Diastereoselective Synthesis of 10-(Alkylsulfinyl)- and 10-(Alkenylsulfinyl)isoborneols by Oxidation of the Corresponding Sulfides with 3-Chloroperoxybenzoic Acid

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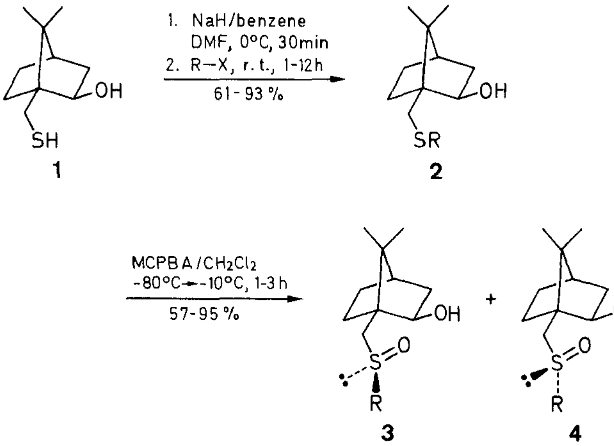
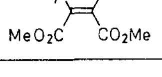
The oxidation of 10-(alkylsulfinyl)- and 10-(alkenylsulfinyl)isoborneols with 3-chloroperoxybenzoic acid gives the corresponding *S*-oxides in good yields and with high diastereoselectivity.

Asymmetric reactions using chiral sulfoxides have provided useful new methods for synthetic organic chemistry.[1] Generally, two procedures for the preparation of chiral sulfoxides are available: asymmetric oxidation of parent sulfides by chemical and microbiological methods[2] and the Andersen procedure[3] (reaction of organometallic reagents such as alkylmagnesium halides with chiral sulfinic esters). In the oxidation methods, the optical purity of the sulfoxides depends on the oxidizing agent used and the sulfide, whilst Andersen's method suffers from the fact that only a few chiral sulfinates such as menthyl 4-methylbenzenesulfinate are easily available. Therefore, the search for a general method for the highly asymmetric oxidation of sulfides is still of considerable practical interest.

In the course of research on asymmetric induction reactions using chiral sulfoxides, we introduced dimethyl $(R)_S$-2-(2-*exo*-hydroxy-10-bornylsulfinyl)maleate (10-[1,2-bis(methoxycarbonyl)ethenylsulfinyl]isoborneol **3j**) as a useful dienophile.[4] The chiral sulfoxide **3j** is readily obtained by oxidation of the corresponding sulfide **2j** with 3-chloroperoxybenzoic acid in a highly diastereoselective manner. Similar oxidations of 10-(alkenylthio)isoborneols with 3-chloroperoxybenzoic acid have been described.[5]

It has been shown[6] for a related system (6-methylthio-2-hydroxymethylnorbornane) that a hydroxy group in a suitable position may exert a directing effect on the diastereoselectivity of the oxidation of alkylthio-substituted bicyclo[2.2.1]heptane derivatives. We now descibe a facile diastereoselective synthesis of sulfoxides **3** [10-(alkylsulfinyl)- and 10-(alkenylsulfinyl)isoborneols] by oxidation of the corresponding sulfides **2** [10-(alkylthio)- and 10-(alkenylthio)isoborneols] with 3-chloroperoxybenzoic acid.



2,3,4	R	2,3,4	R
a	Me	**g**	$CH_2\overset{O}{\overset{\Vert}{C}}CH_3$
b	Et	**h**	$CH_2\overset{O}{\overset{\Vert}{C}}Ph$
c	*i*-Pr	**i**	$CH_2\overset{O}{\overset{\Vert}{P}}(OEt)_2$
d	$CH_2CH{=}CH_2$	**j**	
e	CH_2Ph		
f	CH_2CH_2Ph		

The sulfides **2a–h** were prepared by *S*-alkylation (or *S*-alkenylation) of (1*S*)-10-mercaptoisoborneol[7] (**1**) via successive treatment with sodium hydride and alkyl or alkenyl halides in benzene/dimethylformamide. The sul-

