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SELENIUM DERIVATIVES OF L-ARABINOSE, D-RIBOSE, AND D-XYLOSE

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ABSTRACT

Attempted cyclization of 2,3,4-tri-*O*-methyl-5-seleno-L-arabinose dimethyl acetal in acidic solution gave the corresponding diselenide. Intramolecular attack by the selenobenzyl group at C-5 of 5-*O*-*p*-tolylsulfonyl-L-arabinose dibenzyl diselenoacetal resulted in the formation of benzyl 1,5-diseleno-L-arabinopyranoside. Similarly, 2,3,5-tri-*O*-methyl-4-*O*-*p*-tolylsulfonyl-D-xylose dibenzyl diselenoacetal gave benzyl 2,3,5-tri-*O*-methyl-1,4-diseleno-L-arabinofuranoside, and 2,3,4-tri-*O*-acetyl-5-*O*-*p*-tolylsulfonyl-D-xylose (or ribose) dibenzyl diselenoacetal gave benzyl 2,3,4-tri-*O*-acetyl-1,5-diseleno-D-xylo- (or ribo-)pyranoside. The glycosylic benzylseleno group was removed from the pyranoside with mercuric acetate, but attempted deacetylation of the product led to decomposition and not to the expected 5-seleno-D-xylopyranose.

INTRODUCTION

The introduction of a sulfur or nitrogen atom as the hetero-atom in pyranose and furanose rings of a variety of monosaccharides has been very successful[1]. However, when the synthetic methods that had been used for the formation of the thio sugars were applied to the introduction of a selenium atom as the sugar ring hetero-atom, they usually failed. The formation of a selenol group at the terminal position of various *O*-methylpentose derivatives, and treatment with methanolic hydrogen chloride led to the formation of the corresponding diselenides[2], instead of derivatives that contained selenium as the hetero-atom in the ring. Treatment of 1,2-*O*-isopropylidene-5-seleno-D-xylofuranose with methanolic hydrogen chloride did not give the desired methyl 5-seleno-D-xylopyranose but, instead, dehydration between C-2 and C-5 resulted in the formation of D-*threo*-2,3,4,5-tetrahydro-3,4-dihydroxy-2-selenophene-2-carbaldehyde dimethyl acetal[3].

DISCUSSION

5-*O*-*p*-Tolylsulfonyl-L-arabinose diethyl dithioacetal[4] was acetylated and the product (**1**) treated with mercuric chloride in neutral methanol to give the cor-

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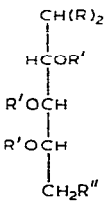
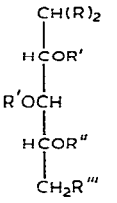
responding dimethyl acetal **2**. Treatment of **2** with phenylmethaneselenol[3] gave 2,3,4-tri-*O*-acetyl-5-*Se*-benzyl-5-seleno-L-arabinose dimethyl acetal (**3**). Methylation of **3** with dimethyl sulfate and potassium hydroxide gave a complex mixture, some of the components having arisen by attack at C-5 in alkaline solution. In an alternative approach to introducing a selenol group at C-5 in L-arabinose, methyl β-L-arabinopyranoside[5] (**25**) was methylated to form methyl 2,3,4-tri-*O*-methyl-β-L-arabinopyranoside (**26**) which, on treatment with ethanethiol in acidic solution, gave 2,3,4-tri-*O*-methyl-L-arabinose diethyl dithioacetal (**4**). Treatment of **4** with mercuric chloride in neutral methanol gave the corresponding dimethyl acetal **5**. *p*-Toluenesulfonylation of **5** gave the 5-*O*-tosyl compound **6**. Reaction of **6** with potassium selenocyanate and subsequent treatment of the crude 5-selenocyanate **7** with alkali gave the diselenide **8**. In an attempt to introduce a selenium atom into the arabinopyranose ring, the diselenide **8** was reduced with a methanolic solution of hydrogen chloride and hypophosphorous acid[6]. The presence of the selenol compound was shown by a positive 2,6-dichlorophenol–indophenol test[6]. However, the only product isolated was the unchanged diselenide **8**.

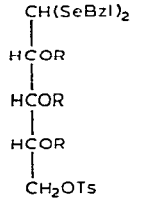
A different approach to the introduction of a selenium atom into the sugar ring was explored. Harness and Hughes[7] reported that intramolecular attack, by a thiobenzyl group, on the tosyloxy group of 5-*O*-*p*-tolylsulfonyl-L-arabinose dibenzyl dithioacetal (**9**), resulted in the formation of benzyl 1,5-dithio-L-arabinopyranosides (**43**), and we reported[8] an extension of this reaction to the formation of benzyl 1,4-dithio-furanosides. In the present work, the required diselenoacetals were prepared by the action of phenylmethaneselenol on the appropriate sugar in acidic solution. On mono-*p*-toluenesulfonylation, D-xylose dibenzyl diselenoacetal (**12**) gave mainly unchanged starting material (**12**) and a small amount of 2,5-anhydro-D-xylose dibenzyl diselenoacetal (**37**). A similar observation has been reported[9] for D-xylose dibenzyl dithioacetal (**38**). On treatment with mercuric chloride in neutral methanol, the 3,4-di-*O*-acetyl derivative (**39**) gave the known[10] 3,4-di-*O*-acetyl-2,5-anhydro-D-xylose dimethyl acetal (**40**). On treatment with *p*-toluenesulfonyl chloride, L-arabinose dibenzyl diselenoacetal (**10**) gave the 5-*O*-tosyl derivative which, without purification, was treated with iodide ions in neutral acetone, to give a small proportion of benzyl 1,5-diseleno-L-arabinopyranoside (**44**). The mass spectrum of **44** showed a molecular ion peak at *m/e* 368 (the isotopic peak intensities showed the presence of two selenium atoms), and **44** rapidly consumed 2.4 moles of periodate, followed by a slower uptake of periodate. This slower uptake may be ascribed to the oxidation of the selenide to a selenoxide group[11]. The acyl derivative of **44** was analyzed by n.m.r. and showed the presence of the expected three acetyl and one benzyl groups. Hydrolysis of **44** in acidic methanol was very slow but a trace of phenylmethaneselenol could be detected. Reductive removal of selenium from **44** with Raney nickel, followed by acetylation, gave 2,3,4-tri-*O*-acetyl-1,5-dideoxy-L-arabinitol[12] (**11**), which was also obtained by reductive desulfurization of benzyl 1,5-dithio-L-arabinopyranoside[7] (**43**). The introduction of a selenium atom into the furanose ring was accomplished by *p*-toluenesulfonylation of 2,3,5-tri-*O*-methyl-D-xylose dibenzyl diselenoacetal (**13**) and



