.

followed by $NaBH_4$ (Scheme 3).

Because we could not find any optical rotation data of **6a** in literature, we resorted to single crystal X-ray crystallography of the minor alcohol obtained from $NaBH_4$ reduction (entry 1) to determine the absolute configuration of carbinol carbon of **5a**.[16,17] As one can see in an ORTEP drawing of **5a** (Fig. 1), this alcohol has the (*S*)-configuration. Therefore, the major alcohol **5a** and diol **6a** should have the (*R*)-configuration. Also, Figure 1 clearly shows the equatorial orientation of the sulfoxide oxygen, which was previously

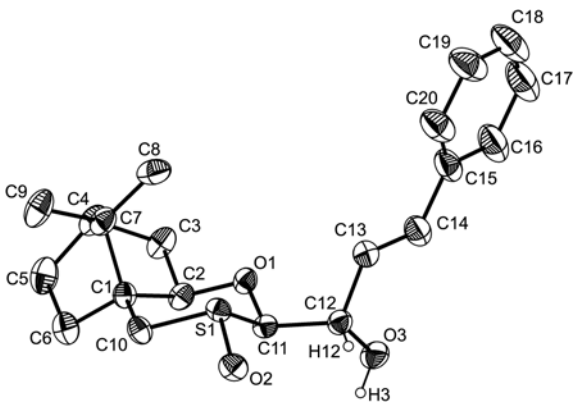
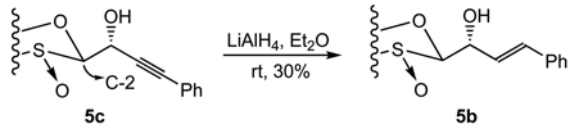


Figure 1. A view of (*S*)-**5a**. Vibrational ellipsoids are drawn at the 30% probability level. Hydrogen atoms except H12 are omitted for clarity.



Scheme 4. Conversion of **5c** to **5b**.

presumed based on the ^{1}H NMR data.[9]

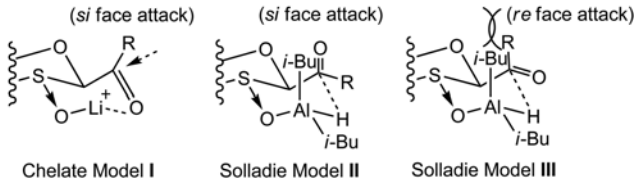
Carbinol (*R*)-**5b** (de 98%) was similarly converted to diol **6b**, $[\alpha]_D^{20}$ −15.6 (c = 1.03, $CHCl_3$). Because (*S*)-**6b** is known to be dextrorotatory,[18] it follows that **6b** derived from **5b** has the (*R*)-configuration as in the case of **6a**.

The absolute configuration of the carbinol center of **5c** (entry 4a, Table 1) was determined by comparing the ^{1}H NMR spectrum of **5b** produced by $LiAlH_4$ reduction[19] of propargylic alcohol **5c** (Scheme 4) with that of **5c**: two spectra were identical, especially in the region of C-2 proton.

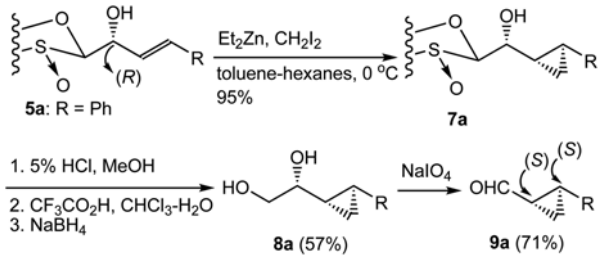
Therefore, we can conclude that the reduction of **4a**, **4b** and **4c** all gives the (*R*)-carbinols **5**.

The formation of (*R*)-carbinols **5** in the reduction by chelating reducing agents can be explained by a chelate model **I** (Scheme 5), where the sulfoxide oxygen, rather than the ring oxygen takes part in chelation with metal ion.[9] In this model, an intermolecular hydride addition from the less hindered *si* face of carbonyl group will give the carbinol of observed stereochemistry. Chelation here is presumed to be rather strong, because the presence of crown ether did not affect the degree of diastereoselectivity (entry 5b *vs.* 5c).[9] The formation of (*R*)-carbinols in DIBAL-H reduction of **4** may proceed according to a Solladié model **II**, where a dsp^3 hybridized aluminum atom chelates with the sulfoxide oxygen in a chair-like conformation. Then, an intramolecular hydride transfer to the *si* face of ketones will lead to the formation of (*R*)-carbinols, which was confirmed as described above. Alternative model **III** will be disfavored due to the steric repulsion between the R group and the isobutyl group.

