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A short and efficient synthesis of α-*C*-(1 → 3)-linked disaccharides containing deoxyhexopyranoses

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Abstract—Ozonolysis of peracetylated α-D-glucopyranosylprop-2-ene, followed by the reaction of the formed ozonide with (thiazol-2-yl)carbonylmethylenetriphenyl phosphorane, afforded substituted 1-oxa-1,3-butadiene, which by a hetero-Diels–Alder reaction with ethyl vinyl ether gave a 1:1 mixture of two diastereoisomeric dihydropyran derivatives. These, after replacement of the acetyl protecting groups by benzyl groups, were separated by chromatography and their thiazole substituent converted to an aldehyde group. Subsequent hydroboration afforded α-*C*-(1 → 3)-linked disaccharides in which D-glucose is linked by a methylene bridge with 2,3-dideoxy-*arabino*-hexopyranose of D- or L-configuration. Structures of the obtained compounds have been confirmed by NMR spectroscopy and X-ray crystallographic analysis.

1. Introduction

Interactions of cell-surface oligosaccharides and glycoconjugates (glycoproteins or glycolipids) with lectins represent an essential part of cell communication system and influence significantly many vital processes, including cell recognition, cell differentiation and cell adhesion.[1] Although many of these processes are generally beneficial, glycoconjugates are also involved in a number of detrimental processes such as inflammation, viral and bacterial infections, and tumour metastasis. It is therefore assumed that compounds that could inhibit, for example, biosynthesis of glycoproteins participating in the mentioned detrimental processes, and/or disturb interactions of glycoproteins with lectins, might find use as compounds with therapeutic effects. One of the more suitable candidates for such compounds are *C*-disaccharides, which are analogues of natural disaccharides but in which the interglycosidic oxygen atom is replaced by a methylene group.[2] Although this change can influence the conformational arrangement about the original C–O–C bonds, it is assumed that *C*-disaccharides mimic well the structures of the natural disaccharides but unlike them resist acidic as well as enzyme hydrolysis.[3] One can therefore expect that *C*-disaccharides could, for example, form nonhydrolyzable epitopes of cell surface glycoconjugates, thus disturbing their interactions with proteins, or they could inhibit the enzymes involved in the biosynthesis of glycoconjugates. For these reasons, there is an increased interest in the search for new synthetic pathways leading to *C*-disaccharides and in the study of their properties.[4–7] Due to the great structural variety of disaccharides, where, for example, one hexopyranose can be attached by an α- or β-anomeric bond to five different positions (i.e., positions 1, 2, 3, 4 or 6) of the second hexopyranose, the existing methods of preparation of *C*-disaccharides are usually multistep syntheses, with low overall yields. As a rule, the hitherto published syntheses make it possible to prepare only one particular type of *C*-disaccharide, and more universal methods enabling synthesis of a wider variety of *C*-disaccharides appear only sporadically (see lit.[4u]). Therefore, a search for further simple syntheses of various types of *C*-disaccharides is desirable, particularly for those which could afford the final compounds in quantities sufficient for testing their activities.

As concerns *C*-(1 → 3)-disaccharides, some types of *C*-(1 → 3)-disaccharides are already known in which the two monosaccharides are linked by a –CH_2–,[5] –CH(OH)–[6] or –CO–[7] bridge. Recently, the epimeric pair α-*C*-(1 → 3)-mannopyranoside of *N*-acetylgalactosamine and α-*C*-(1 → 3)-mannopyranoside of

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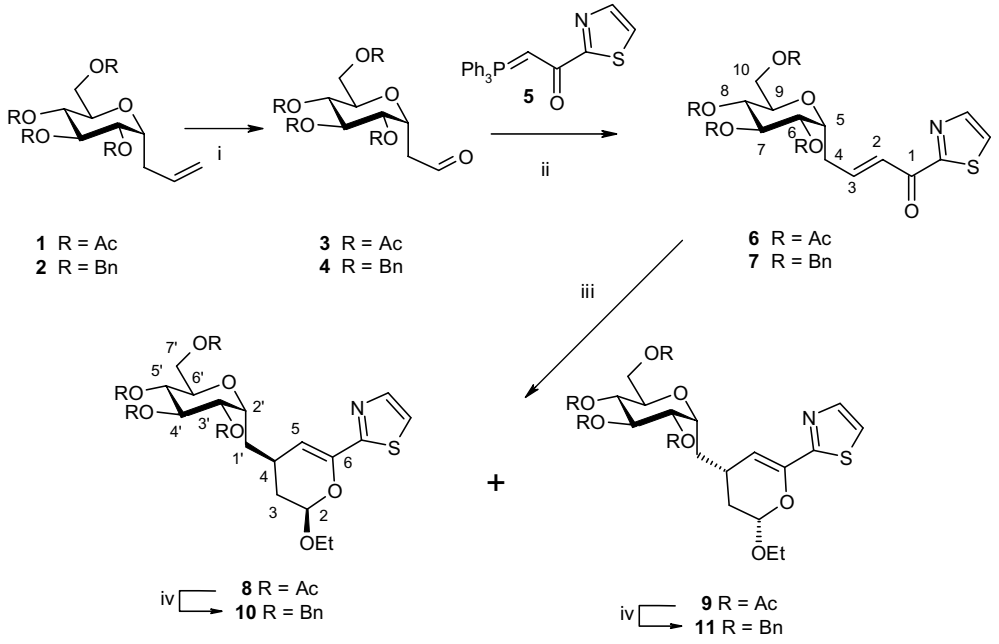
N-acetyltalosamine has been prepared. For the first isomer, it has been shown experimentally that this type of *C*-disaccharide indeed exhibited inhibitory effects towards several glycosidases and human α-1,3-fucosyltransferase.[8] In our previous studies we reported a method of converting a formyl group into a new dideoxyhexopyranose. Using this approach, we prepared compounds in which two monosaccharides were linked either by a direct C–C bond[9] or by a $–CH_2–$ bridge.[10] In a preliminary communication[11] we have shown that new α-*C*-(1 → 3)-disaccharides containing deoxyhexopyranoses can be prepared using the same methodology. We herein report details of this approach that allows direct and rapid synthesis of two diastereoisomeric α-*C*-(1 → 3)-disaccharides in which D-glucose is linked by a methylene bridge with 2,3-dideoxy-*arabino*-hexopyranose in the D- and L-configuration, respectively.

2. Results and discussion

For starting compounds in the synthesis, we used peracetylated and perbenzylated α-D-glucopyranosylprop-2-enes **1** and **2**, respectively, which are accessible even in multigram quantities and with ozonolysis can readily afford the respective peracetylated and perbenzylated α-D-glucopyranosylethanal **3**[12] and **4**[13] (Scheme 1).

