Carbohydrate Research, 154 (1986) 71–80
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

SYNTHESIS OF 3,4-ANHYDRO-1-DEOXY-3-*C*-METHYL-D-HEXULOSE DERIVATIVES*

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(Received December 30th, 1985; accepted for publication, March 31st, 1986)

ABSTRACT

Epoxidation of (*E*)-1,3,4-trideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*glycero*-hex-3-enulose by alkaline hydrogen peroxide gave a mixture of 3,4-anhydro-1-deoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*arabino*- (**2**) and -D-*xylo*-hexulose (**3**) that was resolved by chromatography. From the reaction of **2** with 3-chloroperbenzoic acid, the Baeyer–Villiger rearrangement product (2*R*)-2-*O*-acetyl-2,3-anhydro-1-deoxy-4,5-*O*-isopropylidene-D-*erythro*-pentulose hydrate was isolated. The structures and configurations of the above products were established on the basis of chemical transformations and analytical and spectroscopic data.

INTRODUCTION

In a previous paper, we reported[2] on the synthesis of 3,4-anhydro-1-deoxy-hexuloses by epoxidation with alkaline hydrogen peroxide of enuloses prepared by the Knoevenagel–Doebner or the Wittig reaction between *aldehydo* sugars and β-carbonyl acids[3] or phosphorus ylids[4]. We now report an extension of the method to the synthesis of branched-chain 1-deoxyhexuloses.

RESULTS AND DISCUSSION

Epoxidation of (*E*)-1,3,4-trideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*glycero*-hex-3-enulose (**1**) by alkaline hydrogen peroxide gave a mixture of 3,4-anhydro-1-deoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*arabino*- (**2**) and -D-*xylo*-hexulose (**3**) in a 2:1 ratio as shown by g.l.c. analysis. Compounds **2** and **3** were separated by chromatographic means and their structures established on the basis of spectroscopic data (see Experimental) and by chemical transformations.

The *trans* relationships of the substituents attached to the oxirane rings in **2** and **3** were demonstrated by a method previously reported[2]. Reduction of **1** with sodium borohydride yielded (*E*)-1,3,4-trideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-

*Branched-chain sugars, Part XII. For Part XI, see ref. 1.
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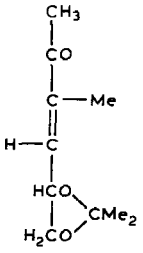

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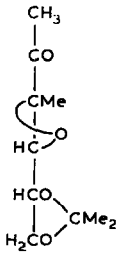

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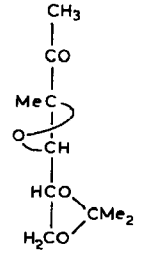

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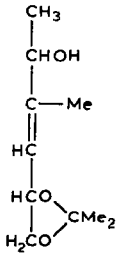

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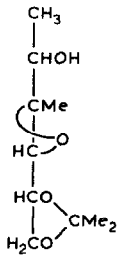

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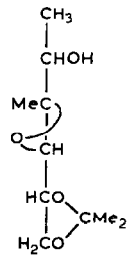

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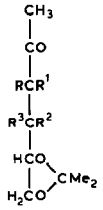
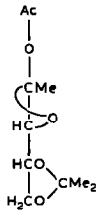
D-*threo*- (or -D-*erythro*)-hex-3-enitol (**4**) which was epoxidised with 3-chloroperbenzoic acid to yield a mixture of 3,4-anhydro-1-deoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*manno* (or -D-*gluco*)- (**5**) and -D-*ido* (or -D-*gulo*)-hexitol (**6**) that was partially resolved by column chromatography. Oxidation with ruthenium tetraoxide of a mixture of **5** and **6** (1:5 ratio, g.l.c. analysis) gave compounds **2** and **3** (1:5 ratio).

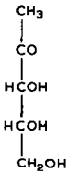
The configurations of **2** and **3** were determined as follows. Reduction of **2** with zinc dust[5] gave a mixture of two β-hydroxyketones, one of which showed optical and spectroscopic data anlogous to those reported[3b,6] for 1,3-dideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*ribo*-hexulose (**7**) as well as for its 4-*O*-acetyl derivative (**9**). The D-*arabino* configuration was assigned to the other β-hydroxyketone (**8**) on the following basis. Reduction of **3** gave a mixture of two β-hydroxyketones that was partially resolved by repeated column chromatography of the 4-*O*-acetyl derivatives, which were shown to be different from **9** and **10**. The compound of lower mobility had optical and spectroscopic data analogous to those reported[3b,6] for 4-*O*-acetyl-1,3-dideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*lyxo*-hexulose (**14**), and consequently the D-*xylo* configuration was assigned to **13**. These results indicated that the opening of the oxirane ring occurred with retention of the configuration at C-4[2,5] and epimerisation at C-3.

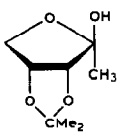
Epoxidation of **1** with 3-chloroperbenzoic acid afforded (2*R*)-2-*O*-acetyl-2,3-anhydro-1-deoxy-4,5-*O*-isopropylidene-D-*erythro*-pentulose hydrate (**15**) as a result of a Baeyer–Villiger rearrangement[2,7].

