Analysis of the reactivity of the dithioacetal mono-*S*-oxide 1-deoxy-1-ethylsulfinyl-1-ethylthio-3,4-*O*-isopropylidene-D-erythritol under different conditions of reduction

Yolanda Arroyo-Gómez, Juan A. López-Sastre, J. Felix Rodríguez-Amo and Mª Ascension Sanz-Tejedor *

Departamento de Química Orgánica, Instituto de Investigación y Desarrollo Tecnológico Industrial, Universidad de Valladolid, Paseo del Cauce s/n. 47011, Valladolid, Spain

The chemistry of dithioacetal mono-*S*-oxides has not been studied very frequently. Their usual chemistry aims at recovering the carbonyl function by a sequence of reduction and hydrolysis. The results of the transformation of the dithioacetal mono-*S*-oxides of 1-deoxy-1-ethylsulfinyl-1-ethylthio-3,4-*O*-isopropylidene-D-erythritol, 2, under different reduction conditions, are reported in this paper. We also report how the coexistence of functional groups influences the resulting products. Hence, reductions with $LiAlH_4$, Ph_3P, $(Me_2N)_3P$, $(CF_3CO)_2O$–NaI and AcONa–Ac_2O under Pummerer-type rearrangements have been studied.

Introduction

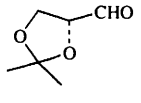
The use as synthons of sulfur derivatives, specially of those having two sulfur moieties β to each other, is a rapidly developing field in organic synthesis.[1] Among these compounds, the dithioacetal mono-*S*-oxides are particularly interesting as regards reactivity umpolung of carbonyl compounds, because their anions may be considered to be synthons of acyl anions and used in optically pure forms.[2,3]

The utility of dithioacetal mono-*S*-oxides, then, is highlighted in alkylation reactions,[3,4] cycloalkylations,[5] hydroxyalkylations,[3,6–8] aminoalkylations,[9] Michael additions[10] and acylations.[11] In most of these reactions the dithioacetal mono-*S*-oxide masks a carbonyl function, later recovered when this group is removed by acidic hydrolysis.

In spite of the synthetic interest in dithioacetals mono-*S*-oxides their use has decreased in the last years because of (i) difficulties in their preparation as pure enantiomers,[12–15] and (ii) a lack of exhaustive research on their transformation into a carbonyl group under conditions different to acidic hydrolysis. In the latter case, two consecutive steps are necessary; first, the sulfoxide group is reduced to a sulfide; second, the resulting dithioacetal is treated with mercury(II) salts. Although a large number of reagents have been described for cleaving the S–O bond of sulfoxides in the first step,[16] the efficacy of any of them has not been demonstrated when the sulfoxide of a dithioacetal mono-*S*-oxide has to be reduced.

Results and discussion

In this paper we describe the results obtained in the transformation of the dithioacetal mono-*S*-oxide 1-deoxy-1-ethylsulfinyl-1-ethylthio-3,4-*O*-isopropylidene-D-erythritol, **2** (synthesized by reaction of the anion of ethyl ethylthiomethyl sulfoxide with 2,3-*O*-isopropylidene-D-glyceraldehyde[3] **1**), under different conditions of reduction.



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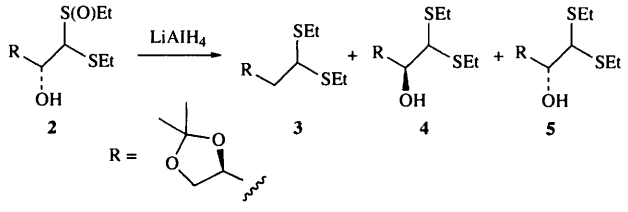
We found that the reduction of some dithioacetal mono-*S*-oxides of D-erythrose derivatives[17] with $LiAlH_4$ occurred with partial inversion of configuration at the carbon atom supporting the free hydroxy group. For this reason we have analysed the influence of both temperature and other reduction agents in this process.