First we used 1-(2′,3′,4′,6′-tetra-*O*-acetyl-α-D-glucopyranosyl)-prop-2-ene **1**,[14] which can be easily separated from the minor β-anomer by crystallization from a ether/light petroleum or chloroform/hexane mixture. The thus obtained pure diastereoisomer **1** (mp 108 °C) on ozonolysis in dichloromethane afforded 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosylethanal **3** in 80% yield, and this on heating with stabilized ylide **5**[15] in chloroform and subsequent chromatography gave oxadiene **6** in a yield of 80%. The *trans*-configuration of oxadiene **6** was unequivocally proven on the basis of the vicinal interaction of olefinic protons H-2/H-3 (15.7 Hz) in the ^1H NMR spectrum. Cycloaddition reaction of oxadiene **6** with ethyl vinyl ether at room temperature, catalyzed by $Eu(fod)_3$ (8 mol %), afforded a mixture of the two *endo*-cycloadducts **8** and **9** in 90% yield. Similarly to the synthesis of branched-chain sugars,[10] we observed no chiral induction of the monosaccharide moiety in the cycloaddition reaction, the *endo*-cycloadducts **8** and **9** being formed in the ratio 1:1 (as determined by ^1H NMR spectroscopy and HPLC). Moreover, the NMR spectra did not detect any other (i.e., *trans*) diastereoisomers in the obtained crude cycloadduct mixture. NMR experiments have shown NOE between protons H-2 and H-4 in both compounds **8** and **9**, which proves their relative *cis*-configuration on the dihydropyran ring. Unfortunately, the obtained mixture of cycloadducts was not separable by simple preparative column chromatography on silica gel. Therefore, we repeated the reaction with 1-(2′,3′,4′,6′-tetra-*O*-benzyl-α-D-glucopyranosyl)-prop-2-ene **2**.

In the case of this compound, the pure α-anomer **2** was not accessible by simple crystallization as in the case of the peracetylated derivative **1**. However, the undesired minor β-anomer could be removed by repeated chromatography on silica gel in light petroleum containing 2.7% of ethyl acetate. Ozonolysis of the thus obtained pure diastereoisomer **2** (mp 59–60 °C) afforded aldehyde **4** in a somewhat lower yield (71%) than in the case of peracetylated derivative **1**. The subsequent Wittig reaction with ylide **5** afforded, after chromatography on



Scheme 1. Reagents and conditions: (i) O_3, CH_2Cl_2, −80 °C, 40 min, then Me_2S, 2 d; (ii) **5**, $CHCl_3$, 60 °C, 24 h; (iii) ethyl vinyl ether, $Eu(fod)_3$ (8 mol %), CH_2Cl_2, rt, 6 h; (iv) (a) KCN/MeOH, rt, 1 h, (b) NaH, BnBr, THF, 50 °C, 5 h.

silica gel, oxadiene **7** in a yield of 70%. In this case, however, it was not possible to prove the *trans*-configuration of the C=C bond in the oxadiene **7** directly from the coupling constants in the ^{1}H NMR spectrum, since in this region the spectrum was overlapped by signals of aromatic protons. The oxadiene **7** was assigned a *trans*-configuration because in the cycloaddition reaction with ethyl vinyl ether, it afforded only two perbenzylated cycloadducts, **10** and **11**, of the same configuration as the peracetylated cycloadducts **8** and **9** arising from *trans*-oxadiene **3** (vide infra).

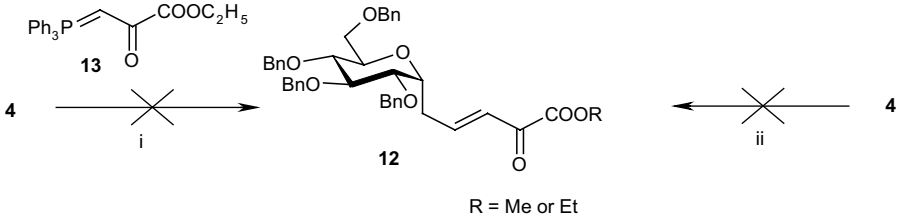
At this stage, we tried to prepare another oxadiene, **12**, substituted by an ester group, which also represents a suitable reactant in the cycloaddition reaction with ethyl vinyl ether. Although we have previously prepared such oxadienes in good yields[16] from other sugar aldehydes by a Wittig reaction with ylide **13**,[17] the reaction with aldehyde **4** under the same conditions afforded only a complex mixture of several compounds. Equally unsatisfactory results (complex reaction mixture) were also obtained in the attempted preparation of oxadiene **12** by a Mukayiama modification of the aldol reaction, that is, by the reaction of dimethylacetal of aldehyde **4** with methyl 2-(trimethylsilyloxy)acrylate[18] (Scheme 2). For this reason we only further studied the cycloaddition reactions of oxadiene **6** or **7**.

Cycloaddition of perbenzylated oxadiene **7** with ethyl vinyl ether under the same conditions as for the reaction with peracetylated oxadiene **6**, afforded a 1:1 mixture of two cycloadducts which, unlike the pair **8** and **9**, could be separated well by preparative flash chromatography on silica gel. As shown by mass and NMR spectra, the products were diastereoisomeric compounds **10** and **11**. The presence of NOE between protons H-2 and H-4 in both compounds proved a relative *cis*-configuration of substituents on the dihydropyran ring, similarly to the pair **8** and **9**. In order to compare the configuration of the peracetylated cycloadducts **8** and **9** with that of the perbenzylated cycloadducts **10** and **11**, we decided to convert the mixture of **8** and **9** into a mixture of **10** and **11** by deacetylation followed by benzylation. For deacetylation, treatment with a solution of KCN in methanol[19] appeared to be the optimal method. This method led to only two diastereoisomeric deacetylated products (according to NMR spectra). Repeated experiments using classical Zemplén deacetylation methods (CH_3ONa in CH_3OH) have shown that in the final neutralization of the alkaline reaction mixture only very small excesses of the acid is needed for partial decomposition of the deacetylation products. Subsequent benzylation in tetrahydrofuran[20] gave a mixture of compounds **10** and **11**, thus proving that the pairs **8** and **9** and **10** and **11** have identical configurations.

