Chiral Diselenides in the Total Synthesis of (+)-Samin

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Received November 28, 1995[⊗]

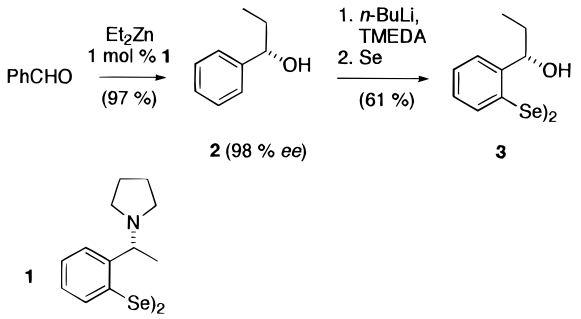
Chiral selenium compounds are applied to stoichiometric as well as to catalytic reactions in the synthesis of substituted tetrahydrofuran derivatives: The selenium compound **1** was used in catalytic amounts for a rapid access to chiral diselenide **3**. The efficient stereoselective addition to alkene **5** yields product **8** with a selenium functionality as a precursor for an intramolecular radical cyclization. In this way a short total synthesis of (+)-samin (**11**), a naturally occurring furofuran lignan, was achieved.

Lignans are widely distributed in the plant kingdom. Within this general class many compounds have been identified and because of the broad range of structures as well as biological activities they have attracted considerable attention.[1] The furofuran lignans are one of the largest groups of naturally occurring lignans and their synthesis is a challenge to organic chemists. Samin is a component of sesame oil[2] and a known precursor for the synthesis of a variety of furofuran lignans.[3] Many efforts have been made to construct the furofuran (3,7-dioxabicyclo[3.3.0]octane) skeleton.[4] To our knowledge only two synthetic strategies to nonracemic samin have been reported to date[5] beside various routes to racemic samin.[6]

Recently we found that simple chiral diselenides are versatile reagents for an asymmetric functionalization of arylalkenes.[7] We now report an optimized and shorter access to the diselenide **3** and its application in the total synthesis of (+)-samin (**11**).

The chiral diselenide **3** is obtained by a two-step synthesis. For the stereoselective addition of diethylzinc to benzaldehyde many powerful catalysts have been reported.[8] We found that nitrogen-based chiral diselenides are suitable procatalysts[9] for this reaction.[10] Diselenide **1** is prepared from (*R*)-1-(1-phenylethyl)-

Scheme 1



pyrrolidine[11] in 83% yield by *ortho*-deprotonation with *tert*-butyllithium,[12] treatment with elemental selenium, and air oxidation. Addition of diethylzinc to benzaldehyde is catalyzed by 1 mol % **1**, and (*S*)-1-phenylpropanol (**2**) is obtained in 97% yield and 98% *ee*. The *ortho*-lithiation of **2** required a slightly modified procedure.[13] Compound **2** must be refluxed with *n*-BuLi in the presence of TMEDA for 12 h. After addition of selenium and oxidative workup diselenide **3** is obtained in 61% yield.

An elegant method for the creation of a heteroatom-substituted asymmetric benzylic carbon atom is the reaction of an arylalkene with a chiral selenium reagent. In the total synthesis of samin we planned to use this stereoselective reaction by reacting alkene **5** with the electrophilic selenium compound **6** derived from diselenide **3**. The newly generated asymmetric carbon could then be used to control the other stereocenters of samin. Facial selectivity in addition reactions of various chiral selenium electrophiles to substituted alkenes has also been observed by other research groups,[14] however, the reasons for this are not yet fully understood and are

[⊗] Abstract published in *Advance ACS Abstracts*, March 15, 1996.