Table 1 Reduction of 1-deoxy-1-ethylsulfinyl-1-ethylthio-3,4-*O*-isopropylidene-D-erythritol **2** with $LiAlH_4$



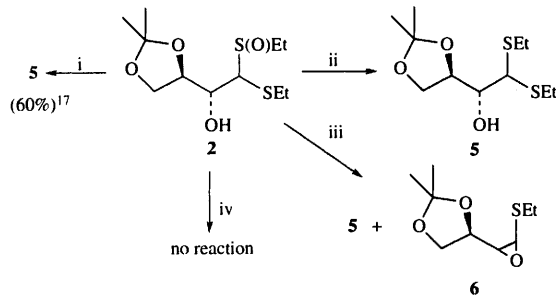
Entry	Solvent	Temp. (*T*/°C)	Proportions **3**:**4**:**5**	Yield (%)[a]
1	Et_2O	reflux	8:35:57	71
2	Et_2O	−20	11:35:54	45
3	THF	45	15:29:56	74
4	THF	reflux	71:11:18	83

[a] Isolated yield.

The reduction of compound **2** with $LiAlH_4$ was carried out in refluxing diethyl ether to afford diethyl dithioacetals of both 3,4-*O*-isopropylidene-D-threose and -D-erythrose, compounds **4** and **5**, and a small amount of the corresponding 2-deoxy derivative **3** (**3**:**4**:**5** = 8:35:57; entry 1, Table 1). Similar results were obtained when operating in diethyl ether at −20 °C (**3**:**4**:**5** = 11:35:54) and in tetrahydrofuran (THF) at 45 °C (**3**:**4**:**5** = 15:29:56), although global yields clearly decreased at low temperatures (entry 2, Table 1).

Curiously, in another experiment carried out in refluxing THF, the ratio of the three compounds changed substantially, with mainly 2-deoxy derivative **3** being obtained (**3**:**4**:**5** = 71:11:18; entry 4, Table 1). This approach would be particularly effective in the synthesis of deoxy sugars, which is of considerable interest from biological standpoints.

We have also studied the reduction of sulfoxide **2** with different trivalent phosphorus compounds in acetonitrile as solvent.[16a,18,19] So treatment of compound **2** with Ph_3P–I_2–NaI furnished dithioacetal **5** as the only reduction product but in low yield (Scheme 1). Unlike reductions with $LiAlH_4$, changes in the configuration of the carbon atom supporting the free hydroxy group were not found.

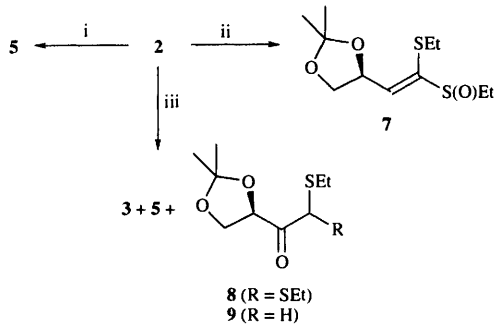


Scheme 1 *Reagents:* i, Ph_3P, CCl_4; ii, Ph_3P, I_2, NaI, MeCN; iii, Ph_3P, I_2, MeCN; iv, Ph_3P, MeCN

With the same reagent although without NaI, compound **5** was also obtained in lower yields together with the epoxide **6** as principal product; this probably formed as the result of an intramolecular nucleophilic substitution, in which the hydroxy oxygen displaced the ethylthio group (SEt).

Finally when the reaction was carried out with Ph_3P as the only reagent, the starting substrate was recovered totally unchanged after 10 days.

Another trivalent phosphorus compound used was $(Me_2N)_3P$ with and without I_2 as co-reagent. In the former experiment only the expected reduction product **5**, in yields of 40%, was obtained (Scheme 2).

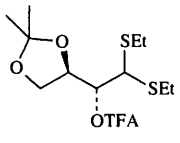


Scheme 2 *Reagents:* i, $(Me_2N)_3P$, I_2, MeCN; ii, $(Me_2N)_3P$, MeCN; iii, $(Me_2N)_3P$, CCl_4

Without I_2 only the dehydration product **7** was found, probably because of the co-ordination of the phosphorus atom of the reagent to the hydroxy group.

The sulfoxide group was reduced also when $(Me_2N)_3P$ was used in CCl_4 as solvent. However, this process lacks synthetic interest since a complex mixture of products was obtained. Among them we have identified compounds **3**, **5**, **8** and **9**.