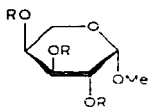
1 R = SEt, R′ = Ac, R″ = Ts
2 R = OMe, R′ = Ac, R″ = Ts
3 R = OMe, R′ = Ac, R″ = SeBzl
4 R = SEt, R′ = Me, R″ = OH
5 R = OMe, R′ = Me, R″ = OH
6 R = OMe, R′ = Me, R″ = Ts
7 R = OMe, R′ = Me, R″ = SeCN
8 R = OMe, R′ = Me, R″ = Se–)$_2$
9 R = SBzl, R′ = H, R″ = Ts
10 R = SeBzl, R′ = H, R″ = OH
11 R = H, R′ = Ac, R″ = H



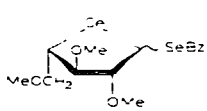
12 R = SeBzl, R′ = R″ = H, R‴ = OH
13 R = SeBzl, R′ = Me, R″ = H, R‴ = OMe
14 R = SBzl, R′ = R″ = Ac, R‴ = Ts
15 R = SBzl, R′ = R″ = Bz, R‴ = Ts
16 R = SeBzl, R′ = R″ = H, R‴ = Ts
17 R = SeBzl, R′ = R″ = Ac, R‴ = Ts
18 R = OAc, H, R′ = R″ = Ac, R‴ = H
19 R = OMe, R′ = R″ = Ac, R‴ = SeBzl
20 R = SEt, R′ = R″ = H, R‴ = SeBzl
21 R = SEt, R′ = R″ = Ac, R‴ = SeBzl
22 R = SeBzl, R′ = R″ = Bz, R‴ = Ts



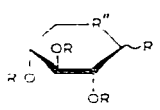
23 R = Ac
24 R = H



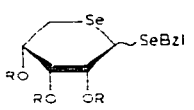
25 R = H
26 R = Me



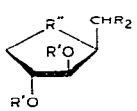
27



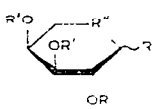
28 R = SBzl, α-anomer R′ = Ac, R″ = S
29 R = SBzl, β-anomer, R = Ac, R′ = S
30 R = OH, R = H, R″ = S
31 R = Br, R′ = Ac, R′ = S
32 R = SBzl, R′ = Bz, R″ = S
33 R = SeBzl, R′ = Ac, R″ = Se
34 R = SeBzl, R′ = Bz, R″ = Se
35 R = R = Ac, R″ = Se
45 R = OMe, R′ = Ac, R″ = Se



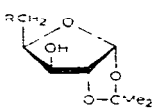
36 R = Ac



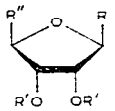
37 R = SeBzl, R′ = H, R″ = O
38 R = SBzl, R′ = H, R″ = O
39 R = SeBzl, R′ = Ac, R″ = O
40 R = OMe, R′ = Ac, R″ = O
41 R = SBzl, R′ = Ac, R″ = O
42 R = OMe, R′ = H, R″ = Se



43 R = SBzl, R′ = H R = S
44 R = SeBz, R′ = H, R″ = Se



46 R = OTs
47 R = SeBzl



48 R = OMe, R′ = CMe$_2$, R″ = CH$_2$OTs
49 R = CH(SeBzl)$_2$, R′ = Ac, R″ = H

treatment of the crude 4-*O*-tosyl compound with iodide ions in neutral acetone to give benzyl 2,3,5-tri-*O*-methyl-1,4-diseleno-L-arabinofuranoside (**27**). The n.m.r. spectrum of **27** showed the presence of three methoxyl and one benzyl groups, and its mass spectrum the molecular ion at *m/e* 410 and other peaks expected for this type of compound.

The difficulty of removal of methoxyl groups was an obstacle in the preparation of seleno- or thio-sugars with the hetero atom in a furanose ring by the method used for **27**. A more convenient starting material for the formation of these sugars would be 5-*O*-*p*-tolylsulfonyl-D-pentose dibenzyl diseleno(thio)acetals but in basic or neutral solution, these compounds rapidly gave the corresponding 2,5-anhydro-D-pentose derivatives[13]. With sodium iodide in neutral acetone, 2,3,4-tri-*O*-acetyl-5-*O*-*p*-tolylsulfonyl-D-xylose dibenzyl dithioacetal (**14**) gave benzyl 2,3,4-tri-*O*-acetyl-1,5-dithio-α-D-xylopyranoside (**28**) and 3,4-di-*O*-acetyl-2,5-anhydro-D-xylose dibenzyl dithioacetal (**41**). Compound **28** and its β anomer **29** were also formed by the action of phenylmethanethiol on 5-thio-D-xylose[14] (**30**). Compound **29** was also obtained from 2,3,4-tri-*O*-acetyl-5-thio-D-xylopyranosyl bromide[15] (**31**) with phenylmethanethiolate ion. Similarly, 2,3,4-tri-*O*-benzoyl-5-*O*-*p*-tolylsulfonyl-D-xylose dibenzyl dithioacetal (**15**) gave the thio sugar benzyl 2,3,4-tri-*O*-benzoyl-1,5-dithio-α-D-xylopyranoside (**32**).