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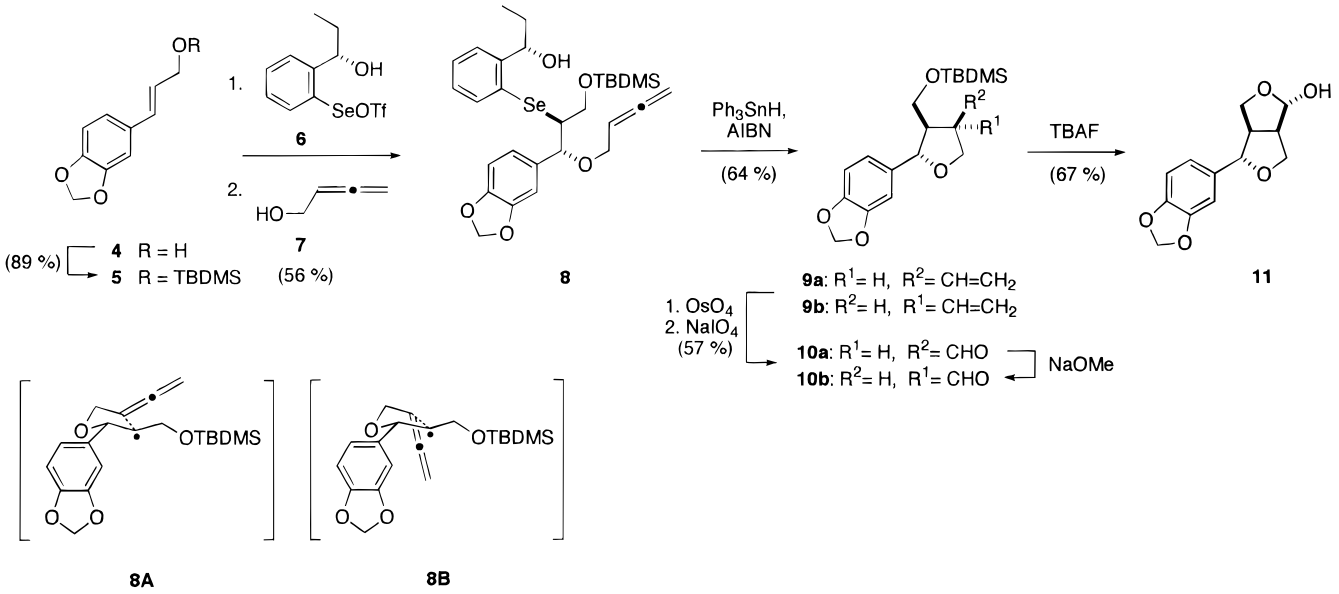
Scheme 2



currently under investigation. To take advantage of the selenium functionality as a radical precursor, we planned to introduce a nucleophile bearing a double bond that can be used for a radical cyclization. Because the double bond of the nucleophile can also be attacked by the selenium reagent, the formation of the selenonium ion by reaction of the selenium cation with the alkene must be performed before adding the nucleophile.

Readily available allylic alcohol **4**[15] was first protected with a TBDMS-group. Cleavage of the diselenide **3** with bromine and then treatment with silver triflate afforded electrophilic selenium species **6**. Reaction with alkene **5** for 15 min, followed by addition of 2,3-butadien-1-ol (**7**)[16] (−100 °C, 3 h) afforded the addition product **8** in 56% yield with a diastereomeric ratio of 16:1.[17] Compound **8** was then subjected to a radical cyclization reaction by treatment with triphenyltin hydride and AIBN. Although intramolecular radical cyclizations of allenes *via* the 6-*endo* pathway have been reported,[18] the normally favored 5-*exo* pathway was observed in the cyclization leading to the tetrahydrofuran derivative **9** in 64% yield. Only a few stereochemical investigations have been performed using 1,2-disubstituted radicals in intramolecular 5-*exo* radical cyclizations leading to furan or pyrrolidine derivatives.[19] Also, intramolecular 5-*exo* cyclizations to cyclopentane derivatives show generally a preference for *anti* stereochemistry with regard to the 1,2-substituents.[20] The stereochemistry of the substituents at C-2 and C-3 in **9** was found to be *anti* also in analogy to results obtained in a synthesis of racemic samin.[6e,f] This can be explained by a transition state in which the aromatic and hydroxymethyl substituents are arranged in pseudoequatorial positions. The stereochemical outcome of the reaction at C-4 is dependent on whether the reaction proceeds *via* the boatlike transition state **8A** or the chairlike transition state **8B**. Treatment of **8** with triphenyltin hydride and AIBN in toluene at 110 °C yields a 1:1 mixture of **9a** and **9b** in 56% yield. Lowering the reaction temperature to 90 °C gives **9** in a 1:2 (**9a**:**9b**) mixture in 64% yield. This shows that the boatlike transition state **8A** (leading to **9a**) is similar in energy to **8B** (leading to **9b**). Experiments[21] and calculations[22] have shown that boatlike and chairlike transition states of comparable systems are only slightly different in energy.[20b] The stereochemistry at C-4 was determined after cleavage of the double bond to the aldehyde **10** with osmium tetroxide followed by sodium periodate (57% yield). The mixture of **10a** and **10b** shows two distinct signals in the ^{1}H NMR for the aldehyde protons. Compound **10** is a known intermediate in the synthesis of samin.[6e,f] By treatment with sodium methoxide it can be isomerized to the thermodynamically more stable stereoisomer which was shown to be the 3,4-*trans*-isomer **10b** after performing a series of NOE experiments.[23] After the final cleavage of the TBDMS-group with tetrabutylammonium fluoride, cyclization to the hemiacetal occurs spontaneously with either the mixture of isomers **10a**/**10b** or only **10b** affording (+)-samin (**11**) in 67% yield. This shows that under the conditions of deprotection, isomerization to the 3,4-*cis*-isomer occurred leading to (+)-samin (**11**) as the only product. The existence of samin as a single stereoisomer was confirmed by NOE experiments.[5b] By comparison of the optical rotation of **11** {$[\alpha]^{25}_D = +74.5$ (*c* 0.49, $CHCl_3$)} with literature data[5a]