Reaction of compound **2** with trifluoroacetic anhydride (TFAA)–NaI gave only 3,4-*O*-isopropylidene-2-*O*-trifluoroacetyl-D-erythrose diethyl dithioacetal **10**, unfortunately in moderate yields, in contrast to Resnati's findings for β-hydroxy *p*-tolyl sulfoxides.[20]



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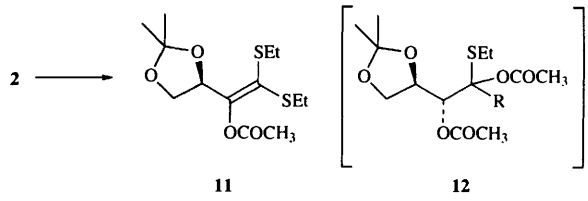
Finally we have studied the behaviour of compound **2** under Pummerer-type rearrangement.[21] So treatment of compound **2** with sodium acetate in refluxing acetic anhydride brought about production of the dithioacetal ketene **11** in good yield, perhaps as a result of the elimination of acetic acid from intermediate **12** (Scheme 3). This approach would be effective in the



Scheme 3 *Reagents and conditions:* AcONa, Ac_2O, reflux, 5 h

synthesis of polyfunctional ketene dithioacetals, whose preparation is actually limited to the reaction of carbon disulfide with appropriately functionalized carbanionic species followed by alkylation at sulfur.

These results might be compared to those found for 2-acyl-1,3-dithiane 1-oxides by Page *et al.*[22]

Experimental

Dry solvents and liquid reagents were distilled under argon immediately before use: THF and diethyl ether were distilled over sodium and benzophenone. Solutions were dried over anhydrous sodium or magnesium sulfate, and the solvent was evaporated under reduced pressure at temperature below 40 °C.

TLC was performed on glass plates coated with Silica Gel G (Merck) or SI-F-254 (Scharlau), spots being detected with iodine vapours or by charring with sulfuric acid in ethanol (10%). Column chromatography was performed using Silica Gel Merck 60 (70–230 mesh, ASTM).

Mps were determined with a Gallenkamp MFB-595 device, and optical rotations were measured at room temperature with a 141 Perkin-Elmer or an Atago 'POLAX' polarimeter. $[\alpha]_D$-Values are given in units of 10^{-1} deg cm^2 g^{-1}. ^{1}H NMR spectra for solutions in $CDCl_3$ were measured using a Bruker AC-300 spectrometer. Chemical-shift values are expressed in ppm (δ), relative to $SiMe_4$ as internal reference; signal multiplicities are noted as s, singlet; d, doublet; t, triplet, dd, double doublet; q, quartet and m, multiplet. *J*-Values are in Hz. The diastereoisomeric ratios were determined by measuring the ^{1}H NMR spectra. ^{13}C NMR spectra were recorded with a Bruker AC-300 spectrometer. IR spectra were measured using a Nicolet FTIR-20-SX spectrometer. Mass spectra were recorded by the direct insertion technique by electronic impact (EI) or chemical ionization (CI), using an HP-588-A spectrometer at 70 eV with a temperature source of 200 °C. Elemental analyses were determined with a Carlo Erba Elemental Analyzer 1106.

1-Deoxy-1-ethylsulfinyl-1-ethylthio-3,4-*O*-isopropylidene-D-erythritol 2

This was prepared as described in a previous paper.[3]

Reduction of 1-deoxy-1-ethylsulfinyl-1-ethylthio-3,4-*O*-isopropylidene-D-erythritol 2 with $LiAlH_4$

Experiment A: General procedure. To a stirred mixture of $LiAlH_4$ (300 mg, 7.9 mmol) in diethyl ether (6 ml) under argon was added a solution of compound **2** (300 mg, 1.06 mmol) in diethyl ether over a period of 10 min. The mixture was heated to reflux for 4 h and then was hydrolysed with saturated aq. diethyl ether and aq. NH_4Cl. The organic layer was separated and the aqueous phase was extracted three times with diethyl ether. The combined organic layers were dried and concentrated. The residue was found to be a mixture of compounds **3**, **4** and **5** (200 mg, 71%) in the proportions 8:35:57 (from H-3 δ-value). Separation of three diastereoisomers by column chromatography (hexane–diethyl ether 15:1) afforded in order of elution:

(a) 2-*Deoxy*-3,4-O-*isopropylidene*-D-glycero-*tetrose diethyl dithioacetal* **3** as a liquid, R_f 0.77 (hexane–diethyl ether, 1:1)