Table 1. Sulfides **2** Prepared

Product	Reaction Time (h)	R-X	Yield (%)	mp (°C)	$[\alpha]_D^a$	Molecular[b] formula	MS (70 eV)[c] *m/z*
2a	12	MeI	73	oil	−62.4°	$C_{11}H_{20}OS$ (200.1)	200 (M^+), 185, 167, 152, 135, 108
2b	1	EtI	80	oil	−57.7°	$C_{12}H_{22}OS$ (214.1)	214 (M^+), 108, 95, 41
2c	2.5	*i*-PrBr	70	oil	−51.0°	$C_{13}H_{24}OS$ (228.2)	228 (M^+), 108, 95, 43, 41
2d	4	$H_2C{=}CHCH_2Br$	93	oil	−40.6°	$C_{13}H_{22}OS$ (226.1)	226 (M^+), 208, 108, 93, 41
2e	1.5	$PhCH_2Br$	63	oil	−59.7°	$C_{17}H_{24}OS$ (276.2)	276 (M^+), 258, 124, 108, 91
2f	6	$PhCH_2CH_2Br$	90	oil	−49.8°	$C_{18}H_{26}OS$ (290.2)	290 (M^+), 138, 108
2g	3.5	$BrCH_2COCH_3$	61	oil	−53.0°	$C_{13}H_{22}O_2S$ (242.1)	242 (M^+), 108, 93, 43, 41
2h	3	$BrCH_2COPh$	86	oil	−12.4°	$C_{18}H_{24}O_2S$ (304.1)	304 (M^+), 286, 200, 153, 152, 105
2i	3	$ICH_2P(O)(OEt)_2$	89	oil	−34.2°	$C_{15}H_{29}O_4SP$ (336.2)	336 (M^+), 319, 303, 249, 184
2j	12	DMAD[d]	79	126–127[e] (CCl_4)	− 8.8°	$C_{16}H_{24}O_5S$ (328.4)	328 (M^+), 310, 295, 267

[a] Recorded on a JASCO DIP-140 digital polarimeter in chloroform solution (c = 1.0, 25–26 °C).

[b] The mircoanalyses or high resolution MS data were in satisfactory agreement with the calculated value: C ±0.05, H ±0.03; $m/z = \pm 0.0042$ (M^+).

[c] Recorded on a JEOL JMS-D 200 spectrometer.

[d] DMAD = dimethyl acetylenedicarboxylate.

[e] Uncorrected and measured with a YANACO micro melting point apparatus.