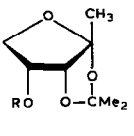
The configuration of **15** was established by hydrolysis to yield 1-deoxy-D-*erythro*-pentulose (**16**), since its acetonation followed by column chromatography











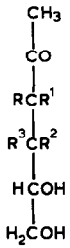
7 R = R^3 = H, R^1 = Me, R^2 = OH
8 R = Me, R^1 = R^3 = H, R^2 = OH
9 R = R^3 = H, R^1 = Me, R^2 = OAc
10 R = Me, R^1 = R^3 = H, R^2 = OAc
11 R = R^2 = H, R^1 = Me, R^3 = OH
12 R = Me, R^1 = R^2 = H, R^3 = OH
13 R = R^2 = H, R^1 = Me, R^3 = OAc
14 R = Me, R^1 = R^2 = H, R^3 = OAc

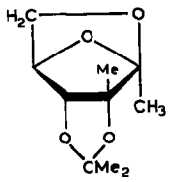
15

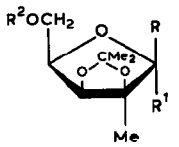
16

17

18 R = H
19 R = Ac







20 R = Me, R^1 = R^2 = OH, R^3 = H
21 R = R^3 = OH, R^1 = Me, R^2 = H

22

23 R = OH, R^1 = Me, R^2 = H
24 R = OH, R^1 = Me, R^2 = Ac
25 R = Me, R^1 = OH, R^2 = H
26 R = Me, R^1 = OH, R^2 = Ac

gave 1-deoxy-3,4-*O*-isopropylidene-β-D-*erythro*-pentulofuranose (**17**) and 1-deoxy-2,3-*O*-isopropylidene-α-D-*erythro*-pentulofuranose (**18**). The structures of **17, 18,** and the 4-*O*-acetyl derivative (**19**) of the latter were determined on the basis of their analytical and spectroscopic data.

Hydrolysis of **2** gave mainly (p.c.) 1-deoxy-3-*C*-methyl-D-psicose (**20**) and likewise **3** gave mainly 1-deoxy-3-*C*-methyl-D-tagatose (**21**), reflecting regioselectivity in the opening of the oxirane ring.

Acetonation of the mixture of **20** and **21** obtained from **2** gave 2,6-anhydro-1-deoxy-3,4-*O*-isopropylidene-3-*C*-methyl-β-D-psicofuranose[8] (**22**) and 1-deoxy-3,4-*O*-isopropylidene-3-*C*-methyl-β-D-tagatofuranose (**23**). On the other hand, acetonation of the mixture of **20** and **21** obtained from **3** gave **22, 23,** and 1-deoxy-3,4-*O*-isopropylidene-3-*C*-methyl-α-D-tagatofuranose (**25**).

The structures of **23** and **25**, as well as those of the corresponding 6-*O*-acetyl derivatives (**24** and **26**) were determined on the basis of their analytical and spectroscopic data. The anomeric configurations of **23** and **25** were assigned from the values of their optical rotations.

EXPERIMENTAL

General methods. — Solutions were dried over $MgSO_4$ before concentration under diminished pressure. ^{1}H-N.m.r. spectra (200 and 80 MHz, $CDCl_3$, internal Me_4Si) were recorded with Bruker WP-200 SY and WP-80 CW spectrometers, i.r. spectra with a Perkin–Elmer 782 instrument, and mass spectra with a Hewlett–Packard 5970 M.S.D. Optical rotations were measured for solutions in chloroform (1-dm tube) with a Perkin–Elmer 141 polarimeter. G.l.c. was performed at 210° on a Perkin–Elmer 8310 Gas Chromatograph equipped with a flame-ionisation detector and a steel column (4 m × 0.25 in. i.d.) packed with 10% of SP 2330 on Chromosorb W (100–120 mesh). The N_2 flow rate was 40 mL/min, the injection-port temperature was 280°, and the zone-detector temperature was 280°. R_F values are reported for t.l.c performed on Silica Gel G (Merck) with ether–hexane (3:1) and detection by charring with sulfuric acid. Column chromatography was performed on silica gel (Merck, 7734). Descending p.c. was performed on Whatman No. 1 paper with 1-butanol–ethanol–water (28:7:13), and detection with silver nitrate[9].

*Epoxidation of (*E*)-1,3,4-trideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-*D*-glycero-hex-3-enulose* (**1**). — To a cooled (ice–water) and stirred solution of **1**[4] (10 g, 54.4 mmol) and aqueous 30% hydrogen peroxide (17 mL) in methanol (50 mL) was added 6M sodium hydroxide (5.5 mL) dropwise at a rate such that the temperature was maintained at ~15°. After the last addition, the mixture was allowed to reach room temperature. After 20 min, g.l.c. revealed that **1** (*T* 3.26 min) had disappeared and that two new compounds (*T* 3.13 min, 60.6%; and *T* 5.01 min, 34.9%) were present. Stirring was continued for a further 10 min, water (100 mL) was added, the resulting solution was saturated with sodium chloride and extracted with ether (3 × 50 mL), and the combined extracts were concentrated. Column chromatography (ether–hexane, 1:5) of the residue (9 g) yielded, first, 3,4-anhydro-1-deoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*arabino*-hexulose (**2**, 4.73 g), isolated as a syrup, $[\alpha]_D$ −54° (*c* 1.4); ν_{max}^{film} 2992, 2944, and 2884 (C–H), 1716 (ketone, C=O), 1384 and 1374 (CMe_2), 1364, 1258, 1223, 1148, 1065, and 841 cm^{-1} (1,3-dioxolane ring). N.m.r. data (200 MHz): δ 4.19 (dd, 1 H, $J_{5,6}$ 6, $J_{6,6'}$ 9 Hz, H-6), 4.08 (dd, 1 H, $J_{5,6'}$ 5 Hz, H-6'), 3.93 (ddd, 1 H, H-5), 3.11 (d, 1 H, $J_{4,5}$ 8 Hz, H-4), 2.08 (s, 3 H, H-1,1,1), 1.53 (s, 3 H, Me-3), 1.45 and 1.38 (2 s, 6 H, CMe_2). Mass spectrum: *m/z* 186 (M^+ + 1 − Me), 185 (M^+ − Me), 157 (M^+ − Ac), 127 (M^+ − Me − Me_2CO), 125 (M^+ − Me − AcOH), 115, 113, 101 ($C_5H_9O_2^+$), 99, (M^+ − $C_5H_9O_2$), 97, 87, 85, 83, 73, 72, 71, 69, 61, 59 (Me_2COH^+), 57, and 43 (Ac^+, base peak).