(Found: C, 52.9; H, 8.8; S, 25.5. $C_{11}H_{22}O_2S_2$ requires C, 52.75; H, 8.86; S, 25.61%); $[\alpha]_D$ +23 (*c* 0.17, $CHCl_3$); ν_{max}(KBr, liquid film)/cm^{-1} 3000, 1455, 1385, 1375, 1220, 1160, 1060, 835 and 740; δ_H($CDCl_3$) 1.27 (6 H, t, J_{vic} 7.4, CH_3CH_2S), 1.36 and 1.41 (6 H, two s, CH_3 isopropylidene), 1.88 (1 H, ddd, $J_{2,1}$ 9.7, $J_{2,3}$ 4.5, J_{gem} 14.1, H-2), 2.15 (1 H, ddd, $J_{2',1}$ 4.8, $J_{2',3}$ 8, J_{gem} 14.1, H'-2), 2.57–2.76 (4 H, m), 3.57 (1 H, dd, $J_{4,3}$ 6.7, $J_{4,4'}$ 8.0, H-4), 3.94 (1 H, dd, $J_{1,2}$ 9.8, $J_{1,2'}$ 4.8, H-1), 4.11 (1 H, dd, $J_{4',3}$ 6, $J_{4',4}$ 8.0, H'-4) and 4.38–4.46 (1 H, ten signals, J_{vic} 8.0, J'_{vic} 6.4, J''_{vic} 4.5, H-3); δ_C($CDCl_3$) 14.43 and 14.51 (CH_3CH_2S), 24.18 and 24.28 (CH_3CH_2S), 25.68 and 27.07 (CH_3 isopropylidene), 40.73 (C-2), 47.83 (C-1), 73.55 (C-4), 76.65 (C-3) and 108.92 [$C(CH_3)_2$]; *m/z* (EI) 250 (M^+, 11%), 189 ($C_9H_{17}O_2S$, 9), 101 ($C_5H_9O_2$, 100) and 43 (C_2H_3O, 24).

(b) 3,4-*O*-Isopropylidene-D-threose diethyl dithioacetal **4** as a liquid, R_f 0.6 (hexane–diethyl ether, 1:1); $[\alpha]_D$ −31 (*c* 1.7, $CHCl_3$).[17] Spectroscopic data are in agreement with those described in the literature.

(c) 3,4-*O*-Isopropylidene-D-erythrose diethyl dithioacetal **5** as a liquid, R_f 0.48 (hexane–diethyl ether, 1:1); $[\alpha]_D$ −1.6 (*c* 1.7, $CHCl_3$).[17] Spectroscopic data are in agreement with those described in the literature.

Experiment B. A solution of compound **2** (5 g, 17.7 mmol) in diethyl ether (100 ml) was treated with $LiAlH_4$ (5 g, 130 mmol) at −20 °C, as described in the General Procedure. The crude reaction mixture was found to contain a mixture of compounds **3**, **4** and **5** (2.14 g, 45%) in the proportions 11:35:54. A crop (1.6 g, 31%) of substrate **2** was recovered.

Experiment C. A solution of compound **2** (282 mg, 1 mmol) in THF (9 ml) was treated with $LiAlH_4$ (282 mg, 7.4 mmol) at 45 °C, as described in the General Procedure. The crude reaction mixture was found to contain a mixture of compounds **3**, **4** and **5** (197 mg, 74%) in the proportions 15:29:56.

Experiment D. A solution of compound **2** (5 g, 17.7 mmol) in THF (100 ml) was treated with $LiAlH_4$ (5 g, 130 mmol) at reflux, as described in the General Procedure. The crude reaction mixture was found to contain a mixture of compounds **3**, **4** and **5** (3.9 g, 83%) in the proportions 71:11:18.

Reduction of 1-deoxy-1-ethylsulfinyl-1-ethylthio-3,4-*O*-isopropylidene-D-erythritol 2 with Ph_3P[18,19a]

Experiment A. Ph_3P (1.39 g, 5.3 mmol) and I_2 (1.35 g, 5.3 mmol) was suspended in CH_3CN (10 ml) under argon. The resulting solution was cooled at 0 °C and then a solution of compound **2** (500 mg, 1.77 mmol) in CH_3CN (5 ml) was added dropwise followed by the addition of NaI (800 mg, 5.3 mmol). After being stirred at room temperature for 6 h, the reaction mixture was taken up in diethyl ether and washed successively with saturated aq. $Na_2S_2O_3$, aq. $NaHCO_3$, and brine. The combined organic layers were dried and concentrated, and the residue was chromatographed (hexane–diethyl ether, 15:1) to give compound **5** (85 mg, 20%).

