Synthesis of (±)-8-Deisopropyladunctin B

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(±)-8-Deisopropyladunctin B, the deisopropyl form of adunctin B, which was isolated from the leaves of *Piper aduncum* (Piperaceae) collected in Papua New Guinea, was synthesized in 0.77% overall yield in 17 steps from 5,7-dimethoxycoumarin-3-carboxylate. The key step was our original stereoconvergent skeleton transformation from 1,2,2a,8b-tetrahydro-3*H*-benzo[*b*]cyclobuta[*d*]pyran-3-one to 1,2,4a,9b-tetrahydrodibenzofuran-4-ol with dimethylsulfoxonium methylide.

Key words adunctin B; 8-deisopropyladunctin B; total synthesis; ylide; skeleton transformation

In 1993, Sticher and colleagues investigated the extract of leaves from *Piper aduncum* (Piperaceae) collected in Papua New Guinea. *P. aduncum* is distributed throughout a large area of the tropical Americas, and has been naturalized in Malaysia and in Papua New Guinea. It has been employed as a traditional medicine in many regions of the world, mostly by application of its leaves. In Papua New Guinea, it is used for treatment of fresh wounds; in Colombia, as a treatment for dysentery and as a haemostatic agent; and in Peru, as a treatment for diarrhea. A crude petroleum-ether extract from its leaves showed significant antibacterial activity in *in vitro* biological screening. Monoterpene-substituted chalcone derivatives such as adunctins A–E (**1**–**5**) and methylinderratin (**6**) were isolated¹⁾ (Fig. 1).

We are interested in the syntheses of biologically active natural products, and have already reported total syntheses of substituted chalcone derivatives, adunctin E (**5**),^{2,3)} methylinderratin (**6**),⁴⁾ and hostmanin A (**7**) which was isolated from the leaves of *Piper hostmannianum* (Piperaceae),^{4,5)} and linderol A (**8**) which was isolated from the fresh bark of *Lindera umbellata* (Lauraceae)^{6–13)} (Fig. 2). As part of our investigations into syntheses of natural products, we focused on the total synthesis of adunctin B (**2**). In this paper, we describe the synthesis of (±)-8-deisopropyladunctin B (**9**), *rac*-(5*aR*,9*aR*)-5*a*,8,9,9*a*-tetrahydro-1-methoxy-5*a*-methyl-4-(3-phenylpropionyl)dibenzofuran-3-ol (Fig. 3, in this text, this numbering was used).

Fig. 1. The Isolated Compounds from *Piper aduncum*

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Results and Discussion

We developed a novel stereoconvergent transformation of 1,2a-disubstituted 1,2,2a,8b-tetrahydro-3*H*-benzo[*b*]cyclobuta[*d*]pyran-3-ones (**11**) to 1,3-disubstituted 1,2,4a,9b-tetrahydrodibenzofuran-4-ols (**12**).^{8,9} The benzocyclobutapyranes (**11**) were easily prepared by photochemical[2+2]cycloaddition of monosubstituted alkenes with coumarin derivatives (**10**) that had electron-withdrawing groups at the 3-position. The benzocyclobutapyranones (**11**) were then treated with dimethylsulfoxonium methylide¹⁴ to give tetrahydrodibenzofuran-

Fig. 2. Natural Products Synthesised by Us

Fig. 3. A Target Compound

4-ols (**12**). However, only alkyl or aryl substituents at the 1-position of **11** were examined (Chart 1).

We were interested in the reaction of dimethylsulfoxonium methylide with the benzocyclobutapyranones (**14**) in which a heteroatom was directly bonded to the carbon at the 1-position. A solution of 3-benzoyloxycarbonylcoumarin (**13a**) and vinyl acetate was irradiated with a 400 W high pressure mercury lamp to give 1-acetyloxycyclobutane (**14a**, Y=OAc), and then the crude **14a** was treated with dimethylsulfoxonium methylide to afford the desired tetrahydrodibenzofuran (**15a**) as a single isomer in 57% yield in two steps. Several substrates were investigated and the single isomers (**15b**, **c**) were obtained in each case. When Y=Br, though cyclobutane **14d** was obtained, the subsequent rearrangement to **15d** did not proceed (Chart 2).

Since the reaction of cyclobutanes (**14**) with dimethylsulfoxonium methylide successfully proceeded as did those of 1-alkyl and 1-arylcyclobutanes (**11**), we planned the synthesis of 8-deisopropyladunctin B (**9**) using this methodology prior to the total synthesis of adunctin B (**2**). The retrosynthesis of **9** is shown in Chart 3. 4-Acetyl compound (**16**) was proposed as the precursor to **9**, and it was thought that **16** would be derived from **17** which would be prepared by the conversion of **15c**.

The cyclobutane (**14c**) was prepared by irradiation with a high pressure mercury lamp to a solution of 5,7-dimethoxycoumarin derivative (**13c**)⁷ and vinyl acetate. The cyclobutane (**14c**) was then treated with dimethylsulfoxonium methylide to give tetrahydrodibenzofuran (**15c**) in 52% yield as a single isomer. After debenzoylation-decarboxylation of **15c**, the ketone in **18** was protected as an acetal. The alcohol (**20**) obtained by hydrolysis of the acetal (**19**) was tosylated, and the tosylate (**21**) was treated with potassium *tert*-butoxide (*t*-BuOK) to give the olefin (**22**). After hydrogenation of **22** over palladium on carbone (Pd-C), the obtained acetal (**23**) was deprotected with iron(III) chloride hexahydrate (FeCl₃·6H₂O) to afford the ketone (**24**)¹⁵ (Chart 4).

The 5a-position of **24** was regio- and stereoselectively

Chart 1. The Stereoconvergent Skeleton Transformation

Chart 2. Photocycloaddition and the Stereoconvergent Skeleton Transformation

Chart 3. The Retrosynthesis of **9** Chart 4. Synthesis of **24** Chart 5. Synthesis of **28**

methylated by treatment of **24** with lithium diisopropylamide (LDA) and methyl iodide at -78°C to give **17** in only 7% yield. The enolate anion at the 5a-position of **24** would be more thermodynamically stable than that of the 7-position, and the methyl group would approach from the less hindered convex face to furnish **17**. The introduction of the methyl group to the 5a-position was confirmed by comparison of the ^1H -NMR spectrum of **17** with that of **24**. Namely, the signal from the 5a-proton at 4.89 ppm in the ^1H -NMR spectrum of **24** disappeared in the spectrum of **17**. Furthermore, the coupling pattern at the 9a-position which was observed as a triplet of doublets ($J=6.8, 9.6\text{Hz}$) in the ^1H -NMR spectrum of **24** changed to a triplet ($J=4.8\text{Hz}$) in that of **17**. The stereochemistry between the introduced 5a-methyl group and the

9a-proton in **17** was determined to be *cis* by observation of nuclear Overhauser enhancement (NOE) correlation between them (Chart 5). After extensive investigation into the reaction conditions, the yield of **17** was increased to 52% when **24** was treated with methyl iodide and LDA in the presence of hexamethylphosphoric triamide (HMPA) as an additive at -20°C to rt. The ketone of **17** was reduced with sodium borohydride (NaBH_4), and then the alcohol (**25**) was transformed into the xanthate (**26**) in order to introduce a double bond at the 6,7-position. Microwave irradiation of **26** gave **27** in 68% yield. Next, **27** was treated with acetic anhydride (Ac_2O) in the presence of lithium perchlorate (LiClO_4) and a catalytic amount of scandium(III) triflate [$\text{Sc}(\text{OTf})_3$] according to the procedure used in our synthesis of ($\pm$)-linderol A, in which

Chart 6. Synthesis of **9**

acetylation at the 4-position occurred regioselectively in high yield.^{6,16–19} However, contrary to our expectations, the yield of **28** was only 15%. Even worse, the regioisomer (**29**) was obtained in 16% yield together with many unidentified by-products. The positions of the introduced acetyl groups were confirmed on the basis of the heteronuclear multiple bond correlation (HMBC) spectra of **28** and **29**, in which the correlations between 2-H and the 1, 3, 4, and 9b carbons in **28** and between 4-H and the 2, 3, 4a, and 9b carbons in **29** were observed (Chart 5). Several conditions were employed to improve the yield and selectivity for **28** without success.