Anal. Calc. for $C_{10}H_{16}O_4$: C, 59.98; H, 8.05. Found: C, 60.09; H, 8.36.

Eluted second was 3,4-anhydro-1-deoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*xylo*-hexulose (**3**, 3 g), isolated as a syrup, $[\alpha]_D$ +51° (*c* 1.4); ν_{max}^{film} 2992, 2944, and 2884 (C–H), 1716 (ketone, C=O), 1384 and 1374 (CMe_2), 1364, 1258, 1223, 1148, 1065, and 841 cm^{-1} (1,3-dioxolane ring). N.m.r. data (200 MHz): δ 4.12 (dd, 1 H,

$J_{6,6'}$ 8 Hz, H-6), 4.00 (dd, 1 H, $J_{4,5} = J_{5,6} = J_{5,6'} = 7$ Hz, H-5), 3.73 (dd, 1 H, H-6'), 3.13 (d, 1 H, H-4), 2.08 (s, 3 H, H-1,1,1), 1.50 and 1.40 (2 s, 6 H, CMe_2), and 1.45 (s, 3 H, Me-3). Mass spectrum: *m/z* 186 ($M^+ + 1 - Me$), 185 ($M^+ - Me$), 127 ($M^+ - Me - Me_2CO$), 125 ($M^+ - Me - AcOH$), 101 ($C_5H_9O_2^+$), 99 ($M^+ - C_5H_9O_2$), 97, 87, 85, 83, 73, 72, 71, 69, 61, 59 (Me_2COH^+), 57, and 43 (Ac^+, base peak).

Anal. Calc. for $C_{10}H_{16}O_4$: C, 59.98; H, 8.05. Found: C, 60.16; H, 8.31.

Reduction of **1** *with sodium borohydride.* — To a cooled solution (ice–water) of **1** (2.76 g, 15 mmol) in methanol (25 mL) was added sodium borohydride (0.35 g, 10 mmol) with stirring. After 30 min, t.l.c. showed a compound of lower mobility (R_F 0.26). The mixture was neutralised with acetic acid, concentrated, and extracted with chloroform (3 × 10 mL). Removal of the solvent gave a residue that was subjected to column chromatography (ether–hexane, 3:1), to yield syrupy (*E*)-1,3,4-trideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*threo*- (or -D-*erythro*)-hex-3-enitol (**4**; 2.55 g, 90%), isolated as a syrup, $[\alpha]_D$ +15° (*c* 1.6); ν_{max}^{film} 3445 (OH), 2987, 2938, and 2877 (C–H), 1675 (C=C), 1381 and 1372 (CMe_2), 1246, 1221, 1157, 1057, and 872 cm^{-1} (1,3-dioxolane ring). N.m.r. data: δ 5.40 (dq, 1 H, $J_{4,Me}$ 1, $J_{4,5}$ 8 Hz, H-4), 4.73 (dt, 1 H, $J_{5,6}$ 6, $J_{5,6'}$ 8 Hz, H-5), 4.15 (broad q, 1 H, $J_{1,2}$ 7 Hz, H-2), 4.00 (dd, 1 H, $J_{6,6'}$ 8 Hz, H-6), 3.45 (t, 1 H, H-6'), 2.65 (broad s, 1 H, HO-2), 1.65 (d, 3 H, Me-3), 1.34 and 1.32 (2 s, 6 H, CMe_2), and 1.18 (d, 3 H, H-1,1,1). Mass spectrum: *m/z* 171 ($M^+ - Me$), 128 ($M^+ - Me - Ac$), 117, 111 ($M^+ - Me - AcOH$), 103, 101 ($C_5H_9O_2^+$), 98, 97, 95, 85 ($M^+ - C_5H_9O_2$), 83, 73, 72, 71, 69, 67, 59 (Me_2COH^+), and 43 (Ac^+, base peak).

Anal. Calc. for $C_{10}H_{18}O_3$: C, 64.48; H, 9.74. Found: C, 64.72; H, 9.71.