Experiment B. Compound **2** (500 mg, 1.77 mmol) was treated with Ph_3P and I_2 as in the previous experiment but without NaI. The residue was chromatographed (hexane–diethyl ether, 20:1) to give two compounds isolated in order of elution as follows:

(a) 1,2-*Anhydro-1-ethylsulfinyl*-3,4-O-*isopropylidene*-D-*erythritol* **6** (233 mg, 60%) as a syrup, R_f 0.6 (hexane–diethyl ether, 5:1) (Found: C, 49.15; H, 7.3; S, 14.6. $C_9H_{16}O_4S$ requires C, 49.07; H, 7.32; S, 14.56%); $[\alpha]_D$ −303.5 (*c* 0.15, $CHCl_3$); ν_{max}(KBr, liquid film)/cm^{-1} 3050, 1455, 1385, 1375, 1270, 1220, 1160, 1080, 1050, 855 and 755; δ_H($CDCl_3$) 1.27 (3 H, t, J_{vic} 7.4, CH_3CH_2SO), 1.50 and 1.31 (6 H, 2 s, CH_3 isopropylidene), 2.53 (1 H, dq, J_{vic} 7.4, J_{gem} 13, CH_3CH_2SO), 2.67 (1 H, dq, J_{vic} 7.4, J_{gem} 13, CH_3CH_2SO), 3.98 (1 H, d, J_{gem} 10.7, H-4), 4.05 (1 H, dd, $J_{4',3}$ 3.4, J_{gem} 10.7, H'-4), 4.55 (1 H, d, $J_{2,3}$ 6, H-2), 4.78 (1 H, dd, $J_{3,2}$ 6, $J_{3,4'}$ 3.4, H-3) and 5.44 (1 H, s, H-1); δ_C($CDCl_3$) 14.74 (CH_3CH_2SO), 24.36 (CH_3CH_2SO), 24.79 and 26.20 (CH_3 isopropylidene), 70.92 (C-4), 80.26 (C-3), 85.41 (C-2), 88.69 (C-1) and 112.35 [$C(CH_3)_2$]; *m/z* (EI) 204 (M^+ − [O], 13.5%), 189 (M^+ − [O] − CH_3, 4.5), 143 ($C_7H_{11}O_3$, 79.5), 114 ($C_6H_{10}O_2$, 14), 101 ($C_5H_9O_2$, 21), 85 (C_4H_5S, 46), 59 (C_3H_7O, 7) and 57 (C_3H_5O, 100).

(b) 3,4-*O*-Isopropylidene-D-erythrose diethyl dithioacetal[17] **5** (50 mg, 10%).

Reduction of 1-deoxy-1-ethylsulfinyl-1-ethylthio-3,4-*O*-isopropylidene-D-erythritol 2 with $(Me_2N)_3P$[19]

Experiment A. I_2 (1.35 g, 5.31 mmol) was suspended in CH_3CN (18 ml) under argon. To this suspension was added $(Me_2N)_3P$ (0.96 ml, 5.31 mmol) slowly at room temperature. The resulting solution was cooled at 0 °C and then a solution of compound **2** (500 mg, 1.77 mmol) in CH_3CN (8 ml) was added dropwise. After being stirred for an additional 1 h at 0 °C, and overnight at room temp., the reaction mixture was taken up in diethyl ether and washed successively with saturated aq. $Na_2S_2O_3$, aq. $NaHCO_3$ and brine. The combined organic layers were dried, concentrated and the residue was chromatographed (hexane–diethyl ether, 15:1) to give compound **5**[17] (190 mg, 40%).