Therefore, the acetylation of **26** was attempted under various conditions. When **26** was treated with Ac_2O in the presence of a catalytic amount of $\text{Sc}(\text{OTf})_3$ as a Lewis acid and LiClO_4 as the additive in nitromethane at 50°C , the 4-acetylated **30** was obtained in 91% yield together with only 3% of the 2-acetylated **31**. Microwave irradiation of the obtained **30** gave **28** in 80% yield. After selective demethylation of **28** in the usual manner,^{20,21} extension of the acetyl group in **16** to the cinnamoyl group was carried out by cross-aldol condensation with benzaldehyde in the presence of $t\text{-BuOK}$ to afford **32** in 80% yield. Finally, the double bond of the α,β -unsaturated carbonyl group of **32** was chemoselectively reduced over the isolated double bond at the 6,7-position to give (±)-8-deisopropyladunctin B (**9**) in 61% yield^{22,23} (Chart 6).

In order to confirm the structure of **9**, the spectral data of **9** were compared with those of adunctin B (**2**) reported in ref. 1 (Fig. 4). The ^1H - and ^{13}C -NMR spectra of **9** and **2** were both very similar except for the existence of the isopropyl group and some signals around it (Fig. 4).

In conclusion, the synthesis of (±)-8-deisopropyladunctin B (**9**) was achieved in 0.77% overall yield in 17 steps from 5,7-dimethoxycoumarin-3-carboxylate (**13c**). The first total synthesis of adunctin B (**2**) is currently underway in our laboratory.

Experimental

Melting points were measured with a Yanaco MP micro-melting point apparatus and uncorrected. NMR spectra were measured on JEOL AL-300 (^1H : 300MHz; ^{13}C : 75.5MHz) and Varian INOVA 400NB (^1H : 400MHz; ^{13}C : 100MHz) spectrometers with tetramethylsilane as an internal standard. Chemical shifts are reported in ppm. IR spectra were taken with Shimadzu FTIR-8400 and Shimadzu IR-435 spectrophotometers. A JEOL JMS-GC mate spectrometer and a Shimadzu GCMS-QP5050A spectrometer were used for low-resolution electron ionization MS (MS) and a JEOL JMS-GC mate spectrometer was used for high-resolution electron ionization MS (HR-MS). The elemental analyses were performed using a Perkin Elmer Series II CHNS/O Analyzer 2400. CEM Discover was used for microwave irradiation. All extracts were washed with water and brine, dried over anhydrous Na_2SO_4 , and evaporated under reduced pressure in the usual work-up procedure. Silica gel 60 (grade 7734, 60–230 mesh, Merck) for column chromatography and Silica gel 60 PF₂₅₄ (5–50 μm , Nacalai tesque) for preparative TLC (PTLC) were used.

General Procedure for Stereoconvergent Transformation of **13 to **15**** A solution of a coumarin derivative (**13**, 1.0mmol) and an alkene (5.0mmol) in benzene (4mL) was placed in a photochemical reactor vessel with a 400W high-pressure mercury lamp in a water-cooled quartz immersion well. The stirred solution was irradiated until the starting material was consumed. After evaporation of the volatile materials, the residue was passed through a short silica gel column in order to remove the unreacted alkene. The solution of the obtained cyclobutapyrane (**14**) in *N,N*-dimethylformamide (DMF) (1 mL) was added to a solution of dimethylsulfoxonium methylide which was prepared *in situ* from trimethylsulfoxonium iodide (440mg, 2.0mmol) and NaH (60% in mineral oil, 80mg, 2.0mmol) in DMF (2mL) under ice-cooling and N_2 atmosphere. The mixture was stirred at room temperature

Fig. 4. Comparison of ^1H - (Top) and ^{13}C - (Bottom) NMR Spectral Data of Deisopropyladunctin B (9) with Those (Numbers in Square Brackets) of Adunctin B (2)

until **14** was consumed. After acidification with 3% HCl solution under ice-cooling, the mixture was extracted with ethyl acetate. The combined organic layers were washed with saturated $\text{Na}_2\text{S}_2\text{O}_3$ aq, water, and brine, dried, and evaporated. The residue was purified by silica gel column chromatography to give **15**.

Benzyl *rac*-(1*R*,4*aS*,9*bS*)-1-Acetoxy-4-hydroxy-1,2,4*a*,9*b*-tetrahydridibenzofuran-3-carboxylate (15a) The reaction was carried out in a similar manner to that described in the general procedure using **13a** (3.06 g, 10.9 mmol) as the coumarin derivative and vinyl acetate (4.69 g, 54.5 mmol) as the alkene. Yield: 2.37 g (57%). Colorless columns (recrystallized from AcOEt -*n*-hexane), mp 115–117°C. ^1H -NMR (400 MHz, CDCl_3) δ : 2.09 [3H, s, $-\text{O}-\text{C}(=\text{O})\text{CH}_3$], 2.43 [1H, dd, $J=6.8$, 16.1 Hz, $-\text{CH}(\text{OAc})-\text{CH}_2-$], 2.69 [1H, dd, $J=4.2$, 16.1 Hz, $-\text{CH}(\text{OAc})-\text{CH}_2-$], 3.75 (1H, t, $J=8.1$ Hz, $\text{Ar}-\text{CH}_2-$), 5.10–5.14 [1H, m, $-\text{CH}(\text{OAc})-$], 5.17–5.24 [3H, m, $\text{Ar}-\text{CH}_2-$ and $-\text{C}(=\text{O})-\text{OCH}_2-\text{Ph}$], 6.88–6.91 (2H, m, $\text{Ar}-\text{H}$), 7.16–7.21 (2H, m, $\text{Ar}-\text{H}$), 7.30–7.39 (5H, m, $\text{Ar}-\text{H}$), 12.9 (1H, s, $-\text{OH}$). ^{13}C -NMR (100 MHz, CDCl_3) δ : 21.1, 25.6, 45.3, 67.8, 70.1, 79.0, 110.5, 121.3, 124.5, 126.4, 128.5, 128.6, 129.3,

135.1, 157.8, 164.7, 170.3, 171.3. IR (CHCl_3) cm^{-1} : 1732, 1660, 1279, 1229, 1024. MS (EI) m/z (rel. int. %): 380 (M^+ , 0.1), 320 (7.7), 212 (3.9), 185 (2.0), 144 (5.3), 91 (100). HR-MS (EI) m/z 380.1261 (Calcd for $\text{C}_{22}\text{H}_{20}\text{O}_6$: 380.1260).