We also briefly studied the cyclopropanation reaction of alcohol **5a**, as shown in Scheme 6.[20] Thus, the treatment of **5a** with excess Et_2Zn and CH_2I_2 gave a *syn* product **7a** in high diastereoselectivity (> de 98%).[21] Conversion of **7a** to diol **8a** was achieved using the similar reaction sequences depicted in Scheme 3. Oxidative cleavage of diol **8a** with $NaIO_4$ gave dextrorotatory aldehyde **9a**. Since it is known that (*R*,*R*)-aldehyde is levorotatory,[22] **9a** from **5a** must have the (*S*,*S*)-configuration. This fact is in agreement with the *syn*-selectivity of cyclopropanation reaction.[20] Thus, the absolute configuration of the carbinol carbon in **5a**, determined through this cyclopropanation route agrees with our previous conclusions obtained from X-ray data.



Scheme 5. Stereochemical models.



Scheme 6. Cyclopropanation of **5a**.

In summary, reduction of chiral 2-(1-alkenoyl)- and 2-(1-alkynoyl)-1,3-oxathiane 3-oxides **4** derived from (1*R*)-(+)-camphor with LiAlH(O-*t*-Bu)$_3$ and L-Selectride® proceeds with high diastereoselectivity. The formation of the major alcohol (*R*)-**5** can be explained by a chelate model **I** (Scheme 5) where the sulfoxide oxygen, rather than the ring oxygen takes part in chelation with metal ion. (*R*)-Diols **6** of high optical purity can be prepared from **4** using acidic hydrolysis followed by $NaBH_4$ reduction.

Experimental Section

Cinnamyl Carbinol 2a. To a chilled and well-stirred (−40 °C) solution of oxathiane **1** (1.97 g, 10.0 mmol) and TMEDA (1.30 g, 12.0 mmol) in dry THF (40 mL) was added 6.0 mL of 2 M *n*-BuLi solution in hexanes during 2 min. The whole mixture was stirred for 6 h. Then, a solution of cinnamaldehyde (1.59 g, 12 mmol) in dry THF (5 mL) was added to the above solution all at once. After 1 h, the reaction was quenched by adding saturated NH_4Cl solution. Usual workup followed by column chromatography gave 3.02 g (91%) of product as pale yellow oil. (*R*)-:(*S*)-carbinol = 2:1. Trituration from hexanes gave 0.89 g (27%) of pure (*R*)-**2a**: mp 121-122 °C; $[\alpha]_D^{20}$ −81.7 (c = 1.00, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 7.42-7.20 (5H, m), 6.73 (1H, d, *J* = 15 Hz), 6.26-6.15 (1H, dd, , *J* = 15, 7 Hz), 4.67 (1H, d, *J* = 7 Hz), 4.38-4.26 (1H, m), 3.64 (1H, dd, *J* = 7, 3 Hz), 3.06, 2.76 (2H, ABq, *J* = 14 Hz), 1.33 (3H, s), 0.92 (3H, s); ^{13}C-NMR ($CDCl_3$) δ 136.3, 132.75, 128.3, 127.6, 126.5, 85.1, 85.0, 83.4, 74.4, 46.5, 45.3, 42.5, 37.6, 34.0, 28.0, 27.1, 23.1, 20.3.

(*E*)-(1-Heptenyl) Carbinol 2b was similarly prepared in 90% yield as a mixture of (*R*)- and (*S*)-carbinol in a ratio of 1.9:1. Column chromatography gave pure (*R*)-**2b** as a less polar component: $[\alpha]_D^{20}$ −86.9 (c = 1.00, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 5.80-5.73 (1H, m), 5.45-5.37 (1H, m), 4.54 (1H, d, *J* = 7 Hz), 4.05 (1H, apparent t, *J* = 7 Hz), 3.57 (1H, dd, *J* = 8, 3 Hz), 3.01, 2.72 (2H, ABq, *J* = 14 Hz); ^{13}C-NMR ($CDCl_3$) δ 135.9, 126.7, 85.2, 84.9, 74.9, 46.6, 45.4, 42.6, 37.7, 34.2, 32.2, 31.3, 28.5, 28.1, 27.2, 23.1, 22.4, 20.4, 14.0.