Synthesis of **2** *and* **3**. — To a stirred solution of **4** (2 g, 10.7 mmol) in dichloromethane (25 mL) at room temperature was added 3-chloroperbenzoic acid (Merck) (2.5 g, 12 mmol). After 40 h, t.l.c. revealed two new compounds (R_F 0.25 and 0.19). The precipitated 3-chlorobenzoic acid was removed, and the filtrate was washed with aqueous 10% sodium sulfite (until negative to starch–iodide paper), aqueous 10% sodium carbonate, and water, and concentrated. Column chromatography (ether–hexane, 1:2) of the residue yielded, first, 3,4-anhydro-1-deoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*manno* (or -D-*gluco*)-hexitol (**5**, 670 mg), isolated as a syrup, $[\alpha]_D$ +4° (*c* 1.3); ν_{max}^{film} 3478 (OH), 2989, 2940, and 2880 (C–H), 1384 and 1373 (CMe_2), 1256, 1223, 1155, 1066, 985, and 851 cm^{-1} (oxirane and 1,3-dioxolane ring). N.m.r. data: δ 4.20–3.50 (m, 4 H, H-2,5,6,6'), 2.96 (d, 1 H, $J_{4,5}$ 7 Hz, H-4), 2.50 (broad s, 1 H, HO-2), 1.36 (s, 3 H, Me-3), 1.28 and 1.26 (2 s, 6 H, CMe_2), and 1.13 (d, 3 H, $J_{1,2}$ 7 Hz, H-1,1,1). Mass spectrum: *m/z* 188 ($M^+ + 1 - Me$), 187 ($M^+ - Me$), 131, 128, 127 ($M^+ - Me - AcOH$), 101 ($C_5H_9O_2^+$), 100, 99, 85, 83, 81, 73, 72, 71, 69, 61, 59 (Me_2COH^+), 57, and 43 (Ac^+, base peak).

Anal. Calc. for $C_{10}H_{18}O_4$: C, 59.38; H, 8.97. Found: C, 59.62, H, 9.06.

Eluted second was 3,4-anhydro-1-deoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*ido*- (or -D-*gulo*)-hexitol (**6**, 410 mg), isolated as a syrup, $[\alpha]_D$ −3.7° (*c* 1.1); ν_{max}^{film} 3465 (OH), 2988, 2939, and 2881 (C–H), 1384 and 1373 (CMe_2), 1257, 1214,

1158, 1057, 963, 860, and 826 cm^{-1} (oxirane and 1,3-dioxolane ring). N.m.r. data: δ 4.20–3.62 (m, 3 H, H-5,6,6'), 3.46 (broad q, 1 H, $J_{1,2}$ 7 Hz, H-2), 3.15–2.90 (m, 1 H, H-4), 2.50 (broad s, 1 H, HO-2), 1.44 and 1.35 (2 s, 6 H, CMe_2), 1.26 (s, 3 H, Me-3), and 1.16 (d, 3 H, H-1,1,1). Mass spectrum: *m/z* 188 ($M^+ + 1 - Me$), 187 ($M^+ - Me$), 131, 128, 127 ($M^+ - Me - AcOH$), 101 ($C_5H_9O_2^+$), 100, 99, 85, 83, 81, 73, 72, 71, 69, 61, 59 (Me_2COH^+), 57, and 43 (Ac^+, base peak).

Anal. Calc. for $C_{10}H_{18}O_4$: C, 59.38; H, 8.97. Found: C, 59.00; H, 8.91.

A mixture of **5** and **6** (1:5, 430 mg) was also obtained, and was used in the following step.

To a stirred mixture of **5** and **6** (1:5 by g.l.c., 430 mg), chloroform (15 mL), ruthenium dioxide (130 mg), and saturated aqueous sodium hydrogencarbonate (10 mL) was added aqueous 5% sodium periodate (15 mL) dropwise during 1 h. The mixture was left at room temperature overnight when g.l.c. revealed **2** (10.7%) and **3** (56.3%).

Reduction of **2**. — To a stirred solution of **2** (1.5 g, 7.5 mmol) in methanol (15 mL) were added aqueous 15% ammonium chloride (10 mL) and zinc dust (3 g). After 7 h, t.l.c. revealed that **2** had disappeared and that two new products (R_F 0.28 and 0.25) were present. The mixture was filtered through a Celite pad, neutralised with conc. hydrochloric acid, and concentrated, and the residue was extracted with ether (3 × 20 mL). Concentration of the combined extracts and column chromatography (ether–hexane, 1:2) of the residue yielded, first, 1,3-dideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*ribo*-hexulose (**7**, 200 mg), isolated as a colourless mobile oil, $[\alpha]_D$ +28° (*c* 1.1); lit.[3b] $[\alpha]_D$ +22° (*c* 1.7); ν_{max}^{film} 3477 (OH), 2990, 2942, and 2888 (C–H), 1715 (ketone, C=O), 1383 and 1373 (CMe_2), 1257, 1218, 1160, 1066, and 854 cm^{-1} (1,3 dioxolane ring). N.m.r. data: δ 4.13–4.75 (m, 3 H, H-5,6,6'), 3.55 (ddd, 1 H, $J_{3,4}$ 4.5, $J_{4,5}$ 3.4, $J_{4,OH}$ 8 Hz, H-4), 3.26 (d, 1 H, HO-4), 2.83 (dq, 1 H, $J_{3,Me}$ 7 Hz, H-3), 2.18 (s, 3 H, H-1,1,1), 1.34 and 1.32 (2 s, 6 H, CMe_2), and 1.16 (d, 3 H, Me-3).