Benzyl *rac*-(1*R*,4*aS*,9*bS*)-1-Acetoxy-4-hydroxy-9-methoxy-1,2,4*a*,9*b*-tetrahydridibenzofuran-3-carboxylate (15b) The reaction was carried out in a similar manner to that described in the general procedure using **13b** (2.79 g, 8.99 mmol) as the coumarin derivative and vinyl acetate (3.87 g, 45.0 mmol) as the alkene. Yield: 2.57 g (70%). Colorless crystals (recrystallized from AcOEt -*n*-hexane), mp 112–113°C. ^1H -NMR (400 MHz, CDCl_3) δ : 2.06 [3H, s, $-\text{O}-\text{C}(=\text{O})\text{CH}_3$], 2.44 [1H, dd, $J=3.5$, 16.7 Hz, $-\text{CH}(\text{OAc})-\text{CH}_2-$], 2.61 [1H, dd, $J=4.4$, 16.7 Hz, $-\text{CH}(\text{OAc})-\text{CH}_2-$], 3.82 (3H, s, $\text{Ar}-\text{O}-\text{CH}_3$), 3.99 (1H, dd, $J=5.3$, 8.8 Hz, $\text{Ar}-\text{CH}_2-$), 5.16 [1H, d, $J=12.3$ Hz, $-\text{C}(=\text{O})-\text{OCH}_2-\text{Ph}$], 5.20 [1H, d, $J=12.3$ Hz, $-\text{C}(=\text{O})-\text{OCH}_2-\text{Ph}$], 5.22 (1H, d, $J=8.8$ Hz, $\text{Ar}-\text{O}-\text{CH}_2-$), 5.73–5.77 [1H, m, $-\text{CH}(\text{OAc})-$], 6.43 (1H, d, $J=7.9$ Hz, $\text{Ar}-\text{H}$), 6.52 (1H, d, $J=8.1$ Hz, $\text{Ar}-\text{H}$), 7.12 (1H, t, $J=8.1$ Hz, $\text{Ar}-\text{H}$), 7.29–7.38 (5H, m, $\text{Ar}-\text{H}$), 12.0 (1H, s, $-\text{OH}$). ^{13}C -NMR (100 MHz, CDCl_3) δ : 21.2, 25.7, 44.9, 55.4,

66.6, 68.5, 79.1, 97.3, 103.7, 112.3, 128.2, 128.4, 128.6, 130.3, 135.2, 157.1, 160.5, 164.9, 170.3, 172.5. IR (CHCl₃) cm⁻¹: 1727, 1661, 1602, 1439, 1229, 1083. MS (EI) *m/z* (rel. int. %): 334 (M⁺, 15.7), 274 (94.2), 242 (100), 234 (40.2), 214 (26.6), 203 (32.0), 174 (39.7). HR-MS (EI) *m/z* 410.1363 (Calcd for C₂₃H₂₂O₇: 410.1365). Anal. Calcd for C₂₃H₂₂O₇: C, 67.31; H, 5.40. Found: C, 67.38; H, 5.49.

Benzyl *rac*-(1R,4aS,9bS)-1-Acetoxy-4-hydroxy-7,9-dimethoxy-1,2,4a,9b-tetrahydrodibenzofuran-3-carboxylate (15c) The reaction was carried out in a similar manner to that described in the general procedure using **13c** (1.02 g, 3.00 mmol) as the coumarin derivative and vinyl acetate (1.28 g, 14.9 mmol) as the alkene. Yield: 690 mg (52%). Colorless crystals (recrystallized from AcOEt-*n*-hexane), mp 144–146°C. ¹H-NMR (400 MHz, CDCl₃) δ: 2.05 [3H, s, -O-C(=O)CH₃], 2.45 [1H, ddd, *J*=1.0, 3.6, 16.7 Hz, -CH(OAc)-CH₂-], 2.59 [1H, dd, *J*=4.4, 16.7 Hz, -CH(OAc)-CH₂-], 3.74 (3H, s, Ar-O-CH₃), 3.78 (3H, s, Ar-O-CH₃), 3.92 (1H, dd, *J*=5.3, 8.6 Hz, Ar-CH-), 5.16 [1H, d, *J*=12.5 Hz, -C(=O)-OCH₂-Ph], 5.20 [1H, d, *J*=12.5 Hz, -C(=O)-OCH₂-Ph], 5.21 (1H, d, *J*=8.8 Hz, Ar-O-CH-), 5.66–5.70 [1H, m, -CH(OAc)-], 6.01 (1H, d, *J*=2.0 Hz, Ar-H), 6.11 (1H, d, *J*=2.0 Hz, Ar-H), 7.26–7.38 (5H, m, Ar-H), 12.0 (1H, s, -OH). ¹³C-NMR (100 MHz, CDCl₃) δ: 21.3, 25.0, 44.6, 55.3, 55.5, 66.6, 68.8, 79.7, 89.1, 91.9, 97.3, 104.6, 128.2, 128.4, 128.6, 135.2, 157.3, 161.3, 162.3, 165.0, 170.3, 171.5. IR (CHCl₃) cm⁻¹: 1724, 1660, 1620, 1598, 1230, 1141. MS (EI) *m/z* (rel. int. %): 440 (M⁺, 0.2), 380 (23.5), 272 (6.5), 245 (6.5), 204 (8.8), 91 (100). HR-MS (EI) *m/z* 440.1469 (Calcd for C₂₄H₂₄O₈: 440.1471).

***rac*-(1R,4aS,9bS)-1-Acetoxy-7,9-dimethoxy-1,2,4a,9b-tetrahydrodibenzofuran-4(3H)-one (18)** A suspension of **15c** (4.14 g, 9.40 mmol) and 10% palladium on activated charcoal (2.00 g) in ethyl acetate (AcOEt, 30 mL) was stirred for 1 h under H₂ atmosphere at room temperature. After filtration, the filtrate was evaporated. The residue was dissolved in xylene (30 mL) and the solution was refluxed for 1 h under N₂ atmosphere. The xylene was evaporated and the residue was chromatographed on silica gel (AcOEt/*n*-hexane=1/5) to give **18** (2.44 g, 85%) as colorless crystals. mp 122–123°C (recrystallized from AcOEt-*n*-hexane). ¹H-NMR (400 MHz, CDCl₃) δ: 1.93–2.02 [1H, m, -CH(OAc)-CH₂-], 2.10 [3H, s, -OC(C=O)CH₃], 2.13–2.20 [1H, m, -CH(OAc)-CH₂-], 2.54–2.57 [2H, m, -C(=O)-CH₂-], 3.77 (3H, s, Ar-O-CH₃), 3.80 (3H, s, Ar-O-CH₃), 4.06 (1H, dt, *J*=2.2, 8.8 Hz, Ar-CH-), 4.84 (1H, d, *J*=8.8 Hz, Ar-O-CH-), 5.51–5.53 [1H, m, -CH(OAc)-], 6.05 (1H, d, *J*=2.0 Hz, Ar-H), 6.14 (1H, d, *J*=2.0 Hz, Ar-H). ¹³C-NMR (100 MHz, CDCl₃) δ: 21.2, 23.8, 32.8, 48.6, 55.4, 55.6, 68.7, 84.6, 88.8, 92.3, 104.1, 157.0, 161.7, 162.8, 169.9, 206.0. IR (CHCl₃) cm⁻¹: 1722, 1621, 1598, 1233, 1140. MS (EI) *m/z* (rel. int. %): 306 (M⁺, 0.9), 246 (91.6), 218 (6.5), 205 (14.1), 204 (100), 178 (4.1). HR-MS (EI) *m/z* 306.1100 (Calcd for C₁₆H₁₈O₆: 306.1103).

***rac*-(1R,4aS,9bS)-1-Acetoxy-7,9-dimethoxy-1,2,4a,9b-tetrahydrodibenzofuran-4(3H)-one Ethylene Acetal (19)** A solution of **18** (360 mg, 1.18 mmol), ethylene glycol (88 mg, 1.42 mmol), and *p*-toluenesulfonic acid monohydrate (45 mg, 0.237 mmol) in benzene (6 mL) was refluxed for 3 h during which the generated water was removed with a Dean-Stark trap. After addition of water, the mixture was extracted with AcOEt (20 mL×3). The combined extracts were washed,

dried, and evaporated. The residue was chromatographed on silica gel (AcOEt/*n*-hexane=1/3) to give **19** (298 mg, 72%) as a colorless oil. ¹H-NMR (400 MHz, CDCl₃) δ: 1.74–1.94 [4H, m, -CH(OAc)-CH₂-CH₂-], 2.05 [3H, s, -O-C(=O)-CH₃], 3.49 (1H, tt, *J*=2.0, 9.1 Hz, Ar-CH-), 3.75 (3H, s, Ar-O-CH₃), 3.76 (3H, s, Ar-O-CH₃), 3.99–4.13 (4H, m, -O-CH₂-CH₂-O-), 4.39 (1H, d, *J*=6.8 Hz, Ar-O-CH-), 5.04–5.09 [1H, m, -CH(OAc)-], 6.01 (1H, d, *J*=2.0 Hz, Ar-H), 6.14 (1H, d, *J*=2.0 Hz, Ar-H). ¹³C-NMR (100 MHz, CDCl₃) δ: 21.2, 26.1, 28.7, 44.9, 55.2, 55.4, 65.1, 65.7, 73.1, 85.4, 89.2, 91.8, 106.7, 109.1, 156.5, 161.2, 161.8, 170.1. IR (CHCl₃) cm⁻¹: 2934, 1723, 1618, 1135, 1084. MS (EI) *m/z* (rel. int. %): 350 (M⁺, 0.4), 290 (93.7), 246 (9.9), 204 (100), 178 (1.7). HR-MS (EI) *m/z* 350.1371 (Calcd for C₁₈H₂₂O₇: 350.1365).