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(17) Propargylic alcohol can be used as nucleophile as well, but the yield of the addition reaction is lower (20%) and the subsequent radical cyclization to the already known tetrahydrofuran intermediate [lit. 6e,f] less efficient (29%).

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{$[\alpha]^{24}_D = -88.2$ (*c* 1.1, $CHCl_3$) for the (−)-enantiomer}, the enantiomeric excess of **11** is 85% consistent with the diastereomeric ratio of **8** that was measured by ^1H NMR to be 1:16 (88% de).

In conclusion, we have accomplished a short total synthesis of (+)-samin (**11**) in 12% overall yield from allylic alcohol **4**. Moreover, we have provided further evidence of the value of easily accessible chiral selenium reagents for stereoselective addition reactions to double bonds. Further investigations of the scope and mechanisms of stoichiometric and catalytic reactions of chiral selenium compounds are in progress.

Experimental Section

General. All reactions were carried out under a dry argon atmosphere. The ^1H and ^{13}C NMR spectra were measured in $CDCl_3$ using TMS as an internal standard at 300 and 75 MHz, respectively. ^{77}Se NMR spectra were recorded in $CDCl_3$ at 76 MHz using $(PhSe)_2$ (δ = 475 ppm) as an external standard. Diethyl ether and tetrahydrofuran were distilled from sodium−benzophenone prior to use. Melting points are uncorrected.

(*R*,*R*)-Bis[2-[1-pyrrolidin-1-yl-ethyl]phenyl] Diselenide (1). To a solution of (*R*)-1-(1-phenylethyl)pyrrolidine[11] (1.75 g, 10 mmol) in dry pentane (10 mL) was added 1.6 M *tert*-butyllithium solution in pentane (6.25 mL, 10 mmol). After stirring for 40 h the solution was cooled to −78 °C and dry THF (10 mL) was added. The reaction mixture was allowed to warm up to room temperature and was again cooled to −78 °C. After addition of selenium (0.79 g, 10 mmol) the solution was warmed up to room temperature and quenched after all selenium was dissolved by adding aqueous saturated NH_4Cl. The solution was extracted five times with *tert*-butyl methyl ether. The combined organic phases were dried and concentrated to leave a residue which was purified by flash-chromatography (silica gel, acetone:pentane 1:3) affording **1** (2.11 g, 83% yield): yellow oil; $[\alpha]^{25}_D = -42.1$ (*c* 0.82, $CHCl_3$); ^1H NMR δ 1.44 (d, J = 6.6 Hz, 6H), 1.80 (m, 8H), 2.58 (m, 8H), 3.74 (q, J = 6.6 Hz, 2H), 7.06 (td, J = 7.5, 1.7 Hz, 2H), 7.13 (td, J = 7.2, 1.4 Hz, 2H), 7.23 (dd, J = 7.5, 1.6 Hz, 2H), 7.79 (dd, J = 7.8, 1.4 Hz, 2H); ^{13}C NMR δ 19.0 (q) (2C), 23.7 (t) (4C), 51.1 (t) (4C), 63.7 (d) (2C), 126.0 (d) (2C), 126.5 (d) (2C), 127.4 (d) (2C), 131.3 (d) (2C), 131.3 (s) (2C), 144.9 (s) (2C); ^{77}Se NMR δ 439.9; MS (EI) *m*/*z* (relative intensity) 508(M^+, 0.5), 254(100), 183(27), 174(28), 104(23), 91(11), 70(62); IR ($CHCl_3$) ν 2973, 2805, 1584, 1462, 1434, 1371, 1219, 1143 cm^{-1}. Anal. Calcd for $C_{24}H_{32}N_2Se_2$: C, 56.92; H, 6.37; N, 5.53. Found: C, 56.85; H, 6.12; N, 5.58.