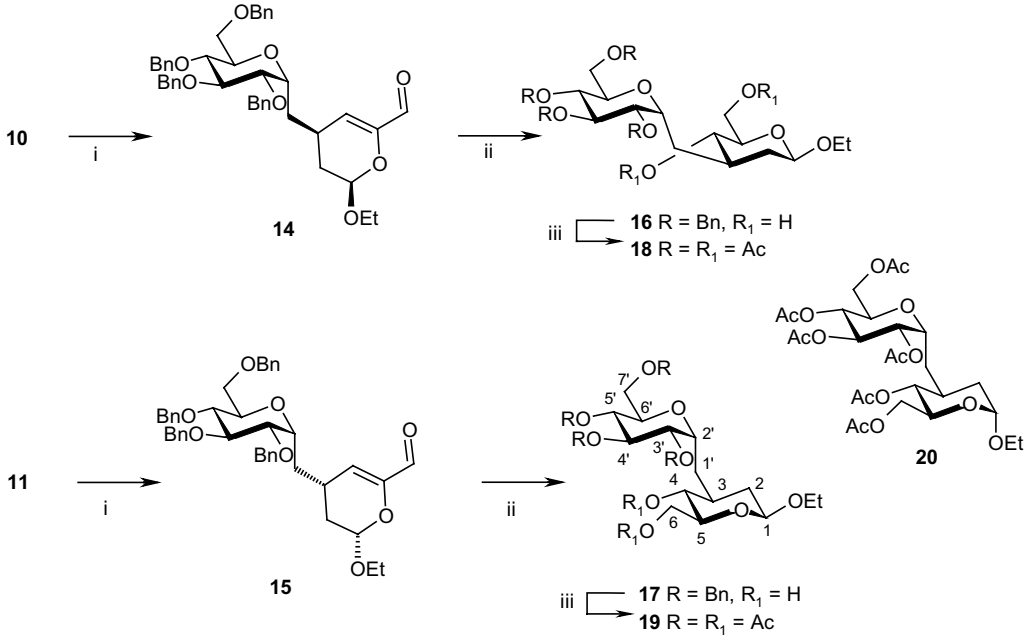
Concerning the economy of the synthesis, the optimal method consists at the combined use of both the protecting groups. We have found that when starting with the easily accessible peracetylated α-D-glucopyranosylprop-2-ene **1**, it is not necessary to isolate the arising aldehyde **3**, as the intermediary ozonide can be decomposed directly with the thiazole ylide **5**, analogously as already described for decomposition of ozonides with other stabilized ylides.[21] In this way, we converted the starting compound **1** into *trans*-oxadiene **6** in 75% yield without isolating aldehyde **3**. Further synthetic steps, consisting of cycloaddition, deacetylation and finally benzylation of the mixture of cycloadducts **8** and **9** (see Scheme 1), afforded a chromatographically well separable 1:1 mixture of diastereoisomers **10** and **11**. Thus, the starting compound **1** was converted in four reaction steps into **10** and **11** in an overall yield of 56%.

After separation on silica gel, the individual diastereoisomers **10** and **11** were converted to the *C*-(1→3)-disaccharides. First, the thiazole ring was converted into an aldehyde group using a known procedure.[22] Thus, compounds **10** and **11** gave the respective aldehydes **14** and **15**, which were characterized by NMR spectra but, as potentially unstable compounds, they were immediately, without purification, subjected to hydroboration. Use of an excess of $BH_3{\cdot}S(CH_3)_2$ resulted in the simultaneous reduction of the aldehyde group and hydroboration of the C=C bond, which proceeded stereoselectively from the less hindered side of the dihydropyran ring. In this way, cycloadduct **14** was converted into partially benzylated *C*-(1→3)-disaccharide **16** and **15** into **17** (Scheme 3).

We decided to characterize both the obtained products as peracetylated derivatives. To this end, the crude products were debenzylated by hydrogenation on palladium and subsequently acetylated. In both cases we obtained crystalline products **18** (mp 160–162 °C, overall yield 53% from **10**) and **19** (mp 149–151 °C, overall yield 55% from **11**). According to NMR spectra, all substituents in both the new deoxypyranoses are in equatorial positions. This follows from the existence of NOE between protons H-1, H-3 and H-5 in both compounds, as well as from the well discernible coupling constants of protons H-1 and H-4, identical for both **18** and **19**



Scheme 2. Reagents and conditions: (i) **13**, $CHCl_3$, 60 °C; (ii) (a) trimethyl orthoformate, TsOH, (b) methyl 2-(trimethylsilyloxy)acrylate, TMSOTf.



Scheme 3. Reagents and conditions: (i) (a) MeOTf, MeCN, rt, 15 min, (b) $NaBH_4$, MeOH, rt, 15 min, (c) $AgNO_3$, $MeCN/H_2O$, rt, 20 min; (ii) (a) $Me_2S{\cdot}BH_3$, THF, rt, 18 h, (b) NaOH, H_2O_2, rt, 40 min; (iii) (a) H_2/Pd–C, MeOH, rt, 8 h, (b) Ac_2O, pyridine, DMAP, rt, 1 h.

($J_{1,2ax} = 9.3$ Hz, $J_{3,4} = J_{4,5} = 10.0$ Hz). These data confirm that the new deoxypyranoses in compounds **18** and **19** have the same relative configuration (*arabino*) and must be in an enantiomeric relationship. In one experiment, debenzylation of compound **17** was performed on Pd on carbon catalyst, contaminated by traces of acid, and after acetylation we obtained compound **19**, mixed with its anomer **20**. Repeated crystallization of this mixture from acetone/light petroleum afforded an analytical sample of pure compound **20**, mp 137–139 °C. Its NMR spectra confirmed an axial position of the ethoxy group ($J_{1,2ax} = 3.4$ Hz, $J_{1,2eq} \approx 0$ Hz). Both compounds gave monocrystals suitable for X-ray crystallographic analysis. The obtained structures of compounds **19** and **20** are given in Figure 1. As can be seen, the X-ray analysis confirms the relative configuration of the dideoxy-*arabino*-hexopyranose ring as has been determined by the NMR spectra and shows unequivocally that the dideoxy-*arabino*-hexopyranose moiety in compounds **19** and **20** has the L-configuration. From this fact it follows that the dideoxy-*arabino*-hexopyranose moiety in compound **18** has the D-configuration.

3. Conclusion

In summary, we have described a short and efficient route to α-*C*-(1→3)-disaccharides in which either D-glucose is linked with ethyl 2,3-dideoxy-*arabino*-hexopyranoside of D- or L-configuration. The starting compound is the easily accessible peracetylated α-D-glucopyranosylprop-2-ene. The key step of the synthesis is the *endo*-selective cycloaddition reaction affording, after the exchange of the protecting groups, a mixture of

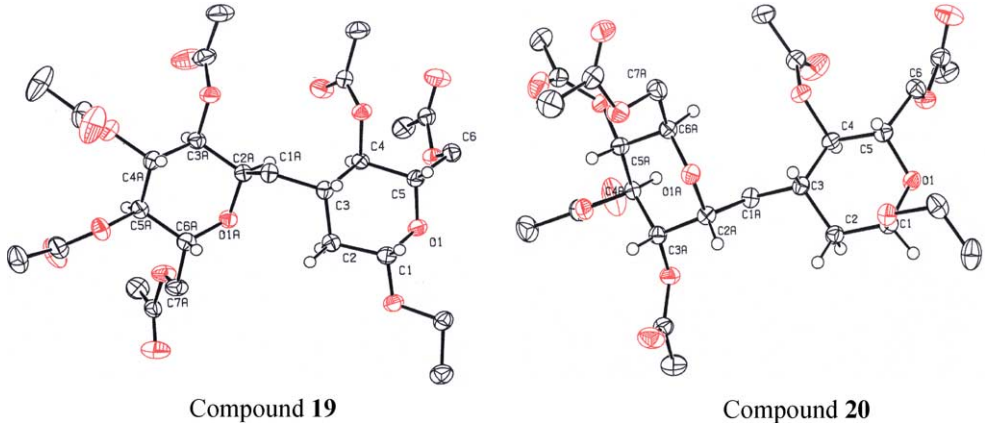


Figure 1. ORTEP drawing of **19** and **20** (30% probability ellipsoids). The hydrogen atoms (except ring hydrogens) are omitted for clarity.

only two *cis*-cycloadducts **10** and **11**, which upon separation by flash chromatography on silica gel, gave in two reaction steps α-*C*-(1 → 3)-disaccharides **16** and **17**. The structure of the obtained α-*C*-(1 → 3)-disaccharides was unequivocally determined by the NMR spectra of compounds **18**, **19** and **20** and X-ray crystallographic analysis of compounds **19** and **20**. Since pyranosylprop-2-enes of other configurations (e.g., *galacto* and *manno*) are also easily available, we suppose that our strategy enables the preparation of a wider series of *C*-(1 → 3)-disaccharides in quantities sufficient enough for extended screenings of their properties.