Treatment of 1,2-*O*-isopropylidene-5-*O*-*p*-tolylsulfonyl-α-D-xylofuranose (**46**) with phenylmethaneselenol in acidic solution gave crystalline, unstable 5-*O*-*p*-tolylsulfonyl D-xylose dibenzyl diselenoacetal (**16**). Compound **16** in pyridine or neutral acetone gave 2,5-anhydro-D-xylose dibenzyl diselenoacetal (**37**). Cyclization of 2,3,4-tri-*O*-acetyl-5-*O*-*p*-tolylsulfonyl-D-xylose dibenzyl diselenoacetal (**17**) gave benzyl 2,3,4-tri-*O*-acetyl-1,5-diseleno-α-D-xylopyranoside (**33**) and the anhydro compound **39**. Similarly, the benzoate derivative **22** gave the corresponding seleno sugar **34**. Benzyl 2,3,4-tri-*O*-acetyl-1,5-diseleno-D-ribopyranoside (**36**) was prepared, in the same manner as **33**, from the acetyl derivative **23** of 5-*O*-*p*-tolylsulfonyl-D-ribose dibenzyl diselenoacetal (**24**) which was obtained as an unstable syrup from methyl 2,3-*O*-isopropylidene-5-*O*-*p*-tolylsulfonyl-β-D-ribofuranoside[16] (48) and phenylmethaneselenol in acidic solution.

The removal of the benzylseleno group from both glycosides **33** and **36** by hydrolysis in acidic solution was extremely slow, in agreement with the observations of Clayton and Hughes on the hydrolysis of thioglycosides of 5-deoxy-5-thio-D-ribose[17]. Acetolysis of the glycoside **33** with 9:1 acetic anhydride–sulfuric acid at room temperature resulted in extensive decomposition, as a large amount of elemental selenium separated from the reaction mixture. The glycosidic benzylseleno group was successfully removed from **33** with mercuric acetate in acetic acid for 4 h at 45–50° to give 1,2,3,4-tetra-*O*-acetyl-5-seleno-D-xylopyranosides (**35**). Reductive removal of selenium from **35** with Raney nickel gave 1,2,3,4-tetra-*O*-acetyl-5-deoxy-D-xylitol (**18**) Compound **18** was also synthesized from 5-deoxy-D-xylose[18] by reduction with sodium borohydride followed by acetylation. Methanolysis of the *O*-acetyl derivative **35** gave D-*threo*-2,3,4,5-tetrahydro-3,4-dihydroxy-2-selenophene-2-carbaldehyde dimethyl acetal (**42**). The removal of the acetate groups from **35** in methanol with a

catalytic amount of sodium methoxide resulted in extensive decomposition, accompanied by the formation of elemental selenium. In an attempt to form the methyl glycoside **45**, the selenobenzyl glycoside **33** was treated with mercuric chloride in neutral methanol. However, only unchanged starting material **33** and a rearrangement product, 2,3,4-tri-*O*-acetyl-5-*Se*-benzyl-5-seleno-D-xylose dimethyl acetal (**19**) were recovered. The n.m.r. spectrum of **19** showed the presence of one benzyl-, two methoxyl-, and three acetate groups. Its mass spectrum showed a molecular ion at *m/e* 476, containing one atom of selenium and an intense peak at *m/e* 75, characteristic for dimethyl acetals. Compound **19** was also synthesized by the action of ethanethiol on 5-*Se*-benzyl-1,2-*O*-isopropylidene-5-seleno-α-D-xylofuranose[2] (**47**) to give the crystalline 5-*Se*-benzyl-5-seleno-D-xylose diethyl dithioacetal (**20**), which was then acetylated, and the di-*O*-acetyl dithioacetal **21** was converted into the dimethyl acetal **19** by treatment with mercuric chloride in neutral methanol.

EXPERIMENTAL

General methods. — Column chromatography was performed on Merck Silica gel (60–200 mesh). I.r. spectra were determined with a Perkin–Elmer 700 spectrometer and n.m.r. spectra with a Varian T-60 spectrometer with tetramethylsilane as internal standard. Mass spectra were determined with a Hitachi–Perkin–Elmer RMU-7 mass spectrometer. G.l.c. analysis was performed with a Bendix Gas Chromatograph 2600 equipped with a column (1.8 m) containing 10% of EGSS-X on Gas-Chrom P (Applied Sciences Labs., State College, Pa. 16801, U.S.A.) with nitrogen as the carrier gas. High-pressure liquid chromatography (h.p.l.c.) analysis was performed on a column (3.2 × 250 mm) of Lichrosorb (5 μm, Merck) at 160 atm. with hexane–dichloromethane–2-propanol as eluent, and an Altex detector at 254 nm.