(*S*)-1-Phenylpropanol (2). To a cold (0 °C) solution of **1** in toluene (100 mL) was added diethylzinc (6.15 mL, 60 mmol), and after 10 min benzaldehyde (5.31 g, 50 mmol) was added. After stirring for 20 h at 0 °C 1 N HCl (100 mL) was added and the solution extracted twice with *tert*-butyl methyl ether. The combined organic phases were dried, concentrated, and subjected to a kugelrohr distillation affording **2** (6.61 g, 97% yield). The enantiomeric excess of 98% was determined by GC (Chrompack, β-CD-permethylated, 25 m).

(*S*,*S*)-Bis[2-[1-hydroxypropyl]phenyl] Diselenide (3). To a cold (0 °C) solution of (*S*)-1-phenylpropanol (4.49 g, 33 mmol) and tetramethylethylenediamine (7.67 g, 66 mmol) in dry pentane (50 mL) was added dropwise 2.0 M *n*-butyllithium solution in pentane (33 mL, 66 mmol). The bright yellow solution was refluxed for 12 h. The solution was cooled to 0 °C, and dry THF (30 mL) was added followed by selenium (2.61 g, 33 mmol). After stirring for 5 h at room temperature 1 N HCl (250 mL) was added and the solution extracted five times with *tert*-butyl methyl ether. The combined organic phases were dried and concentrated to leave a residue which was purified by flash-chromatography (silica gel, pentane:*tert*-butyl methyl ether 4:1) affording **3** (3.91 g, 61% yield): yellow oil; $[\alpha]^{25}_D = +262.0$ (*c* 1.00, $CHCl_3$); ^1H NMR δ 0.82 (t, J = 7.0 Hz, 6H), 1.65 (quint, J = 7.0 Hz, 4H), 2.28 (s, 2H), 4.76 (t, J = 7.0 Hz, 2H), 7.19 (t, J = 7.5 Hz, 2H), 7.33 (t, J = 7.5 Hz, 2H), 7.45 (d, J = 7.5 Hz, 2H), 7.75 (d, J = 7.5 Hz, 2H); ^{13}C NMR δ 10.3 (q) (2C), 31.3 (t) (2C), 74.7 (d) (2C), 126.4 (d) (2C), 128.3 (d) (2C), 129.1 (d) (2C), 130.0 (s) (2C), 135.3 (d) (2C), 146.5 (s) (2C); ^{77}Se NMR δ 456.1; MS (EI) *m*/*z* (relative intensity) 430(M^+, 39), 213(43), 197(100), 185(83), 183(79), 157(32), 116(93), 105(24), 91(45), 77(79), 57(33) 51(37); IR ($CHCl_3$) ν 3601, 3413, 3018, 2967, 1462, 1434, 1210, 1096, 973 cm^{-1}. Anal. Calcd for $C_{18}H_{22}O_2Se_2$: C, 50.49; H, 5.18. Found: C, 50.35; H, 5.43.