Experiment B. Compound **2** (500 mg, 1.77 mmol) was treated with $(Me_2N)_3P$ (0.96 ml) in CH_3CN as in the previous experiment but without I_2. The residue was chromatographed (hexane–diethyl ether, 2:1) to give (E)-1,2-*dideoxy*-1-*ethylsulfinyl*-1-*ethylthio*-3,4-O-*isopropylidene*-D-glycero-*tetr*-1-*enitol* **7** (187 mg, 40%) as a liquid, R_f 0.55 (diethyl ether) (Found: C, 50.0; H, 7.6; S, 24.2. $C_{11}H_{20}O_3S_2$ requires C, 49.98; H, 7.62; S, 24.25%); $[\alpha]_D$ +127.4 (*c* 0.5, $CHCl_3$); ν_{max}(KBr, liquid film)/cm^{-1} 3000, 1610, 1460, 1385, 1375, 1250, 1220, 1160, 1065, 970, 840 and 760; δ_H($CDCl_3$) 1.19 (3 H, t, J_{vic} 7.3, CH_3CH_2S), 1.30 (3 H, t, J_{vic} 7.3, CH_3CH_2SO), 1.42 and 1.45 (6 H, 2 s, CH_3 isopropylidene), 2.67–2.78 (2 H, m, CH_3CH_2S), 2.84 (1 H, dq, J_{vic} 7.3, J_{gem} 12.9, CH_3CH_2SO), 2.98–3.11 [1 H, m (six signals), J_{vic} 7.3, CH_3CH_2SO], 3.64 (1 H, dd, $J_{4,3}$ 6.9, $J_{4,4'}$ 8.2, H-4), 4.18 (1 H, dd, $J_{4',3}$ 6.5, $J_{4',4}$ 8.2, H'-4), 5.20–5.27 (1 H, m, H-3) and 6.90 (1 H, d, $J_{2,3}$ 8.2, H-2); δ_C($CDCl_3$) 4.88 (CH_3CH_2SO), 15.00 (CH_3CH_2S), 25.79 and 26.48 (CH_3 isopropylidene), 29.65 (CH_3CH_2SO), 44.67 (CH_3CH_2S), 68.91 (C-4), 73.27 (C-3), 110.18 [$C(CH_3)_2$], 139.83 (C-1) and 141.22 (C-2); *m/z* (EI) 264 (M^+, 1%), 189 ($C_9H_{17}O_2S$, 2), 161 ($C_6H_9OS_2$, 12), 145 ($C_6H_9O_2$, 3), 101 (C_5H_9O, 37) and 43 (C_2H_3O, 100).

Experiment C. Compound **2** (1.04 g, 3.69 mmol) was treated with $(Me_2N)_3P$ (1.34 ml, 7.38 mmol) as in the previous experiment but with CCl_4 (0.36 ml) as solvent. After work-up the residue was chromatographed (hexane–diethyl ether, 30:1) to give four compounds in order of elution as follows:

(a) 2-Deoxy-3,4-*O*-isopropylidene-D-*glycero*-tetrose diethyl dithioacetal **3** (28 mg, 5%); (b) 3,4-*O*-isopropylidene-D-*glycero*-2-tetrulose 1-(diethyl dithioacetal) **8** (24 mg, 2.5%) as a syrup, R_f 0.66 (hexane–diethyl ether, 2:1) (Found: C, 50.0; H, 7.6; S, 24.1. $C_{11}H_{20}O_3S_2$ requires C, 49.98; H, 7.62; S, 24.25%); $[\alpha]_D$ +96.25 (*c* 0.16, $CHCl_3$); ν_{max}(KBr, liquid film)/cm^{-1} 3000, 1715, 1455, 1385, 1375, 1220, 1155, 1070, 970, 850 and 790; δ_H($CDCl_3$) 1.26 and 1.24 (6 H, 2 t, J_{vic} 7.4, CH_3CH_2S), 1.48 and 1.41 (6 H, 2 s, CH_3 isopropylidene), 2.45–2.62 (2 H, m, CH_3CH_2S), 2.63–2.75 (2 H, m, CH_3CH_2S), 4.14 (1 H, dd, $J_{4,3}$ 5.5, $J_{4,4'}$ 8.5, H-4), 4.25 (1 H, dd, $J_{4',3}$ 7.5, $J_{4,4'}$ 8.5, H'-4), 4.87 (1 H, dd, $J_{3,4}$ 5.5, $J_{3,4'}$ 7.5, H-3) and 4.99 (1 H, s, H-1); δ_C($CDCl_3$) 13.97 and 14.14 (CH_3CH_2S), 23.54 and 24.15 (CH_3CH_2S), 25.19 and 26.04 (CH_3 isopropylidene), 52.75 (C-1), 67.23 (C-4), 77.22 (C-3) and 111.17 [$C(CH_3)_2$]; *m/z* (EI) 264 (M^+, 1%), 135 ($C_5H_{11}S_2$, 100), 101 ($C_5H_9O_2$, 26), 73 (C_3H_5S, 11) and 43 (C_2H_3O, 89); (c) 1-S-*ethyl*-3,4-O-*isopropylidene*-1-*thio*-D-glycero-2-*tetrulose* **9** (150 mg, 20%) as a syrup, R_f 0.51 (hexane–diethyl ether, 2:1) (Found: 52.8; H, 7.9; S, 15.7. $C_9H_{16}O_3S$ requires C, 52.91; H, 7.89; S, 15.70); $[\alpha]_D$ +2.93 (*c* 1.70, $CHCl_3$); ν_{max}(KBr, liquid film)/cm^{-1} 3000, 1705, 1455, 1385, 1220, 1155, 1070, 960 and 850; δ_H($CDCl_3$) 1.25 (3 H, t, J_{vic} 7.3, CH_3CH_2S), 1.40 and 1.49 (6 H, 2 s, CH_3 isopropylidene), 2.53 (2 H, c, J_{vic} 7.3, CH_3CH_2S), 3.37 (1 H, d,