***rac*-(1R,4aS,9bS)-1-Hydroxy-7,9-dimethoxy-1,2,4a,9b-tetrahydrodibenzofuran-4(3H)-one Ethylene Acetal (20)** A suspension of **19** (115 mg, 0.328 mmol) and K₂CO₃ (90 mg, 0.651 mmol) in MeOH (1.5 mL) was stirred for 5 min. After concentration under reduced pressure, 10% HCl aq (2 mL) and water (10 mL) were added to the concentrate, and the mixture was extracted with AcOEt (20 mL×3). The combined extracts were washed, dried, and evaporated. The residue was chromatographed on silica gel (AcOEt/*n*-hexane=1/3) to give **20** (94 mg, 93%) as a colorless oil. ¹H-NMR (400 MHz, CDCl₃) δ: 1.77–1.95 [4H, m, -CH(OH)-CH₂-CH₂-], 3.38 (1H, t, *J*=7.9 Hz, Ar-CH-), 3.41 (1H, d, *J*=2.4 Hz, -OH), 3.66–3.73 [1H, m, -CH(OH)-], 3.76 (3H, s, Ar-O-CH₃), 3.84 (3H, s, Ar-O-CH₃), 4.02–4.14 (4H, m, -O-CH₂-CH₂-O-), 4.46 (1H, dd, *J*=1.3, 7.9 Hz, Ar-O-CH-), 6.09 (1H, d, *J*=2.0 Hz, Ar-H), 6.17 (1H, d, *J*=2.0 Hz, Ar-H). ¹³C-NMR (100 MHz, CDCl₃) δ: 27.5, 28.8, 48.2, 55.6×2, 65.2, 65.6, 72.4, 85.2, 89.6, 91.7, 107.1, 110.5, 155.9, 161.1, 161.8. IR (CHCl₃) cm⁻¹: 2924, 1617, 1494, 1137. MS (EI) *m/z* (rel. int. %): 308 (M⁺, 46.8), 249 (5.5), 179 (27.9), 129 (42.1), 86 (100). HR-MS (EI) *m/z* 308.1262 (Calcd for C₁₆H₂₀O₆: 308.1260).

***rac*-(1R,4aS,9bR)-7,9-Dimethoxy-1-tosyloxy-1,2,4a,9b-tetrahydrodibenzofuran-4(3H)-one Ethylene Acetal (21)** A solution of **20** (1.04 g, 3.37 mmol), *p*-toluenesulfonyl chloride (TsCl, 1.04 g, 5.46 mmol), triethylamine (Et₃N, 1.84 g, 18.2 mmol), and 4-(dimethylamino)pyridine (DMAP, 443 mg, 3.63 mmol) in CHCl₃ (20 mL) was stirred for 24 h at room temperature. After addition of water, the mixture was extracted with CHCl₃ (30 mL×2). The combined extracts were washed, dried, and evaporated. The residue was chromatographed on silica gel (AcOEt/*n*-hexane=1/3) to give **21** (1.14 g, 73%) as colorless crystals. mp 123–124°C (recrystallized from AcOEt). ¹H-NMR (400 MHz, CDCl₃) δ: 1.68–1.97 [4H, m, -CH(OTs)-CH₂-CH₂-], 2.43 (3H, s, Ts-CH₃), 3.65 (1H, dd, *J*=4.4, 7.7 Hz, Ar-CH-), 3.69 (3H, s, Ar-O-CH₃), 3.74 (3H, s, Ar-O-CH₃), 3.91–3.97 (3H, m, -O-CH₂-CH₂-O-), 4.05–4.10 (1H, m, -O-CH₂-CH₂-O-), 4.52 (1H, d, *J*=7.7 Hz, Ar-O-CH-), 5.16–5.19 [1H, m, -CH(OTs)-], 5.93 (1H, d, *J*=2.0 Hz, Ar-H), 6.05 (1H, d, *J*=2.0 Hz, Ar-H), 7.30 (2H, d, *J*=8.2 Hz, Ar-H), 7.78 (2H, d, *J*=8.2 Hz, Ar-H). ¹³C-NMR (100 MHz, CDCl₃) δ: 21.6, 26.1, 27.8, 46.1, 55.1, 55.4, 65.1, 66.0, 80.1, 85.2, 88.6, 91.5, 106.1, 106.9, 127.7, 129.6, 134.3, 144.4, 156.7, 161.7, 162.0. IR (CHCl₃) cm⁻¹: 1621, 1599, 1495, 1349, 1171, 1140, 1086, 907. MS (EI) *m/z* (rel. int. %): 462 (M⁺, 0.6), 290 (100), 218 (44.4), 204 (66.2), 192 (9.5). HR-MS (EI) *m/z* 462.1351 (Calcd for C₂₃H₂₆O₈S: 462.1348).

***rac*-2,3-Dihydro-7,9-dimethoxydibenzofuran-4(4aH)-one**

Ethylene Acetal (22) *tert*-BuOK (364 mg, 3.24 mmol) was added to a solution of **21** (500 mg, 1.08 mmol) in anhydrous THF (10 mL) under ice-cooling, and the mixture was stirred for 1 h at room temperature under N₂ atmosphere. After addition of water, the mixture was extracted with AcOEt (10 mL×3). The combined extracts were washed, dried, and evaporated. The residue was chromatographed on silica gel (AcOEt/*n*-hexane=1/6) to give **22** (253 mg, 81%) as a colorless oil. ¹H-NMR (400 MHz, CDCl₃) δ: 1.82–1.98 (2H, m, –Cy–H), 2.48–2.58 (2H, m, –Cy–H), 3.75 (3H, s, –O–CH₃), 3.81 (3H, s, –O–CH₃), 3.96–4.06 (2H, m, –OCH₂CH₂O–), 4.11 (1H, q, *J*=6.0 Hz, –OCH₂CH₂O–), 4.24 (1H, q, *J*=6.0 Hz, –OCH₂CH₂O–), 5.10 (1H, q, *J*=3.6 Hz, Ar–OCH–), 5.93 (1H, q, *J*=3.6 Hz, Ar–C=CH), 6.00 (1H, d, *J*=2.0 Hz, Ar–H), 6.09 (1H, d, *J*=2.0 Hz, Ar–H). ¹³C-NMR (100 MHz, CDCl₃) δ: 25.3, 30.1, 55.2, 55.4, 65.3, 66.0, 86.1, 88.6, 91.7, 106.7, 106.9, 114.5, 133.8, 156.5, 162.3, 163.7. IR (CHCl₃) cm^{–1}: 2893, 2841, 1612, 1502. MS (EI) *m/z* (rel. int. %): 290 (M⁺, 14), 204 (100), 189 (24). HR-MS (EI) *m/z* 290.1160 (Calcd for C₁₆H₁₈O₅: 290.1154).