(*E*)-[3-(1,3-Benzodioxol-5-yl)-2-propenyloxy](1,1-dimethylethyl)dimethylsilane (5). To a solution of **4**[15] (248 mg, 1.39 mmol), TBDMSCl (486 mg, 3.22 mmol), and 4-(dimethylamino)pyridine (17 mg, 0.14 mmol) in CH_2Cl_2 (10 mL) was added triethylamine (0.9 mL, 12.3 mmol) and stirred for 24 h. The reaction mixture was diluted with CH_2Cl_2 and washed with 1 N HCl. The organic phase was concentrated leaving a residue which was purified by flash-chromatography (silica gel, pentane:*tert*-butyl methyl ether 10:1) affording **5** (360 mg, 89% yield): colorless oil; ^1H NMR δ 0.11 (s, 6H), 0.94 (s, 9H), 4.33 (dd, J = 5.2, 1.7 Hz, 2H), 5.95 (s, 2H), 6.12 (dt, J = 15.8, 5.2 Hz, 1H), 6.50 (dt, J = 15.8, 1.7 Hz, 1H), 6.75 (d, J = 8.0 Hz, 1H), 6.81 (dd, J = 8.0, 1.6 Hz, 1H), 6.93 (d, J = 1.6 Hz, 1H); ^{13}C NMR δ -5.2 (q) (2C), 18.4 (s), 26.0 (q) (3C), 63.9 (t), 101.0 (t), 105.7 (d), 108.2 (d), 120.9 (d), 127.4 (d), 129.2 (d), 131.6 (s), 147.0 (s), 147.9 (s); MS (EI) *m*/*z* (relative intensity) 292(M^+, 14), 235(26), 179(6), 161(100), 131(83), 103(43), 77(19), 59(6); IR ($CHCl_3$) ν 3007, 2956, 2857, 1607, 1503, 1490, 1446, 1254, 1126, 1112, 1041, 838 cm^{-1}. Anal. Calcd for $C_{16}H_{24}O_3Si$: C, 65.71; H, 8.27. Found: C, 65.83; H, 8.38.

(2*S*,3*R*)-[3-(1,3-Benzodioxol-5-yl)-3-(buta-2,3-dienyloxy)-2-[[2-[(*S*)-1-hydroxypropyl]phenyl]selenyl]propoxy](1,1-dimethylethyl)dimethylsilane (8). To a stirred solution of diselenide **3** (254 mg, 0.59 mmol) in dry diethyl ether (24 mL) at −78 °C was added a 1 M solution of bromine in CCl_4 (0.65 mL, 0.65 mmol). After 15 min a solution of silver trifluoromethane sulfonate (360 mg, 1.4 mmol) in dry THF (0.7 mL) was added dropwise. The resulting yellowish heterogenous solution was stirred for 10 min and cooled to −100 °C. Alkene **5** was added (230 mg, 0.78 mmol) followed after 15 min by 2,3-butadien-1-ol (**7**)[16] (105 mg, 1.5 mmol). After stirring for 3 h at −100 °C the reaction mixture was quenched by adding 2,4,6-collidine (0.2 mL, 1.8 mmol) and a 7% aqueous solution of citric acid (10 mL). After warming up to room temperature the aqueous phase was extracted three times with *tert*-butyl methyl ether, and the combined organic phases were dried and concentrated. The crude material was then purified by flash-chromatography (silica gel, pentane:*tert*-butyl methyl ether 5:1) to afford **8** (250 mg, 56% yield): colorless oil; $[\alpha]^{25}_D = -36.5$ (*c* 0.53, $CHCl_3$); ^1H NMR δ 0.00 (s, 6H), 0.89 (s, 9H), 0.95 (t, J = 7.4 Hz, 3H), 1.74 (m, 2H), 2.32 (d, J = 4.4 Hz, 1H), 3.49 (dt, J = 6.4, 4.5 Hz, 1H), 3.70 (dd, J = 10.5, 6.4 Hz, 1H), 3.82 (ddt, J = 11.5, 7.6, 2.2 Hz, 1H), 4.00 (m, 2H), 4.74 (m, 3H), 5.00 (q, J = 5.9 Hz, 1H), 5.21 (dq, J = 7.6, 6.5 Hz, 1H), 5.94 (dd, J = 6.5, 1.5 Hz, 2H), 6.74 (d, J = 7.9 Hz, 1H), 6.80 (dd, J = 7.9, 1.6 Hz, 1H), 6.83 (d, J = 1.6 Hz, 1H), 7.08 (td, J = 7.7, 1.5 Hz, 1H), 7.25 (td, J = 7.7, 1.5 Hz, 1H), 7.39 (dd, J = 7.7, 1.5 Hz, 1H), 7.43 (dd, J = 7.7, 1.5 Hz, 1H); ^{13}C NMR δ -5.5 (q) (2C), 10.4 (q), 18.2 (s), 25.8 (q) (3C), 30.9 (t), 54.8 (d), 62.9 (t), 66.4 (t), 74.5 (d), 75.5 (t), 79.2 (d), 87.6 (d), 100.8 (t), 107.6 (d), 107.7 (d), 121.4 (d), 126.1 (d), 127.4 (d), 127.8 (d), 129.2 (s), 132.7 (s), 135.7 (d), 146.7 (s), 147.2 (s), 147.5 (s), 209.2 (s); ^{77}Se NMR δ 266.5; MS (EI) *m*/*z* (relative intensity) 576(M^+, 2), 449(1), 361(4), 292(6), 251(6), 203(93), 151(100), 73(30), 55(43); IR ($CHCl_3$) ν 2930, 2857, 1956, 1487, 1442, 1249, 1091, 1042, 838 cm^{-1}. Anal. Calcd for $C_{29}H_{40}O_5SeSi$: C, 60.51; H, 7.00. Found: C, 60.62; H, 7.07.