4. Experimental

4.1. General

Melting points are not corrected. TLC was performed on HF_{254} plates (Merck) with detection by UV light or by spraying with a solution of 5 g $Ce(SO_4)_2(H_2O)_4$ in 500 mL 10% H_2SO_4 and subsequent heating. Flash column chromatography was performed on silica gel (Merck, 100–160 μm) in solvents, distilled prior to use. Optical rotations were measured at 25 °C on a spectropolarimeter JASCO DIP-370. ^1H and ^{13}C NMR spectra were taken on a Bruker DRX 500 Avance spectrometer at 500.132 MHz for ^1H NMR and at 125.767 MHz for ^{13}C NMR. The spectra obtained in that $CDCl_3$ solutions and chemical shifts in ^1H and ^{13}C NMR spectra are given in parts per million (δ) relative to the peaks of $CHCl_3$ (7.27 and 77.0, respectively) in $CDCl_3$. ^1H and ^{13}C NMR signal assignments were confirmed by 2D COSY and HMQC when necessary. NOE connectivities were obtained using 1D ^1H DPFGSE-NOE experiment.[23] Mass spectra were measured on a Waters Q-TOF micromass spectrometer operating at a direct inlet system.

4.2. 5,9-Anhydro-6,7,8,10-tetra-*O*-acetyl-2,3,4-trideoxy-1-*C*-(2-thiazolyl)-D-*glycero*-D-*ido*-dec-2-enose 6

A solution of compound **1**[14] (9 g, 24.2 mmol) in dichloromethane (150 mL) was ozonized at −80 °C to a persisting blue colouration (about 40 min). Ylide **5** (14.1 g, 36.4 mmol) was added and the mixture stirred at room temperature for 16 h. The mixture was then partitioned between water and dichloromethane. The organic phase was dried, the solvent evaporated in vacuo and the residue chromatographed on silica gel. Product **6** (8.77 g, 75%) was obtained as a pale yellow oil. $R_F = 0.4$ (light petroleum/ethyl acetate, 2:1). $[\alpha]_D = +94.5$ (*c* 1.0, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 8.02 (d, 1H, $J = 2.9$ Hz, C*H*-thiazole), 7.70 (d, 1H, $J = 2.9$ Hz, C*H*-thiazole), 7.41 (d, 1H, $J = 15.7$ Hz, H-2), 7.25 (ddd, 1H, $J = 15.7$ Hz, $J = 7.1$ Hz, $J = 3.0$ Hz, H-3), 5.34 (dd, 1H, $J = 9.2$ Hz, $J = 8.9$ Hz, H-7), 5.13 (dd, 1H, $J = 8.9$ Hz, $J = 5.5$ Hz, H-6), 4.96 (dd, 1H, $J = 8.9$ Hz, $J = 8.8$ Hz, H-8), 4.42 (ddd, 1H, $J = 4.9$ Hz, $J = 4.8$ Hz, $J = 5.5$ Hz, H-5), 4.25 (dd, 1H, $J = 12.2$ Hz, $J = 6.0$ Hz, H-10a), 4.04 (dd, 1H, $J = 12.2$ Hz, $J = 2.1$ Hz, H-10b), 3.92 (m, 1H, H-9), 2.85 (m, 1H, H-4a), 2.63 (m, 1H, H-4b), 2.06, 2.05, 2.04, 2.00 (s, 4 × 3H, 4 × O=C–*C*H$_3$). ^{13}C NMR (125 MHz, $CDCl_3$) δ (ppm): 180.85 (C-1), 170.55, 196.88, 169.5, 169.41, 169.37 (4 × O=*C*–CH$_3$), 167.65 (thiazole C-2), 144.68 and 126.46 (2 × *C*H-thiazole), 144.62 (C-2), 126.94 (C-3), 71.16 (C-5), 69.87 (C-7), 69.73 (C-6), 69.17 (C-9), 68.40 (C-8), 61.90 (C-10), 29.74 (C-4), 20.49, 20.47, 20.44, 20.38 (4 × O=C–*C*H$_3$). MS (ESI): 484.2 $(M+H)^+$. Anal. Calcd for $C_{21}H_{25}NO_{10}S$ (MW 483.50): C, 52.17; H, 5.21; N, 2.90; S, 6.63. Found: C, 51.93; H, 5.11; N, 2.99; S, 6.85.

4.3. 5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,3,4-trideoxy-1-*C*-(2-thiazolyl)-D-*glycero*-D-*ido*-dec-2-enose 7

To a solution of aldehyde **4**[13] (5.1 g, 9.0 mmol) in chloroform (40 mL) was added ylide **5** (7.3 g, 18.8 mmol) and the reaction mixture then heated at 60 °C for 24 h. The solvent was evaporated in vacuo and the residue was purified by chromatography on silica gel in light petroleum/ethyl acetate (15:1). Yield 4.2 g (70%) of compound **7** as oil. $R_F = 0.8$ (light petroleum/ethyl acetate, 5:1). $[\alpha]_D = +59.5$ (*c* 1.0, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.98 (d, 1H, $J = 2.9$ Hz, C*H*-thiazole), 7.63 (d, 1H, $J = 2.9$ Hz, C*H*-thiazole), 7.38–7.13 (m, 22H, 4 × C$_6$*H*$_5$, H-2, H-3), 4.95–4.41 (m, 8H, 4 × –O–C*H*$_2$–Ph), 4.28 (ddd, 1H, $J = 9.7$ Hz, $J = 4.9$ Hz, $J = 4.9$ Hz, H-5), 3.81–3.59 (m, 6H, H-6, H-7, H-8, H-9, H-10a, H-10b), 2.78 (m, 2H, H-4a, H-4b). ^{13}C NMR (125 MHz, $CDCl_3$) δ (ppm): 181.14 (C-1), 168.06 (thiazole C-2), 147.35, (C-3), 144.59 and 126.16 (2 × *C*H-thiazole), 128.39–126.36 (aromatic C, C-2), 82.17, 79.59, 77.45, 71.49 (C-6, C-7, C-8, C-9), 75.37, 74.93, 73.37, 73.28 (4 × –O–*C*H$_2$–Ph), 73.18 (C-5), 68.59 (C-10), 29.33 (C-4). MS (ESI): 676.4 $(M+H)^+$. Anal. Calcd for $C_{41}H_{41}NO_6S$ (MW 604.61): C, 72.86; H, 6.11; N, 2.07; S, 4.74. Found: C, 73.08; H, 6.32; N, 1.95; S, 4.52.