Table 2. Spectral Data of Compounds **2**

Compound	IR (neat)[a] ν (cm^{-1})	^{1}H-NMR (TMS)[b] δ, J (Hz)
2a	3450, 2950, 1640, 1070	0.82 (s, 3H, CH_3), 1.03 (s, 3H, CH_3), 1.0–2.0 (m, 7H), 2.10 (s, 3H, SCH_3), 2.38 (d, 1H, $J = 12$, C$\underline{H}$HS), 2.75 (d, 1H, $J = 12$, CH$\underline{H}$S), 3.8 (m, 1H, C$\underline{H}$OH)
2b	3480, 2960, 1455, 1260, 1070	0.84 (s, 3H, CH_3), 1.07 (s, 3H, CH_3), 1.29 (t, 3H, $J = 7$, CH_3), 1.0–1.9 (m, 7H), 2.45 (d, 1H, $J = 11$, CH$\underline{H}$S), 2.56 (d, 1H, $J = 11$, CH$\underline{H}$S), 2.58 (q, 2H, $J = 7$, CH_2S), 2.79 (d, 1H, $J = 11$, C$\underline{H}$HS), 3.88 (dt, 1H, $J = 8, 3$, C$\underline{H}$OH), 3.6–4.0 (br, 1H, CHO$\underline{H}$)
2c	3470, 2950, 1450, 1065, 1045	0.84 (s, 3H, CH_3), 1.07 (s, 3H, CH_3), 1.30 [d, 6H, $J = 7$, CH(C$\underline{H}_3$)$_2$], 1.0–1.9 (m, 7H), 2.47 (br d, 1H, $J = 3$, OH), 2.54 (d, 1H, $J = 11$, CHS), 2.78 (d, 1H, $J = 11$, CHS), 2.91 (sep, 1H, $J = 7$, C$\underline{H}$CH$_3$), 3.86 (m, 1H, C$\underline{H}$OH)
2d	3470, 2930, 1630, 1070, 1020, 910	0.83 (s, 3H, CH_3), 1.04 (s, 3H, CH_3), 0.8–2.0 (m, 7H), 2.15 (d, 1H, $J = 3$, OH), 2.33 (d, 1H, $J = 11$, C$\underline{H}$HS), 2.67 (d, 1H, $J = 11$, CHHS), 3.10 (d, 2H, $J = 6$, CH=C$\underline{H}_2$), 3.80 (m, 1H, C$\underline{H}$O), 4.9–5.2 (m, 2H, =CH_2), 5.4–6.1 (m, 1H, CH=)
2e	3450, 2950, 2870, 1490, 1450, 1070, 700	0.78 (s, 3H, CH_3), 0.98 (s, 3H, CH_3), 1.0–1.8 (m, 7H), 2.07 (br s, 1H, OH), 2.50 (d, 1H, $J = 11$, C$\underline{H}$HS), 2.67 (d, 1H, $J = 11$, CH$\underline{H}$S), 3.69 (d, 1H, $J = 13$, C$\underline{H}$HPh), 3.77 (d, 1H, $J = 11$, CH$\underline{H}$Ph), 3.82 (dt, 1H, $J = 8, 3$, C$\underline{H}$OH), 7.2–7.3 (m, 5H_{arom})
2f	3500, 2970, 1450, 1070, 700	0.83 (s, 3H, CH_3), 1.05 (s, 3H, CH_3), 1.0–1.9 (m, 7H), 2.35 (d, 1H, $J = 4$, OH), 2.52 (d, 1H, $J = 11$, C$\underline{H}$HS), 2.78 (d, 1H, $J = 11$, CH$\underline{H}$S), 2.7–3.0 [m, 4H, S(C$\underline{H}_2$)$_2$Ph], 3.85 (dt, 1H, $J = 8, 4$, C$\underline{H}$OH), 7.2–7.4 (m, 5H_{arom})
2g	3470, 2950, 2870, 1490, 1450, 1070, 700	0.82 (s, 3H, CH_3), 1.04 (s, 3H, CH_3), 1.0–1.9 (m, 7H), 2.29 (s, 3H, CH_3), 2.54 (d, 1H, $J = 11$, C$\underline{H}$HS), 2.71 (d, 1H, $J = 11$, CH$\underline{H}$S), 2.8 (br, 1H, OH), 3.31 (d, 1H, $J = 15$, SC$\underline{H}$HCO), 3.37 (d, 1H, $J = 15$, SCH$\underline{H}$CO), 3.92 (dd, 1H, $J = 8, 4$, C$\underline{H}$OH)
2h	3500, 2950, 1680, 1450, 1280, 1070	0.82 (s, 3H, CH_3), 1.05 (s, 3H, CH_3), 0.8–2.0 (m, 7H), 2.65 (d, 1H, J = 12, CH$\underline{H}$S), 2.78 (d, 1H, $J = 12$, C$\underline{H}$HS), 3.17 (br, 1H, OH), 3.92 (br s, 3H, SCH_2CO, C$\underline{H}$OH), 7.4–8.2 (m, 5H_{arom})
2i	3400, 2950, 1220, 1025	0.85 (s, 3H, CH_3), 1.10 (s, 3H, CH_3), 1.1–1.9 (m, 14H), 2.6–3.0 (m, 4H, SCH_2P, CH_2S), 4.0 (m, 1H, C$\underline{H}$OH), 4.1–4.3 [m, 4H, P(OC$\underline{H}_2$CH$_3$)$_2$]
2j	3300, 2950, 1730, 1380, 1260	0.88 (s, 3H, CH_3), 1.08 (s, 3H, CH_3), 1.1–1.8 (m, 7H), 2.15 (br s, 1H, OH), 2.76 (d, 1H, $J = 10.6$, C$\underline{H}$HS), 3.10 (d, 1H, $J = 10.6$, CH$\underline{H}$S), 3.72 (s, 3H, OCH_3), 3.89 (s, 3H, OCH_3), 5.78 (s, 1H, CH=)

[a] Recorded as film on a JASCO A-102 spectrophotometer except for **2j** (KBr).