Eluted second was 1,3-dideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*arabino*-hexulose (**8**, 270 mg), isolated as a colorless mobile oil, $[\alpha]_D$ −31° (*c* 1.5); ν_{max}^{film} 3471 (OH), 2990, 2940, and 2880 (C–H), 1706 (ketone, C=O), 1387 and 1373 (CMe_2), 1253, 1217, 1159, 1063, and 849 cm^{-1} (1,3-dioxolane ring). N.m.r. data: δ 4.20–3.80 (m, 4 H, H-4,5,6,6'), 3.03 (broad s, 1 H, HO-4), 2.83 (dq, 1 H, $J_{3,4}$ 2, $J_{3,Me}$ 7 Hz, H-3), 2.18 (s, 3 H, H-1,1,1), 1.34 and 1.30 (2 s, 6 H, CMe_2), and 1.15 (d, 3 H, Me-3).

A mixture of **7** and **8** (600 mg) was also obtained.

Acetylation of **7** (70 mg, 0.34 mmol) in dry pyridine (1 mL) with acetic anhydride (0.5 mL) in the usual manner gave, after column chromatography (ether–hexane, 1:1), 4-*O*-acetyl-1,3-dideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*ribo*-hexulose (**9**; 75 mg, 90%), R_F 0.38, $[\alpha]_D$ −21° (*c* 1.3); lit.[3b] $[\alpha]_D$ −14° (*c* 1.5); ν_{max}^{film} 2990, 2942, and 2894 (C–H), 1747 (acetate, C=O), 1721 (ketone, C=O), 1374 (CMe_2), 1231 (acetate, C–O), 1161, 1061, and 850 cm^{-1} (1,3-dioxolane ring). N.m.r. data: δ 5.26 (t, 1 H, $J_{3,4} = J_{4,5} = 6$ Hz, H-4), 4.16 (q, 1 H, $J_{5,6} = J_{5,6'} = 6$

Hz, H-5), 3.96 (dd, 1 H, $J_{6,6'}$ 7.5 Hz, H-6), 3.71 (dd, 1 H, H-6'), 2.87 (dq, 1 H, $J_{3,Me}$ 7 Hz, H-3), 2.17 (s, 3 H, H-1,1,1), 2.02 (s, 3 H, Ac), 1.32 and 1.27 (2 s, 6 H, CMe_2), and 1.11 (d, 3 H, Me-3). Mass spectrum: *m/z* 299 (M^+ − Me), 172, 143 (M^+ − $C_5H_9O_2$), 141, 130, 127, 109 (M^+ − Me − 2AcOH), 101 ($C_5H_9O_2^+$), 85, 83, 73, 72, 59 (Me_2COH^+), and 43 (Ac^+, base peak).

Acetylation of a mixture of **7** and **8** (600 mg) in dry pyridine (4 mL) with acetic anhydride (2 mL) in the usual manner gave, after column chromatography (ether–hexane, 1:2), 4-*O*-acetyl-1,3-dideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*arabino*-hexulose (**10**, 250 mg), then a mixture of **9** and **10** (140 mg), and finally **9** (215 mg). Compound **10** had R_F 0.45, $[\alpha]_D$ +55° (*c* 1.5); ν_{max}^{film} 2991, 2944, and 2887 (C–H), 1748 (acetate, C=O), 1718 (ketone, C=O), 1374 (CMe_2), 1231 (acetate, C–O), 1151, 1061, 1025, 965, and 844 cm^{-1} (1,3-dioxolane ring). N.m.r. data: δ 5.25 (dd, 1 H, $J_{3,4}$ 4.5, $J_{4,5}$ 7 Hz, H-4), 4.21–3.63 (m, 3 H, H-5,6,6'), 2.90 (dq, 1 H, $J_{3,Me}$ 7 Hz, H-3), 2.20 (s, 3 H, H-1,1,1), 2.01 (s, 3 H, Ac), 1.40 and 1.32 (2 s, 6 H, CMe_2), and 1.08 (d, 3 H, Me-3). Mass spectrum: *m/z* 229 (M^+ − Me), 172, 169 (M^+ − Me − AcOH), 143 (M^+ − $C_5H_9O_2$), 141, 130, 127, 115, 109 (M^+ − Me − 2AcOH), 101 ($C_5H_9O_2^+$), 97, 85, 84, 83, 73, 72, 59 (Me_2COH^+), and 43 (Ac^+, base peak).

Anal. Calc. for $C_{12}H_{20}O_5$: C, 58.99; H, 8.25. Found: C, 59.21; H, 8.01.

Reduction of **3**. — Compound **3** (1.5 g, 7.5 mmol) was reduced as described above, to give a mixture (1 g) of compounds **11** and **12**. An aliquot (350 mg) was acetylated in dry pyridine (2 mL) with acetic anhydride (1 mL) in the usual manner. Repeated column chromatography (ether–hexane, 1:5 → 1:3) of the product (300 mg) gave 4-*O*-acetyl-1,3-dideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*xylo*-hexulose (**13**, 85 mg), R_F 0.37, $[\alpha]_D$ +29° (*c* 1.3); ν_{max}^{film} 2990, 2943, 2887 (C–H), 1745 (acetate, C=O), 1717 (ketone, C=O), 1373 (CMe_2), 1238 (acetate, C–O), 1159, 1064, and 849 cm^{-1} (1,3-dioxolane ring). N.m.r. data: δ 5.23 (dd, 1 H, $J_{3,4}$ 7.5, $J_{4,5}$ 3.5 Hz, H-4), 4.20 (dt, 1 H, $J_{5,6} = J_{5,6'} = 6$ Hz, H-5), 3.96 (dd, 1 H, $J_{6,6'}$ 8 Hz, H-6), 3.66 (dd, 1 H, H-6'), 2.95 (broad quintet, 1 H, $J_{3,Me}$ 7.5 Hz, H-3), 2.20 (s, 3 H, H-1,1,1), 2.08 (s, 3 H, Ac), 1.40 and 1.29 (2 s, 6 H, CMe_2), and 1.08 (d, 3 H, Me-3). Mass spectrum: *m/z* 229 (M^+ − Me), 173, 172, 169 (M^+ − Me − AcOH), 143 (M^+ − $C_5H_9O_2$), 141, 130, 127, 115, 109 (M^+ − Me − 2AcOH), 101 ($C_5H_9O_2^+$), 97, 85, 84, 83, 73, 72, 59 (Me_2COH^+), and 43 (Ac^+, base peak).