4.4. (2*R*,4*R*)- and (2*S*,4*S*)-4-(2′,6′-Anhydro-3′,4′,5′,7′-tetra-*O*-benzyl-1′-deoxy-D-*glycero*-D-*ido*-heptitol-1′-yl)-2-ethoxy-6-(2-thiazolyl)-3,4-dihydro-2*H*-pyran 10 and 11

4.4.1. From oxadiene 6. Ethyl vinyl ether (5.3 mL, 55.4 mmol) and $Eu(fod)_3$ (1.1 g, 1.1 mmol) were added to a solution of **6** (6.7 g, 13.8 mmol) in dichloromethane (35 mL) and the reaction mixture sonicated for 6 h at room temperature. The solvent and any excess ethyl vinyl ether were evaporated. Chromatography of the residue (light petroleum/ether, 1:4) afforded 6.95 g of a 1:1 mixture of compound **8** and **9**, $R_F = 0.4$ (dichloromethane/light petroleum/ether, 4:1:1). ESI MS: 556.2. $(M+H)^+$. To a solution of the thus obtained mixture of **8** and **9** in methanol (60 mL) was added KCN (0.41 g, 6.2 mmol) and the mixture stirred at room temperature until the starting compound disappeared (TLC analysis, about 1 h). The solvent was evaporated, the residue dissolved in a chloroform/methanol (5:1) mixture, filtered through a short column of silica gel and the solvent evaporated again. The residue (4.60 g, 11.9 mmol) was dissolved in tetrahydrofuran (350 mL) and NaH

(3.55 g of 60% suspension in mineral oil, 88.9 mmol) added. After stirring at room temperature for 1.5 h, benzyl bromide (8.46 mL, 71.1 mmol) was added dropwise, followed by tetrabutylammonium iodide (0.98 g, 2.7 mmol), and the mixture then heated at 50 °C for 5 h. Methanol (10 mL) was added and the reaction mixture partitioned between dichloromethane and water. The organic phase was dried, evaporated and the residue chromatographed on silica gel (light petroleum/ethyl acetate, 15:1 → 4:1), yielding 3.73 g (36%) of **10** and 3.91 g (38%) of **11**.

4.4.2. From oxadiene 7. Ethyl vinyl ether (1.25 mL, 13.1 mmol) and Eu(fod)$_3$ (0.26 g, 0.26 mmol) were added to a solution of **7** (2.1 g, 3.1 mmol) in dichloromethane (15 mL) and the reaction mixture sonicated at room temperature for 7 h. The solvent and the excess ethyl vinyl ether were evaporated. Chromatography of the residue (light petroleum/ethyl acetate, 15:1 → 4:1) afforded 1.02 g (44%) of compound **10** and 1.05 g (46%) of compound **11**.

Compound **10**: $R_F = 0.29$ (light petroleum/ethyl acetate, 8:1). $[\alpha]_D = +35.2$ (*c* 1.0, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.83 (d, 1H, $J = 3.3$ Hz, C*H*-thiazole), 7.17–7.32 (m, 21H, 4×C$_6H_5$, C*H*-thiazole), 6.08 (d, 1H, $J = 3.4$ Hz, H-5), 5.20 (dd, 1H, $J = 2.1$ Hz, $J = 6.8$ Hz, H-2), 4.96–4.48 (m, 8H, 4×C$_6$H$_5$–CH_2), 4.30 (m, 1H, H-2′), 4.02 (dq, 1H, $J = 9.6$ Hz, $J = 7.0$ Hz, –O–CH_2–CH$_3$), 3.82–3.62 (m, 8H, H-3′, H-4′, H-5′, H-6′, H-7′a, H-7′b, –O–CH_2–CH$_3$), 2.62 (m, 1H, H-4), 2.17 (ddd, 1H, $J = 2.1$ Hz, $J = 4.6$ Hz, $J = 11.5$ Hz, H-3$_{eq}$), 1.98 (m, 2H, H-1′a, H-1′b), 1.88 (ddd, 1H, $J = 6.8$ Hz, $J = 11.5$ Hz, $J = 11.5$ Hz, H-3$_{ax}$), 1.30 (t, 3H, $J = 7.0$ Hz, –O–CH$_2$–CH_3). ^{13}C NMR (125 MHz, $CDCl_3$) δ (ppm): 164.62 (thiazole C-2), 143.73 (C-6), 143.28 (*C*H-thiazole), 138.36, 138.27, 138.22, 138.12 (4×*ipso* C$_6$H$_5$–CH$_2$), 128.36–127.57 (20×C$_6$H$_5$–CH$_2$), 118.48 (*C*H-thiazole), 104.24 (C-5), 99.61 (C-2), 82.36, 80.13, 78.07, 72.31, 71.48 (C-2′, C-3′, C-4′, C-5′, C-6′), 75.42, 74.96, 73.53, 73.14 (4×C$_6$H$_5$-*C*H$_2$), 69.1 (C-7′), 64.65 (–O–*C*H$_2$–CH$_3$), 33.76 (C-3), 30.22 (C-1′), 27.67 (C-4), 15.27 (–O–CH$_2$–*C*H$_3$). MS (ESI): 748.2 (M+H)$^+$. Anal. Calcd for C$_{45}$H$_{49}$NO$_7$S (MW 747.96): C, 72.26; H, 6.60; N, 1.87; S, 4.29. Found: C, 72.11; H, 6.37; N, 1.98; S, 4.07.