[(2*S*,3*S*,4*RS*)-[2-(1,3-Benzodioxol-5-yl)-4-vinyltetrahydrofuran-3-yl]methoxy](1,1-dimethylethyl)dimethylsilane (9). A solution of triphenyltin hydride (118 mg, 0.37 mmol), AIBN (20 mg, 0.12 mmol), and **8** (160 mg, 0.28 mmol) in toluene (60 mL) was degassed and then heated for 1 h to 90 °C. After cooling, the reaction mixture was concentrated and the residue purified by flash-chromatography (silica gel, pentane:*tert*-butyl methyl ether 20:1) affording a mixture of **9a** and **9b** (65 mg, 64% yield): colorless oil; ^1H NMR δ 0.05 (s, 6H), 0.89 (s, 9H), 2.28 (dq, J = 8.2, 6.2 Hz, 1H), 3.06 (m, 1H), 3.65 (m, 2H), 3.79 (dd, J = 8.3, 7.2 Hz, 1H), 4.17 (dd, J = 8.4,

6.9 Hz, 1H), 4.80 (d, J = 6.3 Hz, 1H), 5.09 (m, 2H), 5.86 (m, 1H), 5.94 (s, 2H), 6.74−6.88 (m, 3H); ^{13}C NMR δ -5.4 (q) (2C), 18.2 (s), 25.9 (q) (3C), 46.1 (d), 53.7 (d), 61.1 (t), 72.8 (t), 82.6 (d), 100.9 (t), 106.5 (d), 108.0 (d), 117.1 (t), 119.2 (d), 135.4 (d), 137.2 (s), 146.7 (s), 147.7 (s); MS (EI) *m*/*z* (relative intensity) 362(M^+, 13), 305(9), 275(8), 230(12), 213(18), 176(70), 161(66), 149(100), 135(68), 89(28), 75(69), 73(68), 59(44); IR ($CHCl_3$) ν 2955, 2858, 1504, 1489, 1445, 1251, 1096, 1041, 839 cm^{-1}. Anal. Calcd for $C_{20}H_{30}O_4Si$: C, 66.26; H, 8.34. Found: C, 66.10; H, 8.25.

(3*S*,4*R*,5*S*)-5-(1,3-Benzodioxol-5-yl)-4-[[[(1,1-dimethylethyl)dimethylsilyl]oxy]methyl]tetrahydrofuran-3-carboxaldehyde (10b). To a cold (0 °C) solution of **9** (90 mg, 0.25 mmol) and *N*-methylmorpholine *N*-oxide (0.35 mmol, 47 mg) in acetone (5 mL), *tert*-butyl alcohol (1 mL), and water (0.5 mL) was added OsO_4 (4 mg, 0.016 mmol). The reaction was complete after stirring for 4 h (TLC-monitored). The solvent was removed and after dissolving the residue in THF (3 mL) and water (2 mL), $NaIO_4$ (64 mg, 0.3 mmol) was added. After stirring for 8 h the reaction mixture was diluted with water and extracted three times with *tert*-butyl methyl ether. The combined organic phases were dried and concentrated. Purification of the residue by flash-chromatography (silica gel, pentane:*tert*-butyl methyl ether 3:1) yields **10a**/**b** (52 mg, 57% yield). The ratio of **10a**:**10b** was determined by ^{1}H NMR. For isomerization to **10b** the mixture of **10a**/**10b** was then dissolved in a 0.2 M NaOMe/MeOH solution (3 mL) and stirred for 2 h at 0 °C. The solvent was removed and after addition of water extracted three times with *tert*-butyl methyl ether. The combined organic phases were dried and concentrated leaving **10b** as the only product (50 mg, 55% yield): colorless oil; $[\alpha]^{25}_D$ = +14.3 (*c* 1.29, $CHCl_3$); ^{1}H NMR δ 0.05 (s, 3H), 0.06 (s, 3H), 0.90 (s, 9H), 2.49 (m, 1H), 3.13 (m, 1H), 3.65 ($^1/_2$ ABX, J_{AB} = 10.3, J = 5.1 Hz, 1H), 3.73 ($^1/_2$ ABX, J_{AB} = 10.3, J = 4.4 Hz, 1H), 4.00 (dd, J = 9.3, 8.2 Hz, 1H), 4.38 (dd, J = 9.3, 4.5 Hz, 1H), 4.58 (d, J = 8.2 Hz, 1H), 5.95 (s, 2H), 6.76 (m, 2H), 6.84 (s, 1H), 9.73 (d, J = 2.3 Hz, 1H); ^{13}C NMR δ -5.5 (q) (2C), 18.2 (s), 25.8 (q) (3C), 51.4 (d), 55.3 (d), 61.6 (t), 67.2 (t), 83.1 (d), 101.0 (t), 106.7 (d), 108.1 (d), 119.9 (d), 134.2 (s), 147.4 (s), 147.9 (s), 200.7 (d); MS (EI) *m*/*z* (relative intensity) 364(M^+, 3), 307(17), 277(14), 185(14), 161(24), 157(23), 149(38), 135(100), 131(23), 105(14), 75(33), 59(8); IR ($CHCl_3$) ν 2955, 2859, 1724, 1504, 1490, 1446, 1252, 1098, 1041, 838 cm^{-1}. Anal. Calcd for $C_{19}H_{28}O_5Si$: C, 62.61; H, 7.74. Found: C, 62.60; H, 7.83.