J_{gem} 14.2, H-1), 3.54 (1 H, d, J_{gem} 14.2, H'-1), 4.10 (1 H, dd, $J_{4,3}$ 5.5, $J_{4,4'}$ 8.5, H-4), 4.21–4.27 (1 H, three signals, H'-4) and 4.71 (1 H, dd, $J_{3,4}$ 5.5, $J_{3,4'}$ 7.6, H-3); δ_C($CDCl_3$) 14.10 (CH_3CH_2S), 25.03 and 26.05 (CH_3 isopropylidene), 25.95 (CH_3CH_2S), 36.53 (C-1), 66.90 (C-4), 78.61 (C-3), 111.02 [$C(CH_3)_2$] and 204.61 (C-2); *m/z* (EI) 204 (M^+, 3%), 101 ($C_5H_9O_2$, 78), 75 (C_3H_7S, 38), 73 (C_3H_5S, 22) and 43 (C_2H_3O, 100); (d) 3,4-*O*-isopropylidene-D-erythrose diethyl dithioacetal **5** (30 mg, 3%).

Reduction of 1-deoxy-1-ethylsulfinyl-1-ethylthio-3,4-*O*-isopropylidene-D-erythritol 2 with TFAA–NaI[20]

To a stirred solution of compound **2** (500 mg, 1.77 mmol) in acetone (3 ml), under argon, cooled to −40 °C, was added NaI (1.1 g, 7.34 mmol), and then a solution of TFAA (2 ml, 14.38 mmol) in acetone (2 ml) was slowly added. The reaction mixture was stirred for 45 min and saturated aq. Na_2SO_3 was added (15 ml). The resulting yellow mixture was treated with saturated aq. $NaHCO_3$ (until evolution of CO_2 was finished). The acetone was evaporated off under reduced pressure and the aqueous residue was extracted with diethyl ether (3 × 30 ml). The combined organic layers were dried, concentrated, and the residue was chromatographed (methylene dichloride–diethyl ether, 100:1) to give 3,4-O-*isopropylidene*-2-O-*trifluoracetyl*-D-*erythrose diethyl dithioacetal* **10** (288 mg, 45%) as a syrup, R_f 0.78 (hexane–diethyl ether, 100:1) (Found: C, 43.2; H, 5.8; S, 17.7. $C_{13}H_{21}F_3O_4S_2$ requires C, 43.09; H, 5.85; S, 17.7%); $[\alpha]_D$ +34.9 (*c* 0.41, $CHCl_3$); ν_{max}(KBr, liquid film)/cm^{-1} 3050, 1795, 1455, 1380, 1230, 1150, 1070, 860 and 775; δ_H($CDCl_3$) 1.27 (6 H, t, J_{vic} 7.4, CH_3CH_2S), 1.36 and 1.39 (each 3 H, s, CH_3 isopropylidene), 2.66–2.77 (4 H, m, J_{vic} 7.4, CH_3CH_2S), 3.88 (1 H, dd, $J_{4,3}$ 5.8, $J_{4,4'}$ 8.7, H-4), 4.02 (1 H, d, $J_{1,2}$ 5, H-1), 4.12 (1 H, dd, $J_{4',3}$ 6.4, $J_{4',4}$ 8.7, H'-4), 4.62 (1 H, m, H-3) and 5.43 (1 H, m, H-2); δ_C($CDCl_3$) 14.17 and 14.30 (CH_3CH_2S), 25.20 and 26.35 (CH_3 isopropylidene), 25.31 and 25.59 (CH_3CH_2S), 50.62 (C-1), 65.12 (C-4), 74.32 (C-3), 77.97 (C-2) and 109.75 [$C(CH_3)_2$]; *m/z* (EI) 362 (M^+, 0.5%), 287 ($C_{10}H_{14}F_3O_2S_2$, 1), 248 ($M^+ - F_3C - CO_2H$, 1.5), 177 ($C_6H_9O_2S_2$, 4), 135 ($C_5H_{11}S_2$, 16.5), 101 ($C_5H_9O_2$, 100), 97 ($C_2F_3O_2$, 2) and 43 (C_2H_3O, 35).