Compound **11**: $R_F = 0.42$ (light petroleum/ethyl acetate, 8:1) $[\alpha]_D = +39.1$ (*c* 1.0, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 7.82 (d, 1H, $J = 3.3$ Hz, C*H*-thiazole), 7.15–7.38 (m, 21H, 4×C$_6H_5$, C*H*-thiazole), 5.97 (d, 1H, $J = 3.2$ Hz, H-5), 5.20 (dd, 1H, $J = 1.7$ Hz, $J = 6.7$ Hz, H-2), 4.97–4.50 (m, 8H, 4×C$_6$H$_5$–CH_2), 4.25 (m, 1H, H-2′), 4.05 (dq, 1H, $J = 9.6$ Hz, $J = 7.0$ Hz, –O–CH_2–CH$_3$), 4.08-3.59 (m, 8H, H-3′, H-4′, H-5′, H-6′, H-7′a, H-7′b, –O–CH_2–CH$_3$), 2.67 (m, 1H, H-4), 2.22 (ddd, 1H, $J = 1.7$ Hz, $J = 2.6$ Hz, $J = 13.3$ Hz, H-3$_{eq}$), 2.09 (m, 1H, H-1′a), 1.87 (m, 1H, H-1′b), 1.75 (ddd, 1H, $J = 6.7$ Hz, $J = 13.3$ Hz, $J = 13.3$ Hz, H-3$_{ax}$), 1.30 (t, 3H, $J = 7.0$ Hz, O–CH$_2$–CH_3). ^{13}C NMR (125 MHz, $CDCl_3$) δ (ppm): 164.40 (thiazole C-2), 143.86 (C-6), 143.29 (*C*H-thiazole), 138.68, 138.22, 138.04 (4×*ipso* C$_6$H$_5$–CH$_2$), 128.49–127.57 (20×C$_6$H$_5$–CH$_2$), 118.40 (*C*H-thiazole), 105.65 (C-5), 99.85 (C-2), 82.53, 79.95, 77.99, 71.45, 71.32 (C-2′, C-3′, C-4′, C-5′, C-6′), 77.56, 76.36, 73.47, 72.83 (4×C$_6$H$_5$-*C*H$_2$), 68.89 (C-7′), 64.74 (O-*C*H$_2$–CH$_3$), 32.36 (C-3), 30.16 (C-1′), 27.15 (C-4), 15.28 (–O–CH$_2$–*C*H$_3$). MS (ESI): 748.2 (M+H)$^+$. Anal. Calcd for C$_{45}$H$_{49}$NO$_7$S (MW 747.96): C, 72.26; H, 6.60; N, 1.87; S, 4.29. Found: C, 71.98; H, 6.42; N, 1.73; S, 4.13.

4.5. (2*R*,4*R*)-4-(2′,6′-Anhydro-3′,4′,5′,7′-tetra-*O*-benzyl-1′-deoxy-D-*glycero*-D-*ido*-heptitol-1′-yl)-2-ethoxy-6-formyl-3,4-dihydro-2*H*-pyran 14

Molecular sieves 4 Å (2.6 g) were added to a solution of compound **10** (3.8 g, 5.1 mmol) in acetonitrile (70 mL), and methyl triflate (0.76 mL, 6.7 mmol) added dropwise. After stirring at room temperature for 15 min, methanol (3 mL) was added and the solvent evaporated in vacuo. The residue was treated with methanol (80 mL) and then $NaBH_4$ (0.66 g, 17.4 mmol) was added in portions. After stirring at room temperature for 15 min, acetone (7 mL) was added. The reaction mixture was filtered through Supercel and the filtrate evaporated in vacuo. The residue was dissolved in acetonitrile (60 mL) and a solution of $AgNO_3$ (1.4 g) in water (4.6 mL) was added under vigorous stirring. After stirring for 10 min, phosphate buffer (20 mL, pH 7) was added and after a further 10 min the acetonitrile was evaporated in vacuo and the residue partitioned between dichloromethane and phosphate buffer (pH 7). The organic phase was dried, the solvent evaporated and the residue flash chromatographed through a short silica gel column in light petroleum/ethyl acetate (4:1 → 1:1). Yield 2.47 g (70%) of aldehyde **14**, $R_F = 0.4$ (light petroleum/ethyl acetate, 3:1), which was immediately used in the subsequent reaction step. ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 9.10 (s, 1H, –C*H*=O), 7.37–7.23 (m, 20H, 4×C$_6H_5$), 5.85 (d, 1H, $J = 3.9$ Hz, H-5), 5.14 (dd, 1H, $J = 4.9$ Hz, $J = 2.5$ Hz, H-2), 4.92–4.46 (m, 8H, 4×C$_6$H$_5$–CH_2), 4.09 (m, 1H, H-2′), 3.90 (dq, 1H, $J = 9.6$ Hz, $J = 7.0$ Hz, –O–CH_2–CH$_3$), 3.78–3.55 (m, 7H, H-3′, H-4′, H-5′, H-6′, H-7′a, H-7′b, –O–CH_2–CH$_3$), 2.56 (m, 1H, H-4), 2.01 (m, 3H, H-1′a, H-1′b, H-3$_{eq}$), 1.86 (ddd, 1H, $J = 13.8$ Hz, $J = 4.9$ Hz, $J = 4.9$ Hz, H-3$_{ax}$), 1.18 (t, 3H, $J = 7.1$ Hz, –O–CH$_2$–CH_3). ^{13}C NMR (125 MHz, $CDCl_3$) δ (ppm): 187.06 (–*C*H=O), 149.43 (C-6), 138.60, 138.23, 138.10, 137.88 (4×*ipso* C$_6$H$_5$–CH$_2$), 128.43–127.64 (20×C$_6$H$_5$–CH$_2$), 125.95 (C-5), 98.41 (C-2), 82.37, 80.21, 77.97, 72.07, 71.37 (C-2′, C-3′, C-4′, C-5′, C-6′), 75.49, 74.99, 2×73.49 (4×C$_6$H$_5$–*C*H$_2$), 69.03 (C-7′), 64.54 (O–*C*H$_2$–CH$_3$), 32.49 (C-3), 29.69 (C-1′), 27.23 (C-4), 15.12 (–O–CH$_2$–*C*H$_3$). MS (ESI): 715.2 (M+Na)$^+$.

4.6. (2*S*,4*S*)-4-(2′,6′-Anhydro-3′,4′,5′,7′-tetra-*O*-benzyl-1′-deoxy-D-*glycero*-D-*ido*-heptitol-1′-yl)-2-ethoxy-6-formyl-3,4-dihydro-2*H*-pyran 15

The title aldehyde **15** was prepared from compound **11** (3.9 g) in the same manner as described in the preceding experiment. Yield 2.61 g (72%). ^{1}H NMR (500 MHz, $CDCl_3$): δ (ppm) 9.07 (s, 1H, –C*H*=O), 7.37–7.24 (m, 20H, 4×C$_6H_5$), 5.94 (d, 1H, $J = 3.9$ Hz, H-5), 5.14 (dd,

1H, $J = 5.5$ Hz, $J = 2.1$ Hz, H-2), 4.95–4.43 (m, 8H, $4\times C_6H_5$–CH_2), 4.17 (m, 1H, H-2′), 3.92 (dq, 1H, $J = 9.6$ Hz, $J = 7.0$ Hz, –O–CH_2–CH_3), 3.79–3.54 (m, 7H, H-3′, H-4′, H-5′, H-6′, H-7′a, H-7′b, –O–CH_2–CH_3), 2.58 (m, 1H, H-4), 2.06 (m, 2H, H-1′a, H-1′b), 1.90 (m, 1H, H-3_{eq}), 1.76 (ddd, 1H, $J = 13.8$ Hz, $J = 5.5$ Hz, $J = 5.5$ Hz, H-3_{ax}), 1.19 (t, 3H, $J = 7.0$ Hz, –O–CH_2–CH_3). ^{13}C NMR (125 MHz, $CDCl_3$) δ (ppm): 186.96 (–*C*H=O), 149.45 (C-6), 138.57, 138.07, 138.01, 137.79 ($4\times$ *ipso* C_6H_5–CH_2), 128.50–127.65 ($20\times C_6H_5$–CH_2, C-5), 98.57 (C-2), 82.24, 79.73, 78.07, 72.11, 71.38 (C-2′, C-3′, C-4′, C-5′, C-6′), 75.47, 75.05, 73.52, 73.06 ($4\times C_6H_5$–CH_2), 69.12 (C-7′), 64.58 (–O–CH_2–CH_3), 31.82 (C-3), 29.36 (C-1′), 27.97 (C-4), 15.15 (–O–CH_2–CH_3). MS (ESI): 715.2 $(M+Na)^+$.