Anal. Calc. for $C_{12}H_{20}O_5$: C, 58.99; H, 8.25. Found: C, 58.63; H, 8.40.

Eluted second was 4-*O*-acetyl-1,3-dideoxy-5,6-*O*-isopropylidene-3-*C*-methyl-D-*lyxo*-hexulose (**14**, 205 mg), R_F 0.33, $[\alpha]_D$ +40° (*c* 1.1); lit.[3b] $[\alpha]_D$ +52° (*c* 1.6); ν_{max}^{film} 2990, 2940, and 2896 (C–H), 1745 (acetate, C=O), 1721 (ketone, C=O), 1373 (CMe_2), 1237 (acetate, C–O), 1150, 1060, 960, and 840 cm^{-1} (1,3-dioxolane ring). N.m.r. data: δ 5.13 (dd, 1 H, $J_{3,4}$ 8.5, $J_{4,5}$ 3Hz, H-4), 4.26 (dt, 1 H, $J_{5,6} = J_{5,6'} = 6$ Hz, H-5), 3.99 (dd, 1 H, $J_{6,6'}$ 8.5 Hz, H-6), 3.68 (dd, 1 H, H-6'), 3.05 (broad quintet, 1 H, H-3), 2.16 (s, 3 H, H-1,1,1), 2.03 (s, 3 H, Ac), 1.40 and 1.32 (2 s, 6 H, CMe_2), and 1.15 (d, 3 H, $J_{3,Me}$ 7.3 Hz, Me-3). Mass spectrum: *m/z* 230 (M^+ + 1 − Me), 229 (M^+ − Me), 172, 143 (M^+ − $C_5H_9O_2$), 141, 130, 127, 115, 110, 109

($M^+ - Me - 2AcOH$), 101 ($C_5H_9O_2^+$), 97, 85, 84, 83, 72, 59 (Me_2COH^+), and 43 (Ac^+, base peak).

Epoxidation of **1**. — To a stirred solution of **1** (2 g, 11 mmol) in dichloromethane (100 mL) at room temperature was added 3-chloroperbenzoic acid (Merck) (6.1 g, 30 mmol). After 3 days, t.l.c. revealed a complex mixture; the main product had *T* 4.03 min. The precipitated 3-chlorobenzoic acid was then removed, the filtrate was washed with aqueous 10% sodium sulfite (until negative to starch–iodide paper), aqueous 5% sodium carbonate, and water, and concentrated. Column chromatography (ether–hexane, 6:1) of the residue (2.31 g) yielded (2*R*)-2-*O*-acetyl-2,3-anhydro-1-deoxy-4,5-*O*-isopropylidene-D-*erythro*-pentulose hydrate (**15**; 1.3 g, 59%), $[\alpha]_D$ −3.3° (*c* 1.5); ν_{max}^{film} 2992, 2943, and 2886 (C–H), 1757 (acetate, C=O), 1384 and 1373 (CMe_2), 1240 (acetate, C–O), 1186, 1155, 1119, 1063, 934, 914, 862, and 844 cm^{-1} (oxirane and 1,3-dioxolane ring). N.m.r. data: δ 4.25–3.67 (m, H-4,5,5'), 3.03 (d, 1 H, $J_{3,4}$ 7 Hz, H-3), 2.00 (s, 3 H, Ac), 1.68 (s, 3 H, H-1,1,1), 1.40 and 1.30 (2 s, 6 H, CMe_2), Mass spectrum: *m/z* 202 ($M^+ + 1 - Me$), 201 ($M^+ - Me$), 145, 141 ($M^+ - Me - AcOH$), 116 ($M^+ + 1 - C_5H_9O_2$), 115 ($M^+ - C_5H_9O_2$), 103, 101 ($C_5H_9O_2^+$), 100, 99, 85, 83, 74, 73, 72, 71, 61, 59 (Me_2COH^+), and 43 (Ac^+, base peak).

Anal. Calc. for $C_{10}H_{16}O_5$: C, 55.54; H, 7.46. Found: C, 55.80; H, 7.32.

Hydrolysis of **15**. — A stirred suspension of **15** (1.2 g, 5.5 mmol) in aqueous 10% acetic acid (20 mL) was heated at 80–90° for 1 h. T.l.c. (ethyl acetate) then showed that **15** had disappeared and that a new compound (R_F 0.27) was present. The solvent was eliminated and the residue chromatographed (ethyl acetate) to give 1-deoxy-D-*erythro*-pentulose (**16**; 630 mg, 85%) as a colourless syrup, $[\alpha]_D$ −19° (*c* 1.4, water); lit.[10] $[\alpha]_D$ −37° (equil.; *c* 1.3, water).