(1*S*,3a*R*,4*S*,6a*R*)-4-(1,3-Benzodioxol-5-yl)-tetrahydro-1*H*,3*H*-furo[3,4-*c*]furan-1-ol, (+)-Samin (11). 10b (22 mg, 0.06 mmol) was dissolved in dry THF (1 mL) at 0 °C, and a 1 M solution of tetrabutylammonium fluoride in THF (0.2 mL, 0.2 mmol) was added. After stirring for 4 h the solvent was removed and after addition of water, the residue was extracted three times with *tert*-butyl methyl ether. The combined organic phases were dried and concentrated. Purification by flash-chromatography (silica gel, pentane:*tert*-butyl methyl ether 1:2) yields **11** (10 mg, 67% yield): colorless crystals; mp 83−85 °C; $[\alpha]^{25}_D$ = +74.5 (*c* 0.49, $CHCl_3$); ^{1}H NMR δ 2.43 (s, 1H), 2.87 (dtd, J = 7.6, 7.2, 1.2 Hz, 1H), 3.08 (q, J = 8.4 Hz, 1H), 3.57 ($^1/_2$ ABX, J_{AB} = 9.1, J = 7.4 Hz, 1H), 3.91 ($^1/_2$ ABX, J_{AB} = 9.1, J = 1.0 Hz, 1H), 4.17 ($^1/_2$ ABX, J_{AB} = 9.1, J = 6.0 Hz, 1H), 4.35 (d, J = 7.1 Hz, 1H), 4.38 ($^1/_2$ ABX, J_{AB} = 9.1, J = 9.1 Hz, 1H), 5.38 (s, 1H), 5.95 (s, 2H), 6.75−6.86 (m, 3H); ^{13}C NMR δ 52.8 (d), 53.6 (d), 69.4 (t), 71.2 (t), 86. 9 (d), 101.1 (t), 102.2 (d), 106.5 (d), 108.2 (d), 119.6 (d), 134.6 (s), 147.3 (s), 148.0 (s); MS (EI) *m*/*z* (relative intensity) 250(M^+, 42), 194(10), 176(17), 150(99), 149(100), 135(22), 121(18), 115(17), 103(15), 93(15),77(25), 65(33); IR (KBr) ν 3390, 2860, 1608, 1504, 1454, 1242, 1100, 1018 cm^{-1}. Anal. Calcd for $C_{13}H_{14}O_5$: C, 62.39; H, 5.64; O, 31.97; Found: C, 62.47; H, 5.61; O, 31.73.

Acknowledgment. Support of this work by the Fonds der Chemischen Industrie with a Liebig-Stipendium to T.W. is gratefully acknowledged. The authors would like to thank Prof. B. Giese for his generous support.

Supporting Information Available: ^{1}H NMR spectra of compounds **1**, **3**, **5**, **8**, **9**, **10b**, and **11** (7 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

JO952093M