4.7. Ethyl 2,3-dideoxy-3-*C*-(2′,6′-anhydro-3′,4′,5′,7′-tetra-*O*-acetyl-1′-deoxy-D-*glycero*-D-*ido*-heptitol-1′-yl)-4,6-di-*O*-acetyl-β-D-*arabino*-hexopyranoside 18

A 2 M solution of $BH_3{\cdot}S(CH_3)_2$ in tetrahydrofuran (4.5 mL, 9 mmol) was added dropwise to a solution of aldehyde **14** (2.29 g, 3.3 mmol) in tetrahydrofuran (70 mL), precooled to 0 °C, and the reaction mixture stirred at room temperature for 16 h. Then a 30% solution of NaOH (3.7 mL) and 30% solution of H_2O_2 (3.7 mL) was added and after stirring at room temperature for 30 min the reaction mixture was partitioned between ethyl acetate and saturated NaCl solution. The organic phase was dried, the solvent evaporated in vacuo and the residue dissolved in ethanol (150 mL) and hydrogenated over Pd/C (10%, 0.9 g) under atmospheric pressure. After 8 h, the catalyst was filtered off and the solvent evaporated. The residue was dissolved in pyridine (25 mL), acetic anhydride (10 mL) and dimethylaminopyridine (0.1 g) then added and the mixture stirred at room temperature for 1 h. The reaction mixture was poured onto ice, partitioned between water and ethyl acetate and the organic phase, after drying and evaporation of the solvent, was chromatographed on silica gel in light petroleum/ether (1:4). Yield 1.5 g (75%) of compound **18**, mp 159–162 °C (acetone/light petroleum).

$R_F = 0.35$ (light petroleum/ether, 1:4). $[\alpha]_D = +21.3$ (*c* 1, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ (ppm) 5.23 (dd, 1H, $J = 9.2$ Hz, $J = 9.6$ Hz, H-4′), 4.97 (dd, 1H, $J = 9.6$ Hz, $J = 5.8$ Hz, H-3′), 4.93 (dd, 1H, $J = 9.1$ Hz, $J = 9.2$ Hz, H-5′), 4.74 (dd, 1H, $J = 10.0$ Hz, $J = 10.0$ Hz, H-4), 4.52 (dd, 1H, $J = 1.3$ Hz, $J = 9.3$ Hz, H-1), 4.27 (dd, 1H, $J = 4.9$ Hz, $J = 12.1$ Hz, H-6a), 4.20 (m, 2H, H-7′a, H-2′), 4.11 (dd, 1H, $J = 2.1$ Hz, $J = 12.1$ Hz, H-7′b), 4.04 (dd, 1H, $J = 2.2$ Hz, $J = 12.1$ Hz, H-6b), 3.95 (dq, 1H, $J = 7.2$ Hz, $J = 9.4$ Hz, –O–CH_2–CH_3), 3.85 (m, 1H, H-6′), 3.59–3.50 (m, 2H, H-5, –O–CH_2–CH_3), 2.20 (m, 1H, H-2_{eq}), 2.14–2.01 (m, 18H, $6\times$O=C–CH_3), 1.90 (m, 1H, H-3), 1.64 (m, 2H, H-1′a, H-1′b), 1.51 (ddd, 1H, $J = 12.8$ Hz, $J = 9.3$ Hz, $J = 9.3$ Hz, H-2_{ax}), 1.23 (t, 3H, $J = 7.2$ Hz, –O–CH_2–CH_3). ^{13}C NMR (125 MHz, $CDCl_3$) δ (ppm): 170.86, 170.63, 170.30, 169.91, 169.63, 169.52 ($6\times$O=*C*–CH_3), 101.00 (C-1), 74.52 (C-5), 73.16 (C-2′), 71.42 (C-4), 70.19 (C-3′), 69.75 (C-4′), 69.01 (C-6′), 68.79 (C-5′), 64.76 (–O–CH_2–CH_3), 62.88 (C-6), 62.40 (C-7′), 37.39 (C-3), 37.23 (C-2), 27.16 (C-1′), 20.80–20.58 ($6\times$O=C–CH_3), 15.04 (–O–CH_2–CH_3). MS (ESI): 627.3 $(M+Na)^+$. HRMS (ESI): calcd for $C_{27}H_{40}NaO_{15}$ $(M+Na)^+$ 627.2265, found 627.2286.

4.8. Ethyl 2,3-dideoxy-3-*C*-(2′,6′-anhydro-3′,4′,5′,7′-tetra-*O*-acetyl-1′-deoxy-D-*glycero*-D-*ido*-heptitol-1′-yl)-4,6-di-*O*-acetyl-β-L-*arabino*-hexopyranoside 19

The title compound **19** was prepared from aldehyde **15** (2.6 g) in the same manner as described in the preceding experiment. Yield 1.72 g (76%) of **19**, mp 149–151 °C (acetone/light petroleum).

$R_F = 0.3$ (light petroleum/ether, 1:4). $[\alpha]_D = +85.9$ (*c* 1, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ (ppm) 5.24 (dd, 1H, $J = 8.9$ Hz, $J = 9.2$ Hz, H-4′), 5.06 (dd, 1H, $J = 9.2$ Hz, $J = 5.8$ Hz, H-3′), 4.91 (dd, 1H, $J = 8.9$ Hz, $J = 8.9$ Hz, H-5′), 4.73 (dd, 1H, $J = 10.0$ Hz, $J = 10.0$ Hz, H-4), 4.52 (dd, 1H, $J = 1.5$ Hz, $J = 9.6$ Hz, H-1), 4.26 (m, 2H, H-1, H-6a), 4.18 (m, 2H, H-7′a, H-7′b), 4.07 (dd, 1H, $J = 2.4$ Hz, $J = 12.1$ Hz, H-6b), 3.94 (dq, 1H, $J = 7.1$ Hz, $J = 9.3$ Hz, –O–CH_2–CH_3), 3.80 (m, 1H, H-6′), 3.59–3.50 (m, 2H, H-5, –O–CH_2–CH_3), 2.14–2.01 (m, 19H, $6\times$O=C–CH_3, H-3), 1.92 (m, 2H, H-2_{eq}, H-1′a), 1.40 (ddd, 1H, $J = 9.6$ Hz, $J = 9.6$ Hz, $J = 12.8$ Hz, H-2_{ax}), 1.29–1.20 (m, 4H, –O–CH_2–CH_3, H-1′b). ^{13}C NMR (125 MHz, $CDCl_3$) δ (ppm): 170.85, 170.50, 170.24, 169.92, $2\times$169.51 ($6\times$O=*C*–CH_3), 101.06 (C-1), 74.73 (C-5), 70.40 (C-4), 70.03 (C-3′), 69.90 (C-4′), 68.89 (C-5′), 68.78 (C-6′), 68.60 (C-2′), 64.79 (–O–CH_2–CH_3), 63.06 (C-6), 62.27 (C-7′), 35.13 (C-2), 34.55 (C-3), 26.64 (C-1′), 20.85–20.61 ($6\times$O=C–CH_3), 15.06 (–O–CH_2–CH_3). MS (ESI): 627.3 $(M+Na)^+$. HRMS (ESI): calcd for $C_{27}H_{40}NaO_{15}$ $(M+Na)^+$ 627.2265, found 627.2295.