*2,3,5-Tri-*O*-acetyl-5-*O*-p-tolylsulfonyl-*L*-arabinose dimethyl acetal* (**2**). — 2,3,5-Tri-*O*-acetyl-5-*O*-*p*-tolylsulfonyl-L-arabinose diethyl dithioacetal (**1**, 2.4 g), mercuric chloride (5.0 g), cadmium carbonate (8.0 g), and methanol (30 ml) were stirred for 6 h at room temperature and heated under reflux for 2 h. The suspension was filtered and the residue repeatedly washed with chloroform. The filtrate was successively washed with water, potassium cyanide solution, and water, dried, and evaporated to a syrup. Chromatography with 1:19 (v/v) methanol–benzene gave **2** as a syrup (1.7 g), $[\alpha]_D^{25}$ −36° (*c* 0.8, chloroform); n.m.r. (chloroform-*d*): δ 2.00, 2.08 (s, 9 H, $OCOCH_3$), 2.46, (s, 3 H, $C_6H_4CH_3$), 3.30, 3.36 (s, 6 H, OCH_3), and 7.40, 7.84 (doublet of doublets, C_6H_4).

Anal. Calc. for $C_{20}H_{28}O_{11}S$: C, 50.4; H, 5.9. Found: C, 50.1; H, 5.9.

*2,3,5-Tri-*O*-acetyl-5-*Se*-benzyl-5-seleno-*L*-arabinose dimethyl acetal* (**3**). — The tosyl ester **2** (1.8 g) was heated under reflux with methanol (40 ml) containing sodium methoxide (from 0.50 g of sodium) and phenylmethaneselenol (4.0 g) for 4 h in an atmosphere of nitrogen. The solution was extracted with chloroform and water. The chloroform extracts were evaporated and the residue treated overnight with pyridine (10 ml) and acetic anhydride (10 ml). Chromatography of the crude acetate with

3:37 (v/v) methanol–benzene gave **3** (1.5 g), $[\alpha]_D^{20}$ −50° (*c* 2.2, chloroform); n.m.r. (chloroform-*d*): δ 2.07, 2.10 (s, 9 H, $OCOCH_3$), 3.34, 3.37 (s, 6 H, OCH_3), 3.77 (s, 2 H, $CH_2C_6H_5$), and 7.28 (s, 5 H, C_6H_5).

Anal. Calc. for $C_{20}H_{28}O_8Se$: C, 50.4; H, 5.9. Found: C, 50.2; H, 5.7.

2,3,4-Tri-O-methyl-L-arabinose diethyl dithioacetal (**4**). — Methyl 2,3,4-tri-*O*-methyl-β-L-arabinopyranoside[8] (5.0 g), ethanethiol (5 ml), and concentrated hydrochloric acid (5 ml) were stirred for 12 h at room temperature. The reaction mixture was extracted with chloroform and water. The chloroform extracts were washed with sodium hydrogencarbonate solution and water, dried, and evaporated to a syrup (6.9 g). Chromatography in 1:39 (v/v) methanol–benzene gave **4** (5.19 g), $[\alpha]_D^{20}$ +63° (*c* 0.64, chloroform); n.m.r. (chloroform-*d*): δ 1.30 (t, 6 H, *J* 7.8 Hz, SCH_2CH_3), 2.68 (q, 4 H, *J* 7.8 Hz, SCH_2CH_3), and 3.46, 3.64 (s, 9 H, OCH_3).

Anal. Calc. for $C_{12}H_{26}O_4S_2$: C, 48.3; H, 8.7. Found: C, 48.4; H, 8.5.

2,3,4-Tri-O-methyl-L-arabinose dimethyl acetal (**5**). — The dithioacetal **4** (4.0 g) was heated under reflux with methanol (40 ml), cadmium carbonate (7.0 g), and mercuric chloride (4.0 g) for 6 h. The reaction mixture was treated as described for **2**, giving a syrup (3.5 g), $[\alpha]_D^{21}$ +98° (*c* 0.50, chloroform).

Anal. Calc. for $C_{10}H_{22}O_6$: C, 50.4, H, 9.2. Found: C, 50.0; H, 9.3.

5,5'-Diselenobis(2,3,4-tri-O-methyl-L-arabinose dimethyl acetal) (**8**). — The dimethyl acetal **5** (3.0 g) in pyridine (15 ml) was treated with *p*-toluenesulfonyl chloride (3.0 g). The solution was kept overnight at room temperature. Sufficient water was added to hydrolyze the excess *p*-toluenesulfonyl chloride. The mixture was extracted with chloroform and water. The chloroform extracts were successively washed with water, ice-cold hydrochloric acid, sodium hydrogencarbonate solution, and water, and dried. The solution was evaporated and the crude tosyl compound **6** was heated under reflux for 20 min with *N*,*N*-dimethylformamide (20 ml) and potassium selenocyanide (5.0 g). The reaction mixture was evaporated and the residue treated with chloroform and water. The chloroform extracts were dried and evaporated to give the crude selenocyanate **7** as a syrup (2.5 g). This product was dissolved in methanol (50 ml) which contained sodium methoxide (from 0.25 g of sodium), and the solution was stored at room temperature overnight. The solution was neutralized with IR-120 (H^+) cation-exchange resin, and the neutral solution evaporated to a syrup. Chromatography with 1:19 (v/v) methanol–benzene gave **8** as a syrup (1.8 g), $[\alpha]_D^{21}$ −26° (*c* 0.60, chloroform).

Anal. Calc. for $C_{20}H_{42}O_{10}Se_2$: C, 39.9; H, 7.0. Found: C, 39.8; H, 7.0.

The diselenide **8** (1.0 g), 2% hydrogen chloride in methanol (25 ml), and hypophosphorous acid (50%, 1 ml) were heated under reflux for 2 h. The solution was neutralized with Dowex 45 (OH^-) anion-exchange resin, and the neutral solution evaporated to a syrup which consisted of unchanged **8**.