[b] Recorded on a JEOL GX 270 spectrometer in $CDCl_3$ solution (except for **2d**) and a JEOL PMX-60 spectrometer in CCl_4 solution (for **2d**).

Table 3. Sulfoxides **3** and **4** Prepared

Product	Reaction Conditions Temperature (°C), Time (h)	Yield (%)	mp (°C)[a] (solvent)	$[\alpha]_D$[b]	de (%)	Molecular Formula[c]	MS (70 eV)[d] m/z
3a[e]	−80 → −40, 1	82	79–81 (hexane)	+31.7°	~100	$C_{11}H_{20}O_2S$ (216.1)	217 (M^+ + 1), 109, 107, 93, 41
3b	−80 → 10, 2	95	100–101 (hexane)	−12.4°	~100	$C_{12}H_{22}O_2S$ (230.1)	231 (M^+ + 1), 135, 109, 93
3c	−80 → 10, 2	89	58–60 (hexane)	+ 0.4°	~100	$C_{13}H_{24}O_2S$ (244.1)	245 (M^+ + 1), 153, 135, 109, 41
3d	−50 → −30, 1	90	oil	+27.9°	~100	$C_{13}H_{22}O_2S$ (242.1)	243 (M^+ + 1), 242 (M^+), 153, 135
3e	−70 → −20, 1	91	oil	+ 6.6°	~100	$C_{17}H_{24}O_2S$ (292.1)	292 (M^+), 184, 109, 91
3f[e]	−80 → 10, 3	68	oil	−39.1°	~100	$C_{18}H_{26}O_2S$ (306.2)	307 (M^+ + 1), 306 (M^+), 153, 135, 109, 92
3g[e]	−80 → 10, 2	76	68–71 (hexane)	+31.7°	~100	$C_{13}H_{22}O_3S$ (258.1)	259 (M^+ + 1), 241, 135, 109, 93, 43
3h[e]	−70 → −10, 2	57	oil	−17.6°	73	$C_{18}H_{24}O_3S$ (320.1)	321 (M^+ + 1), 320 (M^+), 168, 105, 77, 41
4h		9	oil	−27.7°			321 (M^+ + 1), 320 (M^+), 168, 135, 105, 77, 41
3i	−80 → 10, 3	57	oil	+49.5°	61	$C_{15}H_{29}O_5SP$ (352.1)	353 (M^+ + 1), 352 (M^+), 200, 174, 144, 41
4i		14	oil	−110.3°			353 (M^+ + 1), 352 (M^+), 310, 144, 108, 41
3j	−50 → 0, 2	89	oil	+32.8°	93	$C_{16}H_{24}O_6S$ (344.1)	344 (M^+), 328, 310, 144, 108, 41
4j		3	oil	−34.2°			344 (M^+), 328, 310, 279, 177, 41

[a] Uncorrected and measured with a YANACO micro melting point apparatus.

[b] Recorded with a JASCO DIP-140 digital polarometer in $CHCl_3$ solution ($T = 26 \pm 1$ °C, $c = 1.0$).

[c] The microanalyses or high resolution MS data were in satisfactory agreement with the calculated values: C ±0.17, H ±0.23; $m/z = \pm 0.0036$ (M^+).

[d] Recorded on a JEOL JMS-D 200 spectrometer.

[e] Small amounts (5–9%) of the corresponding sulfones were also obtained.

fide **2i** was prepared by adding **1** to diethyl iodomethylphosphonate under phase-transfer conditions (20% sodium hydroxide/tetrabutylammonium bromide) according to the procedure of Lit.[8] The sulfide **2j** was obtained from dimethyl acetylenedicarboxylate and **1** in the presence of a catalytic amount of methyldiphenylphosphine.[9] Treatment of compounds **2** with 3-chloroperoxybenzoic acid afforded the sulfoxides **3** in good yields. The diastereoisomeric excesses (de ~ 100%) of the sulfoxides obtained from sulfides **2a–g** were determined by ^{1}H-NMR analysis of the crude oxidation product. From the oxidation of sulfides **2h,i,j**, the minor diastereoisomers **4** were also obtained (Table 3). Since the absolute stereochemistry of **3j** has been confirmed by single-crystal X-ray analysis of the cycloadduct of **3j**,[4] the stereochemistry of the sulfur center of other sulfoxides was tentatively assigned assuming the same stereochemistry of oxidation of **2a–i** in these cases. The results show that 10-(alkylthio)isoborneols can be easily and diastereoselectively converted into the sulfoxides by oxidation with 3-chloroperoxybenzoic acid. The procedure is simple and suitable for large-scale preparations.