Treatment of **16** (600 mg) at room temperature with dry acetone (30 mL), conc. sulfuric acid (0.1 mL), and anhydrous copper sulfate (1.5 g) for 4 h, followed by work-up in the usual manner and column chromatography of the residue (ether–hexane, 2:3), afforded, first, 1-deoxy-3,4-*O*-isopropylidene-β-D-*erythro*-pentulofuranose (**17**, 275 mg), R_F 0.29, m.p. 87–89° (from hexane), $[\alpha]_D$ −58.5° (*c* 1.2); ν_{max}^{KBr} 3236 (OH), 2992, 2984, 2955, 2940, 2887, and 2792 (C–H), 1384 and 1369 (CMe_2), 1275, 1250, 1210, 1198, 1119, 1099, 1073, 1014, 921, and 864 cm^{-1} (1,3-dioxolane ring). N.m.r. data: ^1H, δ 4.83 (ddd, 1 H, $J_{3,4}$ 6, $J_{4,5}$ 3, $J_{4,5'}$ 1.5 Hz, H-4), 4.39 (d, 1 H, H-3), 4.03 (dd, 1 H, $J_{5,5'}$ 10 Hz, H-5), 3.87 (dd, 1 H, H-5'), 2.26 (s, 1 H, HO-1), 1.53 (s, 3 H, H-1,1,1), 1.46 and 1.31 (2 s, 6 H, CMe_2); ^{13}C, δ 112.49 (CMe_2), 106.02 (C-2), 85.23 (C-3), 80.97 (C-4), 71.01 (C-5), 26.39 and 24.99 (CMe_2), and 22.37 (C-1).

Anal. Calc. for $C_8H_{14}O_4$: C, 55.16; H, 8.10. Found: C, 55.05; H, 8.03.

Eluted second was impure 1-deoxy-2,3-*O*-isopropylidene-α-D-*erythro*-pentulofuranose (**18**, 170 mg), isolated as a syrup; ν_{max}^{film} 3451 (OH), 2992, 2941, and 2884 (C–H), 1381 (CMe_2), 1203, 1103, 1015, and 867 cm^{-1} (1,3-dioxolane ring). N.m.r. data: δ 4.33–4.18 (m, 1 H, H-4), 4.20 (s, 1 H, H-3), 4.13 (dd, 1 H, $J_{4,5}$ 2.75, $J_{5,5'}$ 9.5 Hz, H-5), 3.85 (dd, 1 H, $J_{4,5'}$ 1 Hz, H-5'), 2.35 (s, 1 H, HO-2), 1.68 (s, 3 H, H-1,1,1), 1.45 and 1.33 (2 s, 6 H, CMe_2).

Acetylation of **18**, in the usual manner, afforded 4-*O*-acetyl-1-deoxy-2,3-*O*-isopropylidene-α-D-*erythro*-pentulofuranose (**19**), $[\alpha]_D$ −34° (*c* 1.15); ν_{max}^{film} 2993, 2942, and 2884 (C–H), 1745 (acetate, C=O), 1382 (CMe_2), 1237 (acetate, C–O), 1202, 1109, 1082, 1023, and 845 cm^{-1} (1,3-dioxolane ring). N.m.r. data: δ 5.10 (broad d, 1 H, H-4), 4.26 (broad s, 1 H, H-3), 4.20 (dd, 1 H, $J_{4,5}$ 2.4, $J_{5,5'}$ 9.5 Hz, H-5), 3.93 (dd, 1 H, $J_{4,5'}$ 1 Hz, H-5'), 2.06 (s, 3 H, Ac), 1.65 (s, 3 H, H-1,1,1), 1.46 and 1.32 (2 s, 6 H, CMe_2). Mass spectrum: *m/z* 202 ($M^+ + 1 - Me$), 201 ($M^+ - Me$), 143 ($M^+ - Me - Me_2CO$), 142 ($M^+ + 1 - Me - AcOH$), 141 ($M^+ - Me - AcOH$), 116, 115, 113, 101, 100, 99, 86, 85, 83, 73, 71, 61, 60, 59 (Me_2COH^+), and 43 (Ac^+, base peak).

Anal. Calc. for $C_{10}H_{16}O_5$: C, 55.54; H, 7.46. Found: C, 55.72; H, 7.23.

Hydrolysis of **2**. — A stirred suspension of **2** (1.8 g, 9 mmol) in aqueous 0.5M perchloric acid (60 mL) was heated under reflux for 3 h. T.l.c. (ethyl acetate) then showed that **2** had disappeared and that a new product (not mobile) was present. The mixture was neutralised with Lewatid MP 69 (HCO_3^-) resin and concentrated to dryness, and a solution of the residue in methanol (20 mL) was treated with activated charcoal and then concentrated. P.c. of the syrupy residue (1.2 g) revealed two compounds (R_F 0.62 and 0.54); the major component had the same mobility (R_F 0.62) as 1-deoxy-3-*C*-methyl-D-psicose[8] (**20**) and consequently the minor component (R_F 0.54) was 1-deoxy-3-*C*-methyl-D-tagatose (**21**).