1-Heptynyl Carbinol 2c was similarly prepared in 91% yield as a mixture of (*R*)- and (*S*)-carbinol in a ratio of 3:1. (*S*)-**2c**: ^{1}H-NMR ($CDCl_3$) δ 4.77 (d, *J* = 3.3 Hz). (*R*)-**2c**: ^{1}H-NMR ($CDCl_3$) δ 4.67 (d, *J* = 6.8 Hz). This alcohol was converted directly to ketone **3c** without further characterization

Cinnamyl Ketone 3a was prepared in 80% yield by the oxidation of **2a** with pyridinium dichromate: mp 172-173 °C; $[\alpha]_D^{20}$ +126 (c = 0.98, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 7.79 (1H, d, *J* = 16 Hz), 7.58-7.55 (2H, m), 7.39-7.35 (3H, m), 7.13 (1H, d, *J* = 16 Hz), 5.42 (1H, s), 3.69 (1H, dd, *J* = 8, 3 Hz), 3.18, 2.86 (2H, ABq, *J* = 14 Hz), 1.40 (3H, s), 0.93 (3H, s); ^{13}C-NMR ($CDCl_3$) δ 168.5, 135.7, 132.1, 128.2, 127.8, 126.5, 123.9, 84.1, 54.1, 47.0, 45.1, 44.9, 36.4, 30.4, 29.6, 25.9, 19.7.

Ketone 3b: $[\alpha]_D^{20}$ −44.9 (c = 1.19, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 7.05 (1H, dt, *J* = 16, 7 Hz), 6.42 (1H, d, *J* = 16), 5.27 (s, 1H), 3.69 (1H, dd, *J* = 7.6, 3.0 Hz), 3.18, 2.86 (2H, ABq, *J* = 14 Hz), 1.31 (3H, s), 0.88 (3H, s); ^{13}C-NMR ($CDCl_3$) δ 192.6, 150.7, 124.4, 85.1, 84.8, 46.7, 45.4, 42.7, 37.6, 34.0, 32.6, 31.2, 28.7, 27.5, 27.1, 23.0, 22.3, 20.2, 13.8.

Ketone 3c: $[\alpha]_D^{20}$ −28.0 (c = 1.10, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 5.26 (1H, s), 3.61 (1H, dd, *J* = 8, 3 Hz), 3.03, 2.86 (2H, ABq, *J* = 14 Hz), 2.36 (2H, t, *J* = 7 Hz); ^{13}C-NMR ($CDCl_3$) δ 180.4, 99.2, 84.8, 84.6, 78.7, 46.7, 45.2, 43.5, 37.4, 33.4, 30.8, 28.6, 27.1, 27.0, 22.6, 22.0, 20.2, 19.1, 13.8.

Sulfoxide 4a was prepared in 70% yield by the oxidation of **3a** with *m*-chloroperbenzoic acid: mp 138-139 °C; $[\alpha]_D^{20}$ −215 (c = 1.00, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 7.82 (1H, d, *J* = 16 Hz), 7.64-7.59 (2H, m), 7.46-7.39 (3H, m), 7.11 (1H, d, *J* = 16 Hz), 4.83 (1H, s), 3.91 (1H, dd, *J* = 8, 3 Hz), 3.59, 2.96 (2H, ABq, *J* = 12 Hz), 1.18 (3H, s), 0.99 (3H, s); ^{13}C-NMR ($CDCl_3$) δ 189.9, 145.5, 133.8, 130.9, 128.6, 128.5, 121.2, 97.8, 85.6, 53.9, 50.9, 40.6, 45.0, 36.7, 32.9, 26.8, 22.3, 19.9.

Sulfoxide 4b: oil; $[\alpha]_D^{20}$ −185 (c = 1.00, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 7.05 (1H, dt, *J* = 16, 7 Hz), 6.37 (1H, d, *J* = 16 Hz), 4.67 (1H, s), 3.80 (1H, dd, *J* = 8, 3 Hz), 3.46, 2.85 (2H, ABq, *J* = 13 Hz); ^{13}C-NMR ($CDCl_3$) δ 189.9, 152.0, 125.5, 97.7, 85.8, 53.9, 50.9, 46.8, 45.1, 36.8, 33.1, 32.6, 31.1, 27.3, 26.9, 22.3, 22.2, 20.0, 13.7.