D-Xylose dibenzyl diselenoacetal (**12**). — D-Xylose (3.0 g), concentrated hydrochloric acid (10 ml), and phenylmethaneselenol (9.0 g) were stirred for 3 h. The solution was neutralized with Dowex 45 (OH^-) anion-exchange resin, and the neutral

solution evaporated. The residue was acetylated with pyridine and acetic anhydride, and purified from dibenzyl diselenide by chromatography in 1:12 (v/v) methanol–benzene to give the 2,3,4,5-tetra-*O*-acetyl derivative of **12** as a syrup (3.8 g), $[\alpha]_D^{25}$ −25° (*c* 3.74, chloroform); n.m.r. (chloroform-*d*): δ 2.06 (s, 12 H, $OCOCH_3$), and 7.27, 7.30 (s, 10 H, C_6H_5).

Anal. Calc. for $C_{25}H_{30}O_7Se_2$: C, 49.8; H, 5.0. Found: C, 49.7; H, 5.0.

This acetate was deacetylated with a small amount of sodium methoxide in methanol to give **12** as a syrup, $[\alpha]_D^{25}$ −100° (*c* 10.0, chloroform).

Anal. Calc. for $C_{19}H_{24}O_4Se_2$: C, 47.9; H, 5.0. Found: 47.8; H, 5.1.

p-*Toluenesulfonylation of* **12**. — *p*-Toluenesulfonyl chloride (0.11 g) was slowly added to **13** (0.25 g), in pyridine (3 ml) while the solution was kept at −10°. The reaction mixture was allowed to warm to room temperature and stored overnight. Acetic anhydride (3 ml) was added and the reaction mixture stored for an additional 12 h. The reaction mixture was treated as described for **6**. Chromatography of the resultant syrup with 1:19 (v/v) methanol–benzene gave **39** (0.05 g), $[\alpha]_D^{25}$ +60° (*c* 1.81, chloroform); n.m.r. (chloroform-*d*): δ 1.70, 2.04 (s, 6 H, $OCOCH_3$), 3.86 (s, 4 H, $CH_2C_6H_5$), and 7.17, 7.35 (s, 10 H, C_6H_5).

Anal. Calc. for $C_{23}H_{26}O_5Se_2$: C, 50.9; H, 4.8. Found: C, 51.1; H, 4.7.

Further elution gave the tetra-*O*-acetyl derivative of **12** (0.25 g).

*3,4-Di-*O*-acetyl-2,5-anhydro-*D*-xylose dimethyl acetal* (**40**). — Compound **39** (0.20 g), methanol (10 ml), cadmium carbonate (1.0 g), and mercuric chloride (0.5 g) were heated under reflux overnight. The reaction product was isolated as described for **2**. The syrupy product was identical to compound[10] **40** by i.r. spectral analysis and g.l.c. retention time.

L-*Arabinose dibenzyl diselenoacetal* (**10**). — This compound was prepared in the same manner as described for the D-xylose derivative **12** (yield, 2.8 g), m.p. 132–133° (from methanol), $[\alpha]_D^{29}$ −87° (*c* 1.2, chloroform).

Anal. Calc. for $C_{19}H_{24}O_4Se_2$: C, 47.9; H, 5.0. Found: C, 47.8; H, 5.1.

2,3,4,5-Tetra-*O*-acetyl derivative: $[\alpha]_D^{29}$ −57° (*c* 8.2, chloroform); n.m.r. (chloroform-*d*): δ 2.05 (s, 12 H, $OCOCH_3$), and 7.27, 7.34 (s, 10 H, C_6H_5).

Anal. Calc. for $C_{23}H_{26}O_5Se_2$: C, 50.9; H, 4.8. Found: C, 50.6; H, 4.9.

*Benzyl 1,5-diseleno-*L*-arabinopyranoside* (**44**). — A solution of **10** (1.0 g) in pyridine (10 ml) was treated with *p*-toluenesulfonyl chloride (0.90 g) at −10°. The solution was treated as described for **6** and the crude *p*-tolylsulfonyl derivative was heated under reflux overnight in acetone (30 ml) containing barium carbonate (5.0 g) and sodium iodide (5.0 g). The reaction mixture was filtered and the residue repeatedly washed with chloroform. The filtrate was washed with water, sodium thiosulfate solution, and water, and dried. The solution was evaporated to a syrup, and chromatography with 1:7 (v/v) methanol–benzene gave **44**, m.p. 93–94° (from ethyl acetate–hexane), $[\alpha]_D^{21}$ +274° (*c* 0.20, chloroform); periodate consumption: 1.2 moles (20 min), 2.4 moles (40 min), 2.6 moles (60 min), and 3.3 moles (120 min). Under the same reaction conditions, benzyl 1,5-dithio-L-arabinopyranoside[7] (**43**) consumed 1.0 mole (20 min) and 1.9 moles (60 min) of periodate.

Anal. Calc. for $C_{12}H_{16}O_3Se_2$: C, 39.1; H, 4.3; mol. wt. 368. Found: C, 39.0; H, 4.3, mol. wt. 368 (by m.s.).

2,3,4-Tri-*O*-acetyl derivative of **44**: syrup; n.m.r. (chloroform-*d*): δ 1.98, 2.00, 2.08 (s, 9 H, $OCOCH_3$), 3.88 (s, 2 H, $CH_2C_6H_5$), and 7.26 (s, 5 H, C_6H_5).

Anal. Calc. for $C_{18}H_{22}O_6Se_2$: C, 43.7; H, 4.5. Found: C, 43.6; H, 4.5.