Reduction of 1-deoxy-1-ethylsulfinyl-1-ethylthio-3,4-*O*-isopropylidene-D-erythritol 2 with AcONa–Ac_2O[21]

A mixture of compound **2** (4 g, 14.2 mmol) and NaOAc (2.67 g, 32.5 mmol) in Ac_2O (139 ml) is stirred and heated under reflux for 5 h . The mixture was cooled to room temp., diluted with benzene (350 ml), and concentrated *in vacuo*. The residue was dissolved in benzene (350 ml) and passed through a silica gel pad. The solution was concentrated *in vacuo* and the resulting residue was chromatographed (hexane–diethyl ether, 30:1) to give 2-O-*acetyl*-3,4-O-*isopropylidene*-D-glycero-*tetra*-1-*enose diethyl dithioacetal* **11** (3.1 g, 71%) as a liquid, R_f 0.62 (hexane–diethyl ether, 1:1) (Found: C, 50.8; H, 7.2; S, 21.0. $C_{13}H_{22}O_4S_2$ requires C, 50.95; H, 7.24; S, 20.93%); $[\alpha]_D$ +138.4 (*c* 1.06, $CHCl_3$); ν_{max}(KBr, liquid film)/cm^{-1} 3000, 1775, 1590, 1455, 1375, 1220, 1180, 1060 and 860; δ_H($CDCl_3$) 1.18 and 1.25 (6 H, 2 t, J_{vic} 7.2, CH_3CH_2S), 1.39 and 1.43 (6 H, 2 s, CH_3 isopropylidene), 2.23 (3 H, s, OAc), 2.60–2.84 (4 H, m, CH_3CH_2S), 3.81 (1 H, dd, $J_{4,3}$ 7, $J_{4,4'}$ 8.3, H-4), 4.10 (1 H, dd, $J_{4',3}$ 7, $J_{4',4}$ 8.3, H'-4) and 5.61 [1 H, dd (three signals), $J_{3,4} = J_{3,4'} = 7$, H-3]; δ_C($CDCl_3$) 14.52 and 14.91 (2 × CH_3CH_2S), 20.52 ($OCOCH_3$), 25.63 and 25.97 (CH_3 isopropylidene), 26.72 and 27.53 (2 × CH_3CH_2S), 67.05 (C-4), 73.67 (C-3), 110.01 [$C(CH_3)_2$], 125.08 (C-2), 149.77 (C-1) and 168.09 ($OCOCH_3$); *m/z* (EI) 306 (M^+, 2%), 264 ($C_{11}H_{20}O_3S_2$, 4), 248 ($C_{11}H_{20}O_2S_2$, 3), 177 ($C_7H_{13}OS_2$, 36), 162 ($C_6H_{10}OS_2$, 5), 134 ($C_5H_{10}S_2$, 4) and 43 (C_2H_3O, 100).

Acknowledgements

Thanks are due to Junta de Castilla y Leon for financial support and to Pedro A. Fuertes for the English translation.

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Paper 6/02561G
Received 12*th April* 1996
Accepted 9*th August* 1996