(−)-10-(Phenacylthio)isoborneol (2h); Typical Procedure:

To a stirred suspension of NaH (283 mg, 11.8 mmol, prewashed 3 times with dry Et_2O) in dry benzene (10 mL) is added dropwise (1*S*-(−)-10-mercaptoisoborneol[7] (**1**; 2.00 g, 10.8 mmol) in dry benzene (20 mL) at r.t. After completion of the addition, the mixture is cooled to 0°C and DMF (8 mL) is added. The mixture is stirred until a clear solution is obtained (~ 20 min). Then, phenacyl bromide (2.25 g, 11.3 mmol) in dry benzene (10 mL) is added dropwise and the mixture is warmed to r.t. and stirred for 3 h. After removal of most of the solvent under reduced pressure, the residue is poured into cold 1 M aq HCl (50 mL). The aqueous layer is extracted with $CHCl_3$ (3 × 30 mL). The combined extracts are washed with brine (30 mL), dried ($MgSO_4$), and concentrated under reduced pressure. The residual oil is purified by chromatography on silica gel (eluent: hexane/EtOAc, 12:1) to give pure **2h** as a pale yellow oil; yield: 2.83 g (86%).

(+)-10-(Diethoxyphosphorylmethylsulfinyl)isoborneol (3i); Typical Procedure:

To a stirred solution of (−)-10-(diethoxyphosphorylmethylthio) isoborneol (**2i**; 100 mg, 0.3 mmol) in dry CH_2Cl_2 (5 mL) is added dropwise a solution of 3-chloroperoxybenzoic acid (68 mg, 80% purity, 0.31 mmol) in dry CH_2Cl_2 (10 mL) at −80°C. The mixture is warmed to −10°C over a period of 3 h, diluted with Et_2O (30 mL), and then poured into cold aq 1 M $NaHSO_3$ (40 mL).