*2,3,4-Tri-*O*-acetyl-1,5-dideoxy-*L*-arabinitol*[12] (**11**). — Compound **19** (0.25 g), absolute ethanol (30 ml), and an excess of Raney nickel (~4 g) were heated under reflux overnight. The reaction mixture was filtered and the nickel repeatedly extracted with boiling ethanol. The filtrate was evaporated and the residue acetylated with pyridine and acetic anhydride. Chromatography of the crude acetate with 1:39 (v/v) methanol–benzene gave **11** (0.04 g) which was identical by i.r., n.m.r., m.s., and g.l.c. with a sample of the known compound[12] and with the product obtained by Raney nickel treatment of benzyl 1,5-dithio-L-arabinopyranoside[7] (**43**); n.m.r. (chloroform-*d*): δ 1.16, 1.27 (s, 6 H, CH_3), and 2.05, 2.15 (s, 9 H, $OCOCH_3$); g.l.c. retention time (155°) 7.70 min.

*2,3,5-Tri-*O*-methyl-*D*-xylose dibenzyl diselenoacetal* (**13**). — Methyl 2,3,5-tri-*O*-methyl-D-xylofuranosides (3.0 g), concentrated hydrochloric acid, and phenylmethaneselenol (9.0 g) were stirred for 3 h at room temperature. The reaction mixture was extracted with chloroform and water. The chloroform extracts were washed with sodium hydrogencarbonate solution and water, dried, and evaporated to a syrup. Chromatography with 1:19 (v/v) methanol–benzene gave **13** (3.5 g), $[\alpha]_D^{21}$ +45° (*c* 1.2, chloroform).

Anal. Calc. for $C_{22}H_{30}O_4Se_2$: C, 51.0; H, 5.8. Found: C, 50.7; H, 5.7.

*Benzyl 2,3,5-tri-*O*-methyl-1,4-diseleno-*L*-arabinofuranosides* (**27**). — Compound **27** was prepared from **13** as described for **44**, syrup, $[\alpha]_D^{21}$ +59° (*c* 1.95, chloroform); n.m.r. (chloroform-*d*): δ 3.30, 3.34, 3.40 (s, 9 H, OCH_3), and 7.20, 7.27 (s, 5 H, C_6H_5).

Anal. Calc. for $C_{15}H_{22}O_3Se_2$: C, 43.9; H, 5.4; mol. wt. 410. Found: C, 44.1; H, 5.5; mol. wt. 410 (m.s.).

*2,3,4-Tri-*O*-acetyl-5-*O*-p-tolylsulfonyl-*D*-xylose dibenzyl dithioacetal* (**14**). — From 5-*O*-*p*-tolylsulfonyl-D-xylose dibenzyl dithioacetal[13] by treatment with pyridine and acetic anhydride, syrup, $[\alpha]_D^{25}$ −50° (*c* 1.1, chloroform); n.m.r. (chloroform-*d*): δ 1.88, 1.92, 2.02 (s, 9 H, $OCOCH_3$), 2.35 (s, 3 H, $C_6H_4CH_3$), 3.72 (s, 4 H, $C_6H_5CH_2$), and 7.20 (s, 10 H, C_6H_5) (C_6H_4 partially obscured).

*Benzyl 2,3,4-tri-*O*-acetyl-1,5-dithio-α-*D*-xylopyranoside* (**28**). — Compound **14** (6.5 g) was treated with iodide ions as described for **44**. The syrupy product was shown by h.p.l.c. to consist of two main components, namely **28** and the 2,5-anhydro compound[13] **41**, and a small amount of β-D-glycoside **29**. Chromatography with 1:39 (v/v) methanol–benzene gave **41** (1.22 g) and the glycoside **28** (0.73 g), m.p. 108–109° (from ethyl acetate–hexane), $[\alpha]_D^{21}$ +346° (*c* 0.21, chloroform); n.m.r. (chloroform-*d*): δ 1.93, 1.97, 2.00 (s, 9 H, $OCOCH_3$), 3.80 (s, 2 H, $C_6H_5CH_2$), and 7.22 (s, 5 H, C_6H_5).

Anal. Calc. for $C_{18}H_{22}O_6S_2$: C, 54.3; H, 5.5. Found: C, 54.4; H, 5.6.

Deacetylation of **28** with sodium methoxide in methanol gave benzyl 1,5-dithio-

α-D-xylopyranoside m.p. 133° (from ethyl actate), $[\alpha]_D^{21}$ +335° (*c* 0.40, chloroform).

Anal. Calc. for $C_{12}H_{16}O_3S_2$: C, 52.9; H, 5.9. Found: C, 52.9; H, 5.8.

*Benzyl 2,3,4-tri-*O*-acetyl-1,5-dithio-*D*-xylopyranosides* (**28** *and* **29**). — (*a*). 5-Thio-D-xylopyranose (**30**, 1.5 g), concentrated hydrochloric acid (5 ml), and phenylmethanethiol (3.0 g) were stirred for 3 h at room temperature. The reaction mixture was treated as described for **12**. Chromatography with 1:39 (v/v) methanol–benzene gave **28** (0.40 g) and **29** (0.95 g), m.p. 124–126° (from ethyl acetate–hexane), $[\alpha]_D^{21}$ −67° (*c* 0.42, chloroform).

Anal. Calc. for $C_{18}H_{22}O_6S_2$: C, 54.3; H, 5.5. Found: C, 54.3; H, 5.4.

(*b*). 1,2,3,4-Tetra-*O*-acetyl-5-thio-D-xylopyranosyl bromide[15] (**31**, 1.9 g), phenylmethanethiol (0.50 g), methanol (20 ml), and sodium methoxide (from 0.09 g of sodium) were allowed to react overnight at room temperature. The reaction mixture was neutralized with IR 120 (H^+) cation-exchange resin and evaporated. The residue was acetylated with pyridine and acetic anhydride. Chromatography of the crude acetate with 1:39 (v/v) methanol–benzene gave **29** (0.85 g), m.p. 124–126°.