***rac*-(4a*R*,9b*S*)-1,2,4a,9b-Tetrahydro-7,9-dimethoxydibenzofuran-4(3*H*)-one Ethylene Acetal (23)** A suspension of **22** (256 mg, 0.88 mmol) and 10% palladium on activated charcoal (188 mg) in AcOEt (2.5 mL) was stirred for 10 d under H₂ atmosphere at room temperature. After filtration, the filtrate was evaporated. The residue was chromatographed on silica gel (AcOEt/*n*-hexane=1/3) to give **23** (180 mg, 70%) as a colorless oil. ¹H-NMR (400 MHz, CDCl₃) δ: 1.26 (1H, dt, *J*=6.4, 1.6 Hz, –Cy–H), 1.57–1.62 (2H, m, –Cy–H), 1.72 (1H, dtd, *J*=1.6, 5.2, 12.0 Hz, –Cy–H), 1.83 (1H, m, –Cy–H), 1.95–1.96 (1H, m, –Cy–H), 3.41 (1H, dt, *J*=9.2, 6.8 Hz, Ar–CH), 3.75 (3H, s, –O–CH₃), 3.78 (3H, s, –O–CH₃), 3.99–4.13 (4H, m, –OCH₂CH₂O–), 4.32 (1H, dd, *J*=6.8, 1.2 Hz, Ar–OCH–), 6.02 (1H, d, *J*=2.0 Hz, Ar–H), 6.15 (1H, d, *J*=2.0 Hz, Ar–H). ¹³C-NMR (100 MHz, CDCl₃) δ: 19.8, 26.6, 30.9, 39.2, 55.2, 55.4, 65.0, 65.2, 84.9, 89.0, 91.5, 107.5, 112.1, 156.1, 160.6, 161.3. IR (CHCl₃) cm^{–1}: 3013, 2955, 1611, 1501. MS (EI) *m/z* (rel. int. %): 292 (M⁺, 52), 192 (81), 86 (100). HR-MS (EI) *m/z* 292.1306 (Calcd for C₁₆H₂₀O₅: 292.1310).

***rac*-(4a*R*,9b*S*)-1,2,4a,9b-Tetrahydro-7,9-dimethoxydibenzofuran-4(3*H*)-one (24)** A mixture of **23** (150 mg, 0.513 mmol), FeCl₃·6H₂O (485 mg, 1.79 mmol), and H₂O (0.9 mL) in toluene (3.3 mL) was heated at 100°C for 2.5 h with stirring. After cooling, the mixture was extracted with AcOEt (10 mL×3). The combined extracts were washed with saturated NaHCO₃ aq, water, and brine, dried, and evaporated. The residue was chromatographed on silica gel (AcOEt/*n*-hexane=1/6) to give **24** (91 mg, 72%) as colorless cubic crystals. Mp: 91–92°C (recryst. from AcOEt–*n*-hexane). ¹H-NMR (400 MHz, CDCl₃) δ: 1.84–1.96 (3H, m, –CHCH₂CH₂), 2.05–2.13 (1H, m, –CHCH₂CH₂), 2.44 [1H, td, *J*=7.2, 16.4 Hz, –C(=O)CH₂], 2.54 [1H, dtd, *J*=1.6, 6.8, 17.6 Hz, –C(=O)CH₂], 3.76 (3H, s, –O–CH₃), 3.77 (3H, s, –O–CH₃), 4.04 (1H, td, *J*=6.8, 9.6 Hz, Ar–CH), 4.89 (1H, d, *J*=9.6 Hz, –O–CH), 6.03 (1H, d, *J*=2.0 Hz, Ar–H), 6.16 (1H, d, *J*=2.0 Hz, Ar–H). ¹³C-NMR (100 MHz, CDCl₃) δ: 20.8, 26.2, 37.9, 43.5, 55.2, 55.5, 85.8, 88.6, 92.0, 107.5, 156.9, 161.3, 161.9, 208.4. IR (CHCl₃) cm^{–1}: 3013, 2941, 2841, 2870, 1724, 1600, 1225. MS (EI) *m/z* (rel. int. %): 248 (M⁺, 100), 220 (51), 191 (44), 178 (93). HR-MS (EI) *m/z* 248.1043 (Calcd for C₁₄H₁₆O₄: 248.1048). *Anal.* Calcd for C₁₄H₁₆O₄: C, 67.73; H, 6.50. Found: C, 67.56; H, 6.43.

***rac*-(4a*R*,9b*S*)-1,2,4a,9b-Tetrahydro-7,9-dimethoxy-4a-**

methyldibenzofuran-4(3*H*)-one (17) Lithium diisopropylamide (2.30 mL, 2.62 mmol, 1.14 M in *n*-hexane-THF) was added dropwise to a solution of **24** (164 mg, 0.66 mmol) in anhydrous THF (1 mL) at –20°C under N₂ atmosphere and the mixture was gradually warmed to room temperature over 2.5 h with stirring. To the mixture was added HMPA (0.3 mL, 1.72 mmol), and then after 15 min, methyl iodide (0.4 mL, 6.43 mmol) was added. The mixture was stirred for an additional 21 h at room temperature. After addition of water, the mixture was extracted with Et₂O (10 mL×3). The combined extracts were washed, dried, and evaporated. The residue was chromatographed on silica gel (AcOEt/*n*-hexane=1/6) to give **17** (90 mg, 52%) as a colorless oil. ¹H-NMR (400 MHz, CDCl₃) δ: 1.44 (3H, s, CH₃), 1.69–1.85 (3H, m, –CHCH₂CH₂), 1.97–2.03 (1H, m, –CHCH₂CH₂), 2.35 [1H, dtd, *J*=1.6, 8.4, 16.8 Hz, –C(=O)CH₂], 2.49 [1H, dtd, *J*=1.6, 7.6, 9.2 Hz, –C(=O)CH₂], 3.50 (1H, t-like, *J*=5.0 Hz, Ar–CH), 3.69 (3H, s, –O–CH₃), 3.70 (3H, s, –O–CH₃), 6.01 (1H, d, *J*=2.0 Hz, Ar–H), 6.01 (1H, d, *J*=2.0 Hz, Ar–H). ¹³C-NMR (100 MHz, CDCl₃) δ: 20.3, 22.0, 26.0, 37.6, 49.8, 55.2, 55.5, 88.6, 91.0, 91.9, 107.4, 157.0, 160.7, 162.0, 210.1. IR (CHCl₃) cm^{–1}: 3013, 2939, 1720, 1601. MS (EI) *m/z* (rel. int. %): 262 (M⁺, 100), 234 (44), 219 (44). HR-MS (EI) *m/z* 262.1196 (Calcd for C₁₅H₁₈O₄: 262.1205).