Table 4. Spectral Data of Sulfoxides **3** and **4**

Product	IR[a] ν (cm^{-1})	^{1}H-NMR ($CDCl_3$/TMS)[b] δ, J (Hz)
3a	3350, 2950, 1075, 1030	0.83 (s, 3H, CH_3), 1.12 (s, 3H, CH_3), 1.0–2.0 (m, 7H), 2.27 (d, 1H, J = 13, $\mathrm{H\underline{H}CS}$), 2.65 (s, 3H, SCH_3), 3.25 (d, 1H, J = 13, $\mathrm{H\underline{H}CS}$), 3.6–3.8 (m, 1H, OH), 3.8–4.2 (m, 1H, $\mathrm{C\underline{H}OH}$)
3b	3350, 2970, 1455, 1080	0.81 (s, 3H, CH_3), 1.08 (s, 3H, CH_3), 1.34 (t, 3H, J = 8, CH_3), 1.0–1.9 (m, 7H), 2.30 (d, 1H, J = 13, $\mathrm{C\underline{H}HS}$), 2.75 (q, 2H, J = 8, $\mathrm{C\underline{H}_2CH_3}$), 3.19 (d, 1H, J = 13, $\mathrm{CH\underline{H}S}$), 3.8 (br, 1H, OH), 4.04 (dd, 1H, J = 8, 4, $\mathrm{C\underline{H}OH}$)
3c	3310, 2950, 1075, 990	0.84 (s, 3H, CH_3), 1.11 (s, 3H, CH_3), 1.31 (d, 3H, J = 7, CH_3), 1.33 (d, 3H, J = 7, CH_3), 0.8–1.9 (m, 7H), 2.30 (d, J = 13, $\mathrm{C\underline{H}HS}$), 2.81 (sep, 1H, J = 7, $\mathrm{C\underline{H}CH_3}$), 3.12 (d, 1H, J = 13, $\mathrm{CH\underline{H}S}$), 4.07 (dd, 1H, J = 8.5, 4, $\mathrm{C\underline{H}OH}$), 4.09 (br, 1H, OH)
3d	3400, 2950, 1070, 1000	0.83 (s, 3H, CH_3), 1.11 (s, 3H, CH_3), 1.1–1.9 (m, 7H), 2.38 (d, 1H, J = 13, $\mathrm{C\underline{H}HS}$), 3.21 (d, 1H, J = 13, $\mathrm{CH\underline{H}S}$), 3.48 (dd, 1H, J = 12, 6, $\mathrm{SC\underline{H}H}$), 3.54 (dd, 1H, J = 12, 6, $\mathrm{SCH\underline{H}}$), 3.92 (br s, 1H, CH), 4.05 (m, 1H, OH), 5.41 (dd, 1H, J = 16, <1, CH=), 5.46 (d, 1H, J = 8, CH=), 5.90 (ddt, 1H, J = 16, 8, 6, CH=)
3e	3400, 2950, 1070, 1025, 1000	0.76 (s, 3H, CH_3), 1.08 (s, 3H, CH_3), 0.8–1.9 (m, 7H), 2.38 (d, 1H, J = 13, $\mathrm{C\underline{H}HS}$), 3.14 (d, 1H, J = 13, $\mathrm{CH\underline{H}S}$), 3.93 (br, 1H, OH), 3.96 (d, 1H, J = 13, $\mathrm{C\underline{H}HPh}$), 4.0–4.1 (m, 1H, $\mathrm{C\underline{H}OH}$), 4.10 (d, 1H, J = 13, $\mathrm{CH\underline{H}Ph}$), 7.3–7.5 (m, 5$H_{arom}$)
3f	3400, 2950, 1075, 1030, 1000	0.78 (s, 3H, CH_3), 1.09 (s, 3H, CH_3), 1.0–1.9 (m, 7H), 2.28 (d, 1H, J = 13, $\mathrm{C\underline{H}HS}$), 2.9–3.2 [m, 4H, $(CH_2)_2$], 3.25 (d, 1H, J = 13, $\mathrm{CH\underline{H}S}$), 4.0 (br, 1H, OH), 4.05 (dd, 1H, J = 8, 4, $\mathrm{C\underline{H}OH}$), 7.2–7.4 (m, 5$H_{arom}$)
3g	3340, 2950, 1075, 1030, 1000	0.84 (s, 3H, CH_3), 1.11 (s, 3H, CH_3), 0.8–1.9 (m, 7H), 2.37 (s, 3H, CH_3), 2.55 (d, 1H, J = 13, $\mathrm{C\underline{H}HS}$), 3.34 (d, 1H, J = 13, $\mathrm{CH\underline{H}S}$), 3.70 (br, 1H, OH), 3.82 (d, 1H, J = 14, $\mathrm{C\underline{H}HCO}$), 3.88 (d, 1H, J = 14, $\mathrm{CH\underline{H}CO}$), 4.03 (dd, 1H, J = 8, 4, $\mathrm{C\underline{H}OH}$)