*Benzyl 2,3,4-tri-*O*-benzoyl-1,5-dithio-α-D-xylopyranoside* (**32**). — This compound was prepared, in the same manner as described for **28**, from 5-*O*-*p*-tolyl-sulfonyl-D-xylose dibenzyl dithioacetal. The crude product, after treatment with iodide ions was crystallized from ethyl acetate–hexane to give **32** (5.4 g), m.p. 120–121°, $[\alpha]_D^{21}$ +177° (*c* 1.0, chloroform).

Anal. Calc. for $C_{33}H_{28}O_6S_2$: C, 67.9; H, 4.8. Found: C, 67.6; H, 4.8.

*Benzyl 2,3,4-tri-*O*-acetyl-1,5-diseleno-α-D-xylopyranoside* (**33**). — 1,2-*O*-Isopropylidene-5-*O*-*p*-tolylsulfonyl-α-D-xylofuranose (**46**) (5.1 g), anhydrous chloroform (20 ml), trifluoroacetic acid (5 ml), and phenylmethaneselenol (7.0 g) were kept at room temperature for 4 h. The reaction mixture was extracted with chloroform and water. The chloroform extracts were washed with sodium hydrogencarbonate, dried, and evaporated at low temperature to a syrup, which was dissolved in ethyl acetate and precipitated by addition of hexane; this precipitation was repeated two more times. 5-*O*-*p*-Tolylsulfonyl-D-xylose dibenzyl diselenoacetal (**16**) was obtained as a crystalline solid, m.p. 68–70°. Compound **16**, without purification, was acetylated with pyridine and acetic anhydride to give an acetate showing the same n.m.r. data as those of **14**. The crude acetate was treated with iodide ions, as described for **28**, and the crude reaction product crystallized from ethyl acetate–hexane to give **33** (2.0 g), m.p. 118°, $[\alpha]_D^{21}$ +312° (*c* 1.58, chloroform); n.m.r. (chloroform-*d*): δ 1.95, 1.99, 2.02 (s, 9 H, $OCOCH_3$), 3.89 (s, 2 H, $C_6H_5CH_2$) and 7.22 (s, 5 H, C_6H_5).

Anal. Calc. for $C_{18}H_{22}O_6Se_2$: C, 43.7; H, 4.5; mol. wt. 494. Found: C, 43.4; H, 4.5; mol. wt. 494 (m.s.).

The mother liquor from the crystallization was evaporated and the residue deacetylated with sodium methoxide in methanol. On chromatography with 1:9 (v/v) methanol–benzene, the product gave 2,5-anhydro-D-xylose dibenzyl diselenoacetal (**37**) (2.3 g) and benzyl 1,5-diseleno-D-xylopyranosides (0.40 g). The latter material consisted mainly of the α-D anomer and of a small proportion of β-D anomer. It

should be noted that **33** and its β-D anomer showed exactly the same retention time in h.p.l.c. as the corresponding thioglycosides **28** and **29**, respectively.

*2,5-Anhydro-*D*-xylose dibenzyl diselenoacetal* (**37**). — 5-*O*-*p*-Tolylsulfonyl-D-xylose dibenzyl diselenoacetal (1.0 g) was stirred with pyridine (10 ml) overnight at room temperature. The reaction mixture was treated as described for **6** to give **37** (syrup, 0.80 g), $[\alpha]_D^{25}$ +52° (*c* 1.2, chloroform).

Anal. Calc. for $C_{19}H_{22}O_3Se_2$: C, 49.8; H, 4.8. Found: C, 49.5; H, 4.7.

*Benzyl 2,3,4-tri-*O*-benzoyl-1,5-diseleno-α-*D*-xylopyranoside* (**34**). — This compound was prepared in the same way as **33**, except that **16** was benzoylated instead of acetylated. The glycoside **34** crystallized from the crude reaction product (3.4 g), m.p. 122–123° (from ethyl acetate–hexane), $[\alpha]_D^{21}$ +172° (*c* 1.0, chloroform).

Anal. Calc. for $C_{33}H_{28}O_6Se_2$: C, 58.2; H, 5.6. Found: C, 58.0; H, 5.7.

*Benzyl 2,3,4-tri-*O*-acetyl-1,5-diseleno-*D*-ribopyranosides* (**36**). — Methyl 2,3-*O*-isopropylidene-5-*O*-*p*-tolylsulfonyl-β-D-ribofuranoside[16] (**48**, 5.0 g) was treated as described for **33**. The crude reaction product, obtained after reaction with iodide ions, was deacetylated with sodium methoxide in methanol. Chromatography with 1:39 (v/v) methanol–benzene and analysis of individual fractions by h.p.l.c. gave firstly 3,4-di-*O*-acetyl-2,5-anhydro-D-ribose dibenzyl diselenoacetal (**49**) (0.50 g), $[\alpha]_D^{21}$ −46.5° (*c* 2.4, chloroform); n.m.r. (chloroform-*d*): δ 1.97, 2.04 (s, 6 H, $OCOCH_3$), and 7.14, 7.25 (s, 10 H, C_6H_5).

Anal. Calc. for $C_{23}H_{26}O_5Se_2$: C, 50.9; H, 4.8. Found: C, 51.1; H, 4.9.

Subsequent elution gave **36** (1.05 g), $[\alpha]_D^{21}$ +206° (*c* 4.2, chloroform); n.m.r. (chloroform-*d*): δ 1.87, 1.93, 2.10 (s, 9 H, $OCOCH_3$), 3.77 (s, 2 H, $CH_2C_6H_5$), and 7.17 (s, 5 H, C_6H_5).