***rac*-(4a*R*,9b*S*)-1,2,3,4,4a,9b-Hexahydro-7,9-dimethoxy-4a-methyldibenzofuran-4-ol (25)** NaBH₄ (16 mg, 0.423 mmol) was added to a solution of **17** (27 mg, 0.103 mmol) in MeOH (0.5 mL) under ice-cooling and the mixture was stirred for 3 h at room temperature. After addition of water, the mixture was extracted with AcOEt (10 mL×3). The combined extracts were washed, dried, and evaporated. The residue was purified by PTLC (AcOEt/*n*-hexane=1/4) to give **25** (22 mg, 82%) as a colorless oil. The diastereomeric ratio was determined to be 5/1 on the basis of ¹H-NMR integrations. ¹H-NMR (400 MHz, CDCl₃) δ: [major] 1.42 (3H, s, CH₃), 1.48–1.57 (4H, m, Cy–H), 1.82–1.88 (2H, m, Cy–H), 2.21 (1H, d, *J*=8.4 Hz, OH), 3.14 (1H, t, *J*=6.8 Hz, Ar–CH), 3.71–3.74 [1H, m, CH(OH)], 3.75 (3H, s, –O–CH₃), 3.77 (3H, s, –O–CH₃), 6.01 (1H, d, *J*=2.0 Hz, Ar–H), 6.06 (1H, d, *J*=2.0 Hz, Ar–H). [minor] 1.42 (3H, s, CH₃), 1.48–1.57 (4H, m, Cy–H), 1.82–1.88 (2H, m, Cy–H), 2.21 (1H, d, *J*=8.4 Hz, OH), 3.36 (1H, t, *J*=6.8 Hz, Ar–CH), 3.71–3.74 [1H, m, CH(OH)], 3.74 (3H, s, –O–CH₃), 3.77 (3H, s, –O–CH₃), 5.99 (1H, d, *J*=2.0 Hz, Ar–H), 6.04 (1H, d, *J*=2.0 Hz, Ar–H). ¹³C-NMR (100 MHz, CDCl₃, a mixture of major and minor) δ: 18.2, 18.8, 20.1, 24.1, 24.3, 25.5, 27.7, 28.9, 45.6, 47.8, 55.1, 55.4, 72.3, 72.6, 88.7, 89.3, 89.7, 91.1, 92.6, 109.4, 110.9, 156.8, 157.3, 159.6, 160.1, 161.4. IR (CHCl₃) cm^{–1}: 3584, 3489, 3009, 1609. MS (EI) *m/z* (rel. int. %): 264 (M⁺, 71), 248 (28), 193 (100), 154 (41). HR-MS (EI) *m/z* 264.1359 (Calcd for C₁₅H₂₀O₄: 264.1361).

***O*-[*rac*-(4a*R*,9b*S*)-1,2,3,4,4a,9b-Hexahydro-7,9-dimethoxy-4a-methyldibenzofuran-4-yl] *S*-Methyl Dithiocarbonate (26)** CS₂ (63 mg, 0.83 mmol) was added to a suspension of **25** (22 mg, 0.083 mmol) and 60% NaH (10 mg, 0.25 mmol) in THF (0.3 mL) at room temperature and the mixture was stirred. After 1 h, methyl iodide (118 mg, 0.083 mmol) was added to the mixture and the mixture was stirred for 2 h. After addition of water, the mixture was extracted with AcOEt (10 mL×3). The combined extracts were washed, dried, and evaporated. The residue was purified by PTLC (AcOEt/*n*-hexane=1/6) to give **26** (30 mg, 100%) as a pale yellow oil.

¹H-NMR (400 MHz, CDCl₃) δ : [major] 1.37 (3H, s, CH₃), 1.50–1.58 (2H, m, Cy-H), 1.59–1.67 (1H, m, Cy-H), 1.75 (1H, tdd, J =7.2, 10.0, 13.2 Hz, Cy-H), 1.85–1.94 (1H, m, Cy-H), 2.02–2.10 (1H, m, Cy-H), 2.52 (3H, s, S-CH₃), 3.30 (1H, t, J =5.6 Hz, Ar-CH), 3.76 (3H, s, -O-CH₃), 3.78 (3H, s, -O-CH₃), 5.93 {1H, dd, J =6.0, 10.0 Hz, CH[OC(=S)]SCH₃}, 6.02 (1H, d, J =2.0 Hz, Ar-H), 6.11 (1H, d, J =2.0 Hz, Ar-H). [minor] 1.37 (3H, s, CH₃), 1.50–1.58 (2H, m, Cy-H), 1.59–1.67 (1H, m, Cy-H), 1.75 (1H, tdd, J =7.2, 10.0, 13.2 Hz, Cy-H), 1.85–1.94 (1H, m, Cy-H), 2.02–2.10 (1H, m, Cy-H), 2.59 (3H, s, S-CH₃), 3.40 (1H, t, J =4.8 Hz, Ar-CH), 3.74 (3H, s, -O-CH₃), 3.75 (3H, s, -O-CH₃), 5.84 {1H, dd, J =4.4, 9.4 Hz, CH[OC(=S)]SCH₃}, 6.00 (1H, d, J =2.0 Hz, Ar-H), 6.05 (1H, d, J =2.0 Hz, Ar-H). ¹³C-NMR (100 MHz, CDCl₃, a mixture of major and minor) δ : 18.1, 18.8, 19.0, 23.4, 24.1, 25.0, 46.5, 55.1, 55.2, 55.3, 55.5, 55.6, 83.5, 83.6, 83.7, 88.4, 88.6, 88.7, 88.8, 91.2, 91.3, 91.4, 109.5, 156.8, 160.3, 161.7, 216.1. IR (CHCl₃) cm⁻¹: 2959, 2930, 1732, 1609. MS (EI) m/z (rel. int. %): 354 (M⁺, 86), 247 (100), 205 (52), 191 (38), 91 (33). HR-MS (EI) m/z 354.0959 (Calcd for C₁₇H₂₂O₄S₂: 354.0968).

***rac*-(4aR,9bR)-1,2,4a,9b-Tetrahydro-7,9-dimethoxy-4a-methyldibenzofuran (27)** Microwave irradiation (300 W, 200°C) was applied to a solution of **26** (35 mg, 0.10 mmol) in *o*-dichlorobenzene (0.2 mL) for 1 h. After addition of 1.0 M NaOH aq, the mixture was extracted with AcOEt (10 mL×3). The combined extracts were washed, dried, and evaporated. The residue was purified by PTLC (AcOEt/*n*-hexane=1/6) to give **27** (17 mg, 68%) as a colorless oil. ¹H-NMR (400 MHz, CDCl₃) δ : 1.45 (3H, s, CH₃), 1.80–1.97 (3H, m, Cy-H), 1.98–2.07 (1H, m, Cy-H), 3.22 (1H, dd, J =4.4, 8.2 Hz, Ar-CH), 3.74 (3H, s, -O-CH₃), 3.78 (3H, s, -O-CH₃), 5.73 (1H, td, J =2.0, 10.0 Hz, -CH=CH-), 5.96 (1H, td, J =4.0, 10.0 Hz, -CH=CH-), 6.00 (1H, d, J =2.0 Hz, Ar-H), 6.02 (1H, d, J =2.0 Hz, Ar-H). ¹³C-NMR (100 MHz, CDCl₃) δ : 22.3, 24.6, 26.7, 45.1, 55.2, 55.4, 86.0, 88.9, 91.0, 109.6, 129.4, 131.0, 157.4, 160.1, 161.4. IR (CHCl₃) cm⁻¹: 3013, 2928, 1618, 1609, 1501. MS (EI) m/z (rel. int. %): 246 (M⁺, 89), 231 (35), 167 (100), 154 (36). HR-MS (EI) m/z 246.1263 (Calcd for C₁₅H₁₈O₃: 246.1256).

***rac*-(4aR,9bR)-6-Acetyl-1,2,4a,9b-tetrahydro-7,9-dimethoxy-4a-methyldibenzofuran (28) and *rac*-(4aR,9bR)-8-Acetyl-1,2,4a,9b-tetrahydro-7,9-dimethoxy-4a-methyldibenzofuran (29)** Ac₂O (33 mg, 0.35 mmol) was added to a suspension of **27** (47 mg, 0.19 mmol), LiClO₄ (67 mg, 0.63 mmol), and Sc(OTf)₃ (6.0 mg, 0.012 mmol) in MeNO₂ (0.5 mL) and the mixture was stirred for 30 min at room temperature. After addition of saturated NaHCO₃ aq, the mixture was extracted with AcOEt (10 mL×3). The combined extracts were washed, dried, and evaporated. The residue was purified by PTLC (AcOEt/*n*-hexane=1/3) to give **28** (8 mg, 15%) as a colorless oil and **29** (9 mg, 16%) as a colorless oil.