3h	3420, 2950, 1675, 1450, 1290, 1075	0.84 (s, 3H, CH_3), 1.10 (s, 3H, CH_3), 1.0–2.0 (m, 7H), 2.77 (d, 1H, J = 13, $\mathrm{C\underline{H}HS}$), 2.87 (br, 1H, OH), 3.38 (d, 1H, J = 13, $\mathrm{CH\underline{H}S}$), 4.04 (dd, 1H, J = 8, 4, $\mathrm{C\underline{H}OH}$), 4.36 (d, 1H, J = 15, $\mathrm{C\underline{H}HCO}$), 4.59 (d, 1H, J = 15, $\mathrm{CH\underline{H}CO}$), 7.5–8.0 (m, 5$H_{arom}$)
4h	3400, 2960, 1675, 1280, 1075	0.87 (s, 3H, CH_3), 1.10 (s, 3H, CH_3), 1.0–2.2 (m, 7H), 2.72 (d, 1H, J = 13, $\mathrm{C\underline{H}HS}$), 3.50 (d, 1H, J = 13, $\mathrm{CH\underline{H}S}$), 4.12 (dd, 1H, J = 7, 4, $\mathrm{C\underline{H}OH}$), 4.51 (d, 1H, J = 16, $\mathrm{C\underline{H}CO}$), 4.60 (d, 1H, J = 16, $\mathrm{CH\underline{H}CO}$), 7.5–8.0 (m, 5$H_{arom}$)
3i	3450, 2970, 1250, 1050, 1020	0.86 (s, 3H, CH_3), 1.12 (s, 3H, CH_3), 1.20 (t, 6H, J = 6, 2CH_3), 1.0–2.1 (m, 7H), 2.94 (d, 1H, J = 13, $\mathrm{C\underline{H}HS}$), 3.34 (dd, 1H, J = 18, 15, $\mathrm{C\underline{H}HP}$), 3.39 (dd, 1H, J = 16, 15, $\mathrm{CH\underline{H}P}$), 3.39 (d, 1H, J = 13, $\mathrm{CH\underline{H}S}$), 3.73 (d, 1H, J = 3, OH), 4.02 (dd, 1H, J = 8, 3, $\mathrm{C\underline{H}OH}$), 4.1–4.3 (m, 4H, 2$CH_2$)
4i	3420, 2970, 1240, 1025, 970	0.87 (s, 3H, CH_3), 1.10 (s, 3H, CH_3), 1.37 (t, 3H, J = 7, CH_3), 1.38 (t, 3H, J = 7, CH_3), 1.0–2.1 (m, 7H), 2.69 (d, 1H, J = 13, $\mathrm{C\underline{H}HS}$), 3.31 (dd, 1H, J = 18, 15, $\mathrm{C\underline{H}HP}$), 3.55 (dd, 1H, J = 15, 13, $\mathrm{CH\underline{H}P}$), 3.66 (d, 1H, J = 13, $\mathrm{CH\underline{H}S}$), 3.87 (br, 1H, OH), 4.00 (dd, 1H, J = 7, 4, $\mathrm{C\underline{H}OH}$), 4.1–4.3 (m, 4H, 2$CH_2$)
3j	3470, 2960, 1730, 1380, 1260	0.84 (s, 3H, CH_3), 1.07 (s, 3H, CH_3), 1.1–1.8 (m, 7H), 2.90 (d, 1H, J = 13, $\mathrm{C\underline{H}HS}$), 3.17 (d, 1H, J = 13, $\mathrm{CH\underline{H}S}$), 3.86 (s, 3H, OCH_3), 3.89 (s, 3H, OCH_3), 4.10 (m, 1H, $\mathrm{C\underline{H}OH}$), 6.98 (s, 1H, CH=)
4j	3470, 2960, 1730	0.83 (s, 3H, CH_3), 1.06 (s, 3H, CH_3), 1.1–1.8 (m, 7H), 2.62 (d, 1H, J = 14, $\mathrm{C\underline{H}HS}$), 3.57 (d, 1H, J = 14, $\mathrm{CH\underline{H}S}$), 3.83 (s, 3H, OCH_3), 3.85 (s, 3H, OCH_3), 3.85 (m, 1H, $\mathrm{C\underline{H}OH}$), 7.00 (s, 1H, CH=)

[a] Recorded on a JASCO A-102 Infrared spectrophotometer, as film for oily material and in KBr disc for crystalline material.

[b] Recorded on a JEOL GX-270 spectrometer.

The organic layer is washed with 1 M Na_2CO_3 solution (2 × 15 mL) and with brine (20 mL), and dried ($MgSO_4$). The solvent is removed and the residue is purified by flash chromatography (silica gel 12 g, 230–400 mesh; hexane/EtOAc, 1:4 → EtOAc/MeOH, 4:1). Early fractions contain the major diastereoisomer **3i** as a colorless oil; yield: 60 mg (57%). The latter fractions contain the minor diastereoisomer **4i** as a colorless oil; yield: 15 mg (14%).

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