Anal. Calc. for $C_{18}H_{22}O_6Se_2$: C, 43.7; H, 4.5; mol. wt. 494. Found: C, 43.9; H, 4.4; mol. wt. 494 (m.s.).

Compound **49** was also prepared from **24** by treatment with pyridine as described for **37**, followed by acetylation.

*1,2,3,4-Tetra-*O*-acetyl-1,5-diseleno-*D*-xylopyranosides* (**35**). — The glycoside **33** (1.4 g), acetic acid (25 ml), and mercuric acetate (5.0 g) were stirred for 4 h at 45–50°. The reaction mixture was diluted with water and extracted with chloroform. The extracts were washed with sodium hydrogencarbonate and water, dried, and evaporated to a syrup. Chromatography with 1:39 (v/v) methanol–benzene gave **35** (0.70 g), $[\alpha]_D^{23}$ +114° (*c* 1.4, chloroform); n.m.r. (chloroform-*d*): δ 1.96, 2.00, and 2.17 (s, 9 H, $OCOCH_3$).

Anal. Calc. for $C_{13}H_{18}O_8Se$: C, 40.8; H, 4.7; mol. wt. 382. Found: C, 40.6; H, 4.6; mol. wt. 382 (m.s.).

*1,2,3,4-Tetra-*O*-acetyl-5-deoxy-*D*-xylitol* (**18**). — (*a*). The acetate **35** (0.50 g) was treated with Raney nickel as described for **11**. Chromatography with 1:49 (v/v) methanol–benzene gave **18** as a syrup (0.24 g), $[\alpha]_D^{21}$ −2° (*c* 2.3, chloroform); n.m.r. (chloroform-*d*): δ 1.25 (d, 3 H, *J* 6.0 Hz, CH_3) and 2.07, 2.08, 2.12 (s, 12 H, $OCOCH_3$); g.l.c. (170°) retention time 16.00 min.

Anal. Calc. for $C_{13}H_{20}O_8$: C, 51.3; H, 6.6. Found: C, 51.0; H, 6.5.

(*b*). 5-Deoxy-D-xylose[18] (0.75 g), water (25 ml), and sodium borohydride (0.30 g) were kept for 6 h at room temperature. The excess of borohydride was destroyed by addition of glacial acetic acid. The solution was evaporated and the residue treated with pyridine (3 ml) and acetic anhydride (5 ml). Chromatography of the crude acetate with 1:49 (v/v) methanol–benzene gave **18** (0.35 g), showing i.r. and n.m.r. spectra and g.l.c. retention time identical with those of the compound obtained by treatment with Raney nickel (*a*).

2,3,4-Tri-O-acetyl-5-Se-benzyl-5-seleno-D-xylose dimethyl acetal (**19**). — (*a*). The selenoglycoside **33** (1.0 g), methanol (25 ml), cadmium carbonate (5.0 g), and mercuric chloride (3.0 g) were heated under reflux for 18 h. The reaction mixture was treated as described for **2**. Chromatography with 1:39 (v/v) methanol–benzene gave unchanged starting material (**33**) (0.25 g) and **19** (0.20 g), m.p. 89–90° (from ethyl acetate–hexane); $[\alpha]_D^{21}$ −33° (*c* 0.31, chloroform); n.m.r. (carbon tetrachloride): δ 2.00, 2.04 (s, 9 H, $OCOCH_3$), 3.24, 3.34 (s, 6 H, OCH_3), 3.77 (s, 2 H, $C_6H_5CH_2$), and 7.17 (s, 5 H, C_6H_5).

Anal. Calc. for $C_{20}H_{28}O_8Se$: C, 50.4; H, 5.9; mol. wt. 476. Found: C, 50.7; H, 5.7; mol. wt. 476 (m.s.).

(*b*). 1,2-*O*-Isopropylidene-5-*Se*-benzyl-5-seleno-α-D-xylofuranose[3] (**47**, 3.0 g), anhydrous chloroform (6 ml), trifluoroacetic acid (6 ml), and ethanethiol (6 ml) were kept for 20 h at room temperature. The solution was extracted with chloroform and water. The chloroform layer was washed with sodium hydrogencarbonate solution, dried, and evaporated to a syrup. Chromatography with 1:19 (v/v) methanol–benzene gave **20** (1.0 g), m.p. 73–74° (from ethyl acetate–hexane); $[\alpha]_D^{21}$: 43° (*c* 1.0, chloroform); n.m.r. (chloroform-*d*): δ 1.10, 1.22 (t, 6 H, *J* 7.8 Hz, SCH_2CH_3), 3.83 (s, 2 H, $C_6H_5CH_2$), and 7.25 (s, 5 H, C_6H_5).

Anal. Calc. for $C_{16}H_{26}O_3S_2Se$: C, 46.8; H, 6.3. Found: C, 46.7; H, 6.5.

Treatment of **20** with pyridine and acetic anhydride gave the 2,3,4-tri-*O*-acetyl derivative **21**, n.m.r. (chloroform-*d*): δ 1.23, 1.30 (t, 6 H, *J* 7.8 Hz, SCH_2CH_3), 2.01, 2.06, 2.10 (s, 9 H, $OCOCH_3$), 3.78 (s, 2 H, $C_6H_5CH_2$), and 7.20 (s, 5 H, C_6H_5).

The acetate (**21**) (1.0 g), mercuric chloride (2.0 g), cadmium carbonate (5.0 g), and methanol (25 ml) were heated under reflux overnight. The reaction mixture was treated as described for **2** to give **19** (0.50 g), m.p. 89–90°.

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