Sulfoxide 4c: oil; $[\alpha]_D^{20}$ −131 (c = 1.30, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 4.60 (1H, s), 3.83 (1H, dd, *J* = 8, 3 Hz), 3.40, 2.89 (2H, ABq, *J* = 13 Hz), 2.37 (2H, t, *J* = 7 Hz); ^{13}C-NMR ($CDCl_3$) δ 178.2, 101.6, 99.7, 85.3, 79.1, 53.3, 50.4, 46.9, 45.1, 36.9, 33.0, 30.7, 27.0, 26.9, 22.1, 21.9, 20.0, 19.1, 13.7.

Reduction of Ketones 4. An example: A solution of **4a** (30 mg, 0.087 mmol) in THF (5 mL) was treated with a solution (0.35 mL) of 1 M LiAlH(O-*t*-Bu)$_3$ in THF under nitrogen atmosphere at −70 °C. After stirring for 0.5 h, the reaction mixture was quenched with aqueous NH_4Cl and extracted with EtOAc. Usual workup gave crude **5a** (28 mg, 93%), whose ^{1}H NMR spectrum showed that the diastereoselective excess was 98%. Recrystallization from EtOH gave (*R*)-**5a** as a single diastereomer.

(*R*)-**5a:** mp 138-139 °C; $[\alpha]_D^{20}$ −176 (c = 1.00, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 7.43-7.20 (5H, m), 6.46 (1H, d, *J* = 16 Hz), 6.35 (1H, dd, *J* = 16, 7 Hz), 4.86 (1H, broad d, *J* = 4), 4.14 (1H, d, *J* = 2.2 Hz), 3.81 (1H, dd, *J* = 8, 3 Hz), 3.52, 2.79 (2H, ABq, *J* = 13 Hz), 1.07 (3H, s), 0.94 (3H, s); ^{13}C-NMR ($CDCl_3$) δ 136.2, 131.8, 128.1, 127.4, 127.0, 126.3, 98.5, 85.9, 68.8, 52.0, 50.7, 46.4, 45.1, 36.7, 33.0, 26.8, 22.1, 19.8.

(*R*)-**5b:** mp 55-56 °C; $[\alpha]_D^{20}$ −173 (c = 1.00, $CHCl_3$); ^{1}H-

NMR ($CDCl_3$) δ 5.82 (1H, dt, *J* = 15, 7 Hz), 5.58 (1H, dd, *J* = 15, 6 Hz), 4.59 (1H, broad t, *J* = 7 Hz), 3.99 (1H, d, *J* = 2 Hz), 3.77 (1H, dd, *J* = 8, 3 Hz), 3.48, 2.72 (2H, ABq, *J* = 13 Hz), 2.56 (1H, d, *J* = 9), 1.05 (3H, s), 0.87 (3H, s); ^{13}C-NMR ($CDCl_3$) δ 134.9,127.0, 98.2, 86.3, 69.9, 52.8, 51.2, 46.7, 45.4, 36.9, 33.4, 32.1, 31.2, 28.5, 27.1, 22.5, 22.4, 20.2, 14.0.

(*R*)-**5c:** mp 72-73 °C; $[\alpha]_D^{20}$ −148 (c = 1.00, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 4.82 (1H, bs), 4.06 (1H, d, *J* = 2 Hz), 3.82 (1H, dd, *J* = 8, 3 Hz), 3.44, 2.75 (2H, ABq, *J* = 13 Hz), 3.07 (1H, bs), 1.03 (3H, s), 0.90 (3H, s); ^{13}C-NMR ($CDCl_3$) δ 97.6, 87.6, 86.4, 76.8, 61.2, 52.5, 51.0, 46.8, 45.3, 36.9, 33.3, 30.8, 27.9, 27.0, 22.3, 22.0, 20.1, 18.6, 13.9.

(2*R*,3*E*)-4-Phenylbut-3-ene-1,2-diol (**6a**) was prepared in 74% yield by the treatment of (*R*)-**5a** (de 98%) with 5% HCl in MeOH followed by $NaBH_4$: mp 41-42 °C; $[\alpha]_D^{20}$ −29.3 (c = 1.01, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 7.55-7.15 (5H, m), 6.67 (1H, d, *J* = 16 Hz), 6.17 (1H, dd, *J* = 16, 6 Hz), 4.45-4.40 (1H, m), 3.75 (1H, dd, *J* = 11, 3.5 Hz), 3.60 (1H, dd, *J* = 11, 7.4 Hz), 2.98 (bs, 2H); ^{13}C-NMR ($CDCl_3$) δ 136.3, 131.6, 128.4, 127.7, 126.4, 73.1, 66.4.