28: R_f =0.1 (AcOEt/*n*-hexane=1/7). ¹H-NMR (400 MHz, CDCl₃) δ : 1.46 (3H, s, CH₃), 1.77–2.07 (4H, m, Cy-H), 2.50 [3H, s, -O-C(=O)CH₃], 3.18 (1H, dd, J =4.0, 7.2 Hz, Ar-CH), 3.84 (3H, s, -O-CH₃), 3.85 (3H, s, -O-CH₃), 5.77 (1H, td, J =2.0, 10.0 Hz, -CH=CH-), 5.95 (1H, td, J =4.4, 10.0 Hz, -CH=CH-), 5.98 (1H, s, Ar-H). ¹³C-NMR (100 MHz, CDCl₃, a mixture of major and minor) δ : 22.3, 24.3, 26.7, 32.5, 44.4, 55.3, 56.2, 87.0, 87.7, 108.6, 110.6, 129.3, 130.9, 159.0, 159.7, 160.2, 198.0. IR (CHCl₃) cm⁻¹: 3011, 2928, 2841, 1668, 1609. MS (EI) m/z (rel. int. %): 43 (25), 195 (48), 273 (66), 288

(M⁺, 100). HR-MS (EI) m/z 288.1357 (Calcd for C₁₇H₂₀O₄: 288.1361).

29: R_f =0.4 (AcOEt/*n*-hexane=1/7). ¹H-NMR (400 MHz, CDCl₃) δ : 1.48 (3H, s, CH₃), 1.79 (1H, dddd, J =0.8, 3.2, 8.8, 17.4 Hz, Cy-H), 1.90–2.00 (2H, m, Cy-H), 2.05–2.12 (1H, m, Cy-H), 2.49 [3H, s, -O-C(=O)CH₃], 3.28 (1H, dd, J =4.8, 8.6 Hz, Ar-CH), 3.75 (3H, s, -O-CH₃), 3.80 (3H, s, -O-CH₃), 5.75 (1H, td, J =2.0, 10.0 Hz, -CH=CH-), 5.99 (1H, td, J =4.4, 10.0 Hz, -CH=CH-), 6.15 (1H, s, Ar-H). ¹³C-NMR (100 MHz, CDCl₃, a mixture of major and minor) δ : 22.4, 24.9, 26.7, 32.6, 45.5, 55.9, 61.2, 86.4, 90.4, 113.7, 117.2, 128.9, 131.1, 155.2, 158.4, 161.5, 202.1. IR (CHCl₃) cm⁻¹: 3011, 2928, 2841, 1669, 1609. MS (EI) m/z (rel. int. %): 288 (M⁺, 100), 273 (53), 181 (81), 43 (17). HR-MS (EI) m/z 288.1358 (Calcd for C₁₇H₂₀O₄: 288.1361).

From 30 Microwave irradiation (300 W, 200°C) was applied to a suspension of **30** (96 mg, 0.24 mmol) and potassium carbonate (34 mg, 0.25 mmol) in *o*-dichlorobenzene (2 mL) for 15 min. After addition of saturated NaHCO₃ aq, the mixture was extracted with AcOEt (20 mL×3). The combined extracts were washed, dried, and evaporated. The residue was purified by silica gel chromatography (AcOEt/*n*-hexane=1/4) to give **28** (55 mg, 80%) as a colorless oil.

***O*-[*rac*-(4aR,9bS)-(6-Acetyl-1,2,3,4,4a,9b-hexahydro-7,8-dimethoxy-4a-methyldibenzofuran-4-yl)] *S*-Methyl Dithiocarbonate (30) and *O*-[*rac*-(4aR,9bS)-(8-Acetyl-1,2,3,4,4a,9b-hexahydro-7,8-dimethoxy-4a-methyldibenzofuran-4-yl)] *S*-Methyl Dithiocarbonate (31)** Sc(OTf)₃ (19 mg, 0.039 mmol) was added to a suspension of **26** (136 mg, 0.38 mmol), Ac₂O (182 μ L, 1.9 mmol) and LiClO₄ (82 mg, 0.77 mmol) in MeNO₂ (2 mL) and the mixture was heated at 50°C for 5 h with stirring. After cooling, the mixture was poured into saturated NaHCO₃ aq and extracted with AcOEt (20 mL×3). The combined extracts were washed, dried, and evaporated. The residue was purified with silica gel chromatography (AcOEt/*n*-hexane=1/10 to 1/3) to give **30** (137 mg, 91%) as a colorless oil and **31** (4 mg, 3%) as a colorless oil.

30: R_f =0.2 (AcOEt/*n*-hexane=1/7). [dr ratio=1/5] ¹H-NMR (400 MHz, CDCl₃) δ : [major] 1.40 (3H, s, CH₃), 1.52–1.67 (2H, m, Cy-H), 1.73–1.78 (2H, m, Cy-H), 1.89–1.96 (1H, m, Cy-H), 2.04 (1H, td, J =6.0, 12.8 Hz, Cy-H), 2.50 [3H, s, -O-C(=O)CH₃], 2.53 (3H, s, SCH₃), 3.29 (1H, t, J =6.0 Hz, Ar-CH), 3.85 (3H, s, -O-CH₃), 3.86 (3H, s, -O-CH₃), 5.93 {1H, dd, J =5.6, 9.6 Hz, CH[OC(=S)]SCH₃}, 6.01 (1H, s, Ar-H). [minor] 1.40 (3H, s, CH₃), 1.52–1.67 (3H, m, Cy-H), 1.73–1.78 (2H, m, Cy-H), 1.89–1.96 (1H, m, Cy-H), 2.48 [3H, s, -O-C(=O)CH₃], 2.50 (3H, s, SCH₃), 3.29 (1H, t, J =6.0 Hz, Ar-CH), 3.83 (3H, s, -O-CH₃), 3.85 (3H, s, -O-CH₃), 6.01 (1H, s, Ar-H), 6.03 {1H, dd, J =4.4, 18.8 Hz, CH[OC(=S)]SCH₃}. ¹³C-NMR (100 MHz, CDCl₃, a mixture of major and minor) δ : 18.0, 23.5, 24.3, 24.9, 32.5, 45.8, 55.2, 55.4, 55.5, 56.3, 56.4, 56.5, 82.9, 83.0, 83.2, 88.2, 88.3, 88.4, 89.2, 108.1, 110.3, 158.5, 159.8, 160.4, 197.6, 215.3. IR (CHCl₃) cm⁻¹: 3009, 2943, 1692, 1614, 1595. MS (EI) m/z (rel. int. %): 396 (M⁺, 47), 289 (100), 247 (75), 209 (62), 91 (49). HR-MS (EI) m/z 396.1058 (Calcd for C₁₉H₂₄O₅S₂: 396.1065).

31: R_f =0.3 (AcOEt/*n*-hexane=1/7). [dr ratio=1/7] ¹H-NMR (400 MHz, CDCl₃) δ : [major] 1.40 (3H, s, CH₃), 1.51–1.65 (3H, m, Cy-H), 1.69–1.79 (1H, m, Cy-H), 1.92–2.01 (1H, m, Cy-H), 2.08 (1H, td, J =6.4, 13.2 Hz, Cy-H), 2.49 [3H, s, -O-C(=O)CH₃], 2.54 (3H, s, SCH₃), 3.35 (1H, t, J =6.4 Hz,

Ar-CH), 3.77 (3H, s, -O-CH₃), 3.82 (3H, s, -O-CH₃), 5.93 {1H, dd, $J=5.6$, 10.2 Hz, CH[OC(=S)]SCH₃}, 6.26 (1H, s, Ar-H). [minor] 1.34 (3H, s, CH₃), 1.51–1.65 (3H, m, Cy-H), 1.69–1.79 (1H, m, Cy-H), 1.92–2.00 (1H, m, Cy-H), 2.06 (1H, td, $J=6.4$, 13.2 Hz, Cy-H), 2.48 [3H, s, -O-C(=O)CH₃], 2.50 (3H, s, SCH₃), 3.46 (1H, t, $J=6.4$ Hz, Ar-CH), 3.74 (3H, s, -O-CH₃), 3.76 (3H, s, -O-CH₃), 5.93 {1H, dd, $J=5.6$, 10.2 Hz, CH[OC(=S)]SCH₃}, 6.26 (1H, s, Ar-H). ¹³C-NMR (100 MHz, CDCl₃, a mixture of major and minor) δ : 18.7, 23.9, 26.6, 47.2, 55.8, 56.1, 61.1, 83.2, 83.4, 88.6, 90.2, 90.4, 113.5, 154.5, 158.5, 161.6, 202.0. IR (CHCl₃) cm⁻¹: 3005, 2945, 1692, 1614, 1595. MS (EI) m/z (rel. int. %): 396 (M⁺, 100), 289 (90), 247 (35), 209 (22), 91 (25). HR-MS (EI) m/z 396.1068 (Calcd for C₁₉H₂₄O₅S₂: 396.1065).