Treatment of the above mixture (1.2 g) with dry acetone (60 mL), conc. sulfuric acid (0.3 mL), and anhydrous copper sulfate (2 g) gave a product (1.3 g) which was shown by t.l.c. to be a complex mixture. Column chromatography (ether–hexane, 1:3) afforded 2,6-anhydro-1-deoxy-3,4-*O*-isopropylidene-3-*C*-methyl-β-D-psicofuranose (**22**, 640 mg), m.p., 53–54°, $[\alpha]_D$ −53° (*c* 1.2); lit.[8] m.p. 53–54°, $[\alpha]_D$ −52° (*c* 1.2). Eluted second was 1-deoxy-3,4-*O*-isopropylidene-3-*C*-methyl-β-D-tagatofuranose (**23**, 35 mg), R_F 0.09, m.p. 103–105°, $[\alpha]_D$ +11.2° (*c* 0.9); ν_{max}^{KBr} 3433 and 3303 (OH), 2989, 2940, and 2902 (C–H), 1375 (CMe_2), 1244, 1120, 1092, 1039, 959, 894, and 853 cm^{-1} (1,3-dioxolane ring). N.m.r. data: ^1H, δ 4.42 (d, 1 H, $J_{4,5}$ 3.5 Hz, H-4), 4.19 (dt, 1 H, $J_{5,6}$ 5.5 Hz, H-5), 3.85 (broad d, 2 H, H-6,6'), 3.36 (s, 1 H, HO-2), 2.95 (broad s, HO-6), 1.46, 1.42, and 1.39 (3 s, 6, 3, and 3 H, H-1,1,1, Me-3, and CMe_2); ^{13}C, δ 112.95 (CMe_2), 106.43 (C-2), 92.62 (C-3), 87.05 (C-5), 78.42 (C-4), 60.87 (C-6), 27.85 and 27.32 (CMe_2), 22.07 (C-1), and 20.57 (Me-3).

Anal. Calc. for $C_{10}H_{18}O_5$: C, 55.03; H, 8.31. Found: C, 54.81; H, 8.55.

Conventional treatment of **23** (180 mg, 0.8 mmol) with pyridine (2 mL) and acetic anhydride (1 mL) gave, after column chromatography (ether–hexane, 1:1), the 6-acetate **24** (170 mg, 82%), which crystallised on standing; m.p. 71–73°, $[\alpha]_D$ +19° (*c* 1.1); ν_{max}^{film} 3462 (OH), 2992 and 2942 (C–H), 1749 (acetate, C=O), 1378 (CMe_2), 1248 (acetate, C–O), 1120, 1090, 1040, 939, and 880 cm^{-1} (1,3 dioxolane ring). N.m.r. data: δ 4.50–4.05 (m, 4 H, H-4,5,6,6'), 2.22 (s, 1 H, HO-2), 2.08 (s, 3 H, Ac), 1.48, 1.47, 1.42, and 1.40 (4 s, 12 H, H-1,1,1, Me-3, and CMe_2).

Hydrolysis of **3**. — Compound **3** (1.2 g, 6 mmol) was hydrolysed with aqueous

0.5M perchloric acid (40 mL) for 3 h, as described above, to give a syrup (760 mg) which contained (p.c.) **20** and **21** (major product).

Conventional acetonation of the above mixture with dry acetone (40 mL), conc. sulfuric acid (0.2 mL), and anhydrous copper sulfate (1.5 g), followed by column chromatography (ether–hexane, 1:3) of the product (890 mg), gave **22** (140 mg), **23** (135 mg), and 1-deoxy-3,4-*O*-isopropylidene-3-*C*-methyl-α-D-tagatofuranose (**25**, 60 mg), R_F 0.26, $[\alpha]_D$ +26° (*c* 1.1); ν_{max}^{film} 3460 (OH), 2992 and 2942 (C–H), 1379 (CMe_2), 1246, 1216, 1117, 1054, 1025, and 926 cm^{-1} (1,3-dioxolane ring). N.m.r. data: δ 4.35 (broad t, 1 H, H-5), 4.20–3.75 (m, 2 H, H-6,6′), 4.67 (d, 1 H, $J_{4,5}$ 5 Hz, H-4), 2.70 (s, 1 H, HO-2), 2.40 (broad s, 1 H, HO-6), 1.40, 1.38, and 1.36 (3 s, 6, 3, and 3 H, H-1,1,1, Me-3, and CMe_2).

Anal. Calc. for $C_{10}H_{18}O_5$: C, 55.03; H, 8.31. Found: C, 55.39; H, 7.98.

Conventional treatment of **25** (45 mg, 0.2 mmol) with pyridine (0.5 mL) and acetic anhydride (0.25 mL) afforded, after column chromatography (ether–hexane, 1:1), the 6-acetate **26** (30 mg, 58%) as a syrup, $[\alpha]_D$ +38° (*c* 1.2); ν_{max}^{film} 3457 (OH), 2990 and 2941 (C–H), 1746 (acetate, C=O), 1379 (CMe_2), 1244 (acetate, C–O), 1168, 1109, 1038, 940, and 880 cm^{-1} (1,3-dioxolane ring). N.m.r. data: δ 4.47–4.02 (m, 3 H, H-5,6,6′), 3.71 (d, 1 H, $J_{4,5}$ 6 Hz, H-4), 2.25 (s, 1 H, HO-2), 2.05 (s, 3 H, Ac), 1.47, 1.43, and 1.40 (3 s, 3, 6, and 3 H, H-1,1,1, Me-3, and CMe_2).

ACKNOWLEDGMENTS

We thank Dr. M. D. Portal Olea (University of Granada) for collaboration in the initial steps of this work, Dr. J. Garcia Suárez (University of Granada) for the g.l.c. analysis, and the Departamento de Investigaciones Instrumentales de D.G.F. (Granada) for the mass spectra.

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