(2*R*,3*E*)-Non-3-ene-1,2-diol (**6b**)**:** An oil; $[\alpha]_D^{20}$ −15.6 (c = 1.03, $CHCl_3$) (precursor de 98%) [lit.[18] for (*S*)-isomer $[\alpha]_D^{20}$ +17.1 (c = 1.03, $CHCl_3$)]; ^{1}H-NMR ($CDCl_3$) δ 5.76-5.66 (1H, m), 5.37 (1H, dd, *J* = 15, 7 Hz), 4.15-4.10 (1H, m), 3.59-3.52 (1H, m), 3.45-3.38 (1H, m), 2.30 (2H, bs), 2.00-1.93 (2H, m), 1.35-1.18 (6H, m), 0.81 (3H, t, *J* = 7 Hz).

Cyclopropyl Carbinol 7a: A solution of **5a** (de 98%, 650 mg, 1.87 mmol) in dry toluene (5 mL) was treated with 9.4 mL (9.4 mmol) of 1 M Et_2Zn in hexanes at 0 °C. After 5 min, CH_2I_2 (0.76 mL, 9.4 mmol) was added to the above solution and the whole mixture was stirred for 24 h. The reaction was quenched by adding aq. NH_4Cl. Usual workup followed by column chromatography gave 640 mg (95%) of white solid: mp 49-50 °C; $[\alpha]_D^{20}$ −97.3 (c = 1.00, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 7.31-7.03 (5H, m), 4.16 (1H, d, *J* = 2 Hz), 3.80-3.72 (2H, m), 3.51, 2.76 (2H, ABq, *J* = 13 Hz), 3.42 (1H, dt, *J* = 8, 2 Hz), 2.40 (1H, d, *J* = 8 Hz); ^{13}C-NMR ($CDCl_3$) δ 141.8, 128.0, 125.8, 125.4, 98.2, 86.1, 71.0, 52.3, 51.0, 46.5, 45.2, 36.7, 33.1, 26.9, 24.5, 22.3, 20.4, 20.0, 14.0.

(1*R*,1'*S*,2'*S*)-1-(2-Phenylcyclopropyl)ethane-1,2-diol (**8a**) was prepared in 57% yield starting from **7a** using the similar reaction sequences as depicted in Scheme 3: $[\alpha]_D^{20}$ +64.1 (c = 1.04, $CHCl_3$); ^{1}H-NMR ($CDCl_3$) δ 7.31-7.01 (5H, s), 3.80 (1H, d of ABq, *J* = 11, 3 Hz), 3.65 (1H, d of ABq, *J* = 11, 7 Hz), 3.32 (1H, apparent dt, *J* = 7, 3 Hz), 2.4 (2H, bs), 1.91-1.82 (1H, m), 1.35-1.18 (1H, m), 1.17-0.42 (2H, m); ^{13}C-NMR ($CDCl_3$) δ 141.9, 128.4, 125.92, 125.88, 125.81, 75.6, 66.5, 25.2, 20.4, 13.1.

(1*S*,2*S*)-2-Phenylcyclopropane-1-carbaldehyde (**9a**) was prepared in 71% yield by the treatment of **8a** (from (*R*)-**5a** of de 98%) with $NaIO_4$: oil; $[\alpha]_D^{20}$ +356 (c = 0.38, $CHCl_3$) [lit.[22] for (1*R*,2*R*)-isomer $[\alpha]_D^{20}$ −378 (c = 0.378, $CHCl_3$)]; ^{1}H-NMR ($CDCl_3$) δ 9.33 (1H, d, *J* = 4 Hz), 7.36-7.10 (5H, m), 2.67-2.59 (1H, m), 2.21-2.15 (1H, m), 1.79-1.49 (2H, m); ^{13}C-NMR ($CDCl_3$) δ 199.6, 138.9, 129.0, 128.5, 128.4, 126.8, 126.2, 33.7, 26.5, 16.3.