***rac*-(5a*R*,9a*R*)-4-Acetyl-5a,8,9,9a-tetrahydro-1-methoxy-5a-methyldibenzofuran-3-ol (16)** LiI (311 mg, 2.32 mmol) was added to a solution of **28** (45 mg, 0.16 mmol) in pyridine (1 mL) and the mixture was heated at 120°C for 22 h with stirring. After cooling, the mixture was poured into 1% HCl aq and extracted with AcOEt (20 mL×3). The combined extracts were washed with saturated NH₄Cl aq and brine, dried, and evaporated. The residue was purified with silica gel chromatography (AcOEt/*n*-hexane=1/20) to give **16** (26 mg, 59%) as bright yellow crystals. mp 105–106°C (recrystallized from *n*-hexane). ¹H-NMR (400 MHz, CDCl₃) δ : 1.48 (3H, s, CH₃), 1.70–1.79 (1H, m, Cy-H), 1.86–2.07 (3H, m, Cy-H), 2.59 [3H, s, -O-C(=O)CH₃], 3.17 (1H, dd, $J=4.4$, 8.6 Hz, Ar-CH), 3.83 (3H, s, -O-CH₃), 5.77 (1H, td, $J=2.0$, 10.0 Hz, -CH=CH-), 5.98 (1H, s, Ar-H), 6.01 (1H, td, $J=4.4$, 10.0 Hz, -CH=CH-), 13.31 (1H, s, -OH). ¹³C-NMR (100 MHz, CDCl₃) δ : 22.2, 24.6, 26.9, 31.3, 44.3, 55.5, 87.6, 91.9, 102.8, 108.6, 129.0, 131.5, 161.3, 162.6, 165.7, 202.2. IR (CHCl₃) cm⁻¹: 3476, 3007, 1711, 1366, 1225. MS (EI) m/z (rel. int. %): 274 (M⁺, 100), 259 (58), 234 (26), 153 (33). HR-MS (EI) m/z 274.1197 (Calcd for C₁₆H₁₈O₄: 274.1205). *Anal.* Calcd for C₁₆H₁₈O₄: C, 70.06; H, 6.61. Found: C, 70.11; H, 6.59.

***rac*-(5a*R*,9a*R*)-4-Cinnamoyl-5a,8,9,9a-tetrahydro-1-methoxy-5a-methyldibenzofuran-3-ol (32)** To a solution of **16** (29 mg, 0.11 mmol) and PhCHO (16 μ L, 0.16 mmol) in *tert*-BuOH (1 mL) was added *tert*-BuOK (24 mg, 0.21 mmol), and the mixture was stirred at room temperature for 5 h under N₂ atmosphere. After addition of saturated NH₄Cl aq, the mixture was extracted with AcOEt (20 mL×3). The combined extracts were washed, dried, and evaporated. The residue was purified with silica gel chromatography (AcOEt/*n*-hexane=1/50) to give **32** (31 mg, 78%) as orange crystals. mp 145–146°C (recrystallization from *n*-hexane). ¹H-NMR (300 MHz, CDCl₃) δ : 1.54 (3H, s, CH₃), 1.75–1.79 (1H, m, Cy-H), 1.96–2.05 (3H, m, Cy-H), 3.20 (1H, dd, $J=3.9$, 8.4 Hz, Ar-CH), 3.85 (3H, s, -O-CH₃), 5.89 (1H, td, $J=1.8$, 8.4 Hz, -CH=CH-), 6.02–6.07 (1H, overlap, -CH=CH-), 6.04 (1H, s, Ar-H), 7.39–7.44 (3H, m, Ar-H), 7.60–7.63 (2H, m, Ar-H), 7.82 (1H, d, $J=15.6$ Hz, -CH=CH-), 8.13 (1H, d, $J=15.6$ Hz, -CH=CH-), 14.00 (1H, s, OH). ¹³C-NMR (100 MHz, CDCl₃) δ : 22.3, 24.7, 27.1, 44.2, 55.6, 87.7, 92.4, 108.6, 126.2, 128.5, 128.88, 128.94, 130.1, 131.7, 135.5, 142.9, 160.7, 162.9, 167.2, 191.4. IR (CHCl₃) cm⁻¹: 3506, 3011, 2932, 2843, 1630, 1599. MS (EI) m/z (rel. int. %): 362 (M⁺, 100), 344 (62), 257 (72), 193 (23). HR-MS (EI) m/z 362.1526 (Calcd for C₂₃H₂₂O₄: 362.1518). *Anal.* Calcd for C₂₃H₂₂O₄: C, 76.22; H, 6.12. Found: C, 76.27; H, 5.99.

***rac*-(5a*R*,9a*R*)-5a,8,9,9a-Tetrahydro-1-methoxy-5a-methyl-4-(3-phenylpropionyl)-dibenzofuran-3-ol [(±)-8-Deisopropyladunctin B] (9)** A solution of **32** (28 mg, 0.077 mmol), Et₃SiH (20 μ L, 0.19 mmol), and (Ph₃P)₃RhCl (7.1 mg, 0.008 mmol) in benzene (1 mL) was heated at 70°C for 3 h under N₂ atmosphere. After cooling, a solution of concentrated HCl in MeOH (1 mL) was added to the reaction mixture, and the mixture was stirred for an additional 15 min at room temperature. After addition of saturated NaHCO₃ aq, the mixture was extracted with Et₂O (10 mL×3). The combined extracts were washed, dried, and evaporated. The crude product was purified with silica gel chromatography (AcOEt/*n*-hexane=1/50) to give **9** (17 mg, 61%) as a colorless oil. ¹H-NMR (400 MHz, CDCl₃) δ : 1.49 (3H, s, Ar-H), 1.73–1.80 (1H, m, Cy-H), 1.93–2.06 (3H, m, Cy-H), 2.99 [2H, t, $J=7.2$ Hz, C(=O)CH₂CH₂Ph], 3.18 (1H, dd, $J=4.4$, 8.8 Hz, Ar-CH), 3.29 [2H, t, $J=7.2$ Hz, C(=O)CH₂CH₂Ph], 3.83 (3H, s, -O-CH₃), 5.77 (1H, td, $J=2.0$, 10.2 Hz, -CH=CH-), 6.00 (1H, s, Ar-H), 6.01 (1H, td, $J=2.0$, 10.2 Hz, -CH=CH-), 7.21–7.31 (5H, m, Ar-H), 13.39 (1H, s, OH). ¹³C-NMR (100 MHz, CDCl₃) δ : 24.6, 27.0, 29.7, 30.9, 44.3, 55.5, 87.8, 92.1, 108.6, 109.1, 125.9, 128.4, 128.4, 128.9, 131.6, 141.5, 160.9, 162.6, 166.0, 203.7. IR (CHCl₃) cm⁻¹: 3506, 3024, 2928, 1832, 1601. MS (EI) m/z (rel. int. %): 364 (M⁺, 71), 179 (30), 105 (45), 91 (100). HR-MS (EI) m/z 364.1679 (Calcd for C₂₃H₂₄O₄: 364.1674).

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