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References and Notes

1. (a) Mengel, A.; Reiser, O. *Chem. Rev.* **1999**, *99*, 1191. (b) Roberstson, J.; Unsworth, W. P.; Lamont, S. G. *Tetrahedron* **2010**, *66*, 2363.
2. (a) Colombo, L.; Di Giacomo, M.; Brusotti, G.; Milano, E. *Tetrahedron Lett*. **1995**, *36*, 2863. (b) Harder, T.; Lohl, T.; Bolte, M.; Wagner, K.; Hoppe, D. *Tetrahedron Lett*. **1994**, *35*, 7365.
3. Eliel, E. L.; He, X.-C. *J. Org. Chem*. **1990**, *55*, 2114.
4. (a) Fukuzawa, S.; Miura, M.; Matsuzawa, H. *Tetrahedron Lett*. **2001**, *42*, 4167. (b) Uiterweerd, P. G. H.; van der Sluis, M.; Kaptein, B.; de Lange, B.; Kellogg, R. M.; Broxtermanb, Q. B. *Tetrahedron: Asymmetry* **2003**, *14*, 3479.
5. Ko, K.-Y.; Park, J.-Y. *Tetrahedron Lett*. **1997**, *38*, 407.
6. Ko, K.-Y.; Yun, H. *Heterocycles* **2010**, *81*, 2351.
7. Ko, K.-Y.; Frazee, W. J.; Eliel, E. L. *Tetrahedron* **1984**, *40*, 1333.
8. Chacón-García, L.; Lagunas-Rivera, S.; Pérez-Estrada, S.; Vargas-Díaz, M. E.; Joseph-Nathan, P.; Tamariz, J.; Gerardo Zepeda, L. *Tetrahedron Lett*. **2004**, *45*, 2141.
9. Ko, K.-Y.; Kim, K.-I. *Bull. Korean Chem. Soc.* **1998**, *19*, 911.
10. (a) Bailey, W. F.; Reed, D. P.; Clark, D. R.; Kapur, G. N. *Org. Lett*. **2001**, *3*, 1865. (b) Ko, K.-Y.; Park, J.-Y. *Bull. Korean Chem. Soc.* **2002**, *23*, 665.
11. (a) Solladié, G. In *Advanced Asymmetric Synthesis*; Stephenson, G. R., Ed.; Blackie: 1996. (b) Page, P. C. B.; Prodger, J. C. *Synlett*. **1990**, 460.
12. Ko, K.-Y.; Kim, K.-I. *Bull. Korean Chem. Soc.* **1998**, *19*, 379.
13. Herscovici, J.; Antonakis, K. *J. Chem. Soc., Chem. Commun*. **1980**, 561.
14. The enantiomeric excess of **6a** was found to be *ca.* 96% by the proton NMR study of its 2-phenyl-1,3-dioxolanes doped with $Eu(hfc)_3$. See: Eliel, E. L.; Ko, K.-Y. *Tetrahedron Lett*. **1983**, *24*, 3547.
15. Cossy, J. *Synthesis* **1987**, 1113.
16. Two epimeric carbinols were easily separated by column chromatography (EtOAc). In $NaBH_4$ reduction, the major one was less polar (R_f 0.58) than the minor one (R_f 0.3). The minor one was more easily recrystallized into single crystal.
17. Further details of the crystal structure investigations may be obtained from the Cambridge Crystallographic Data Centre (CCDC, 12 Union Road, Cambridge CB2 1EZ (UK); tel.: (+44)1223-336-408, fax: (+44)1223-336-033, e-mail: deposit@ccdc.cam.ac.uk) on quoting the depository number CCDC 835723.
18. Takano, S.; Iwabuchi, Y.; Ogasawara, K. *Synlett*. **1991**, 548.
19. Chun, J.; Byun, H.-S.; Bittman, R. *J. Org. Chem.* **2003**, *68*, 348.
20. (a) Lebel, H.; Marcoux, J.-F.; Molinaro, C.; Charette, A. B. *Chem. Rev.* **2003**, *103*, 977. (b) Ratier, M.; Castaing, M.; Godet, J. Y.; Pereyre, M. *J. Chem. Res., Synop.* **1978**, *179*. (c) Charette, A. B.; Lebel, H. *J. Org. Chem.* **1995**, *60*, 2966.
21. We could not find any signal due to the minor product in ^{1}H NMR or ^{13}C NMR spectrum.
22. Mori, A.; Arai, I.; Yamamoto, H. *Tetrahedron* **1986**, *42*, 6447.