4.9. Ethyl 2,3-dideoxy-3-*C*-(2′,6′-anhydro-3′,4′,5′,7′-tetra-*O*-acetyl-1′-deoxy-D-*glycero*-D-*ido*-heptitol-1′-yl)-4,6-di-*O*-acetyl-α-L-*arabino*-hexopyranoside 20

Aldehyde **15** was treated as described in Section 4.7, except that a Pd-catalyst containing traces of acid, was employed. Crystallization from acetone/light petroleum of the obtained mixture of **19** and **20** afforded an analytical sample of the title compound **20**, mp 137–139 °C (acetone/light petroleum). $R_F = 0.3$ (light petroleum/ether, 1:4). $[\alpha]_D = +21.5$ (*c* 1, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ (ppm) 5.24 (dd, 1H, $J = 9.1$ Hz, $J = 9.3$ Hz, H-4′), 5.06 (dd, 1H, $J = 9.3$ Hz, $J = 5.9$ Hz, H-3′), 4.92 (dd, 1H, $J = 9.1$ Hz, $J = 9.1$ Hz, H-5′), 4.87 (d, 1H, $J = 3.4$ Hz, H-1), 4.75 (dd, 1H, $J = 10.2$ Hz, $J = 10.2$ Hz, H-4), 4.28–4.20 (m, 3H, H-2′, H-7′a, H-6a), 4.11 (dd, 1H, $J = 2.1$ Hz, $J = 12.1$ Hz, H-7′b), 4.01 (dd, 1H, $J = 2.1$ Hz, $J = 12.1$ Hz, H-6b), 3.88 (ddd, 1H, $J = 2.1$ Hz, $J = 4.5$ Hz, $J = 10.2$ Hz, H-5), 3.80 (ddd, 1H, $J = 2.1$ Hz, $J = 5.5$ Hz, $J = 9.1$ Hz, H-6′), 3.68 (dq, 1H, $J = 7.1$ Hz, $J = 9.6$ Hz, –O–CH_2–CH_3), 3.48 (dq, 1H, $J = 7.1$ Hz, $J = 9.6$ Hz, –O–CH_2–CH_3), 2.23 (m, 1H, H-3), 2.14–2.01 (m, 19H, $6\times$O=C–CH_3, H-2_{eq}), 1.89

(ddd, 1H, $J = 2.8$ Hz, $J = 13.5$ Hz, $J = 13.5$ Hz, H-1′a), 1.52 (ddd, 1H, $J = 3.4$ Hz, $J = 13.1$ Hz, $J = 13.1$ Hz, H-2_{ax}), 1.27-1.18 (m, 4H, $J = 7.2$ Hz, –O–CH_2–CH_3, H-1′b). ^{13}C NMR (125 MHz, $CDCl_3$) δ (ppm): 170.83, 170.61, 170.37, 170.02, 169.65, 169.53 (6×O=*C*–CH_3), 96.11 (C-1), 70.82 (C-4), 70.27 (C-4′), 70.17 (C-3′), 69.01 (C-5′), 68.95 (C-2′), 68.65 (C-6′), 68.61 (C-5), 63.01 (C-6), 62.86 (–O–*C*H_2–CH_3), 62.23 (C-7′), 34.14 (C-2), 30.91 (C-3), 27.09 (C-1′), 20.85–20.66 (6×O=C–*C*H_3), 15.03 (–O–CH_2–*C*H_3). MS (ESI): 627.3 $(M+Na)^+$. HRMS (ESI): calcd for $C_{27}H_{40}NaO_{15}$ $(M+Na)^+$ 627.2265, found 627.2296.

4.10. X-ray structure analysis of compounds 19 and 20

The diffraction-quality crystals of compounds **19** and **20** were grown from acetone solutions by vapour diffusion of light petroleum at room temperature. Selected colourless crystals were mounted on glass fibres in random orientations using silicon fat. Diffraction data were collected using Nonius Kappa CCD diffractometer (Enraf–Nonius) at 150(1) K (Cryostream Cooler Oxford Cryosystem) and analyzed using the HKL program package.[24] The structures were solved by the direct, and refined by full-matrix least-squares techniques (SIR92,[25] SHELXL97.[26]) Scattering factors for neutral atoms used were included in the program SHELXL97. The hydrogen atoms were found on a difference Fourier map and refined isotropically. Final geometric calculations were carried out with SHELXL97 and recent version of the PLATON program.[27]

Pertinent crystallographic data for compound **19**: $C_{27}H_{40}O_{15}$, $M_w = 604.59$, monoclinic, space group $P2_1$ (no. 4), $Z = 2$, unit cell parameters $a = 12.8390(3)$ Å, $b = 8.6060(2)$ Å, $c = 13.8230(3)$ Å, $\alpha = \gamma = 90°$, $\beta = 101.021(1)°$, $V = 1499.17(6)$ Å^{-3}, $D_{calcd} = 1.339$ g cm^{-3}, $F(000) = 644$, λ(Mo Kα) = 0.71073 Å, $\mu = 0.11$ mm^{-1}, θ in range from 3.24° to 27.48° (6755 measured reflections, 6729 unique data), $R_1 = 0.0318$, $wR_2 = 0.0749$ for 6178 observed reflections [$\geqslant 4\sigma(F_0)$], goodness-of-fit $S = 1.058$. The residual electron density was found between −0.138 and 0.220 e Å^{-3}. In the crystal, only van der Waals' contact are observed.

Pertinent crystallographic data for compound **20**: $C_{27}H_{40}O_{15}$, $M_w = 604.59$, orthorhombic, space group $P2_12_12_1$ (no. 19), $Z = 4$, unit cell parameters $a = 8.5050$ Å, $b = 12.6950$ Å, $c = 27.6950$ Å, $\alpha = \beta = \gamma = 90°$, $V = 2993.60(6)$ Å^{-3}, $D_{calcd} = 1.341$ g cm^{-3}, $F(000) = 1288$, λ(Mo Kα) = 0.71073 Å, $\mu = 0.11$ mm^{-1}, θ in range from 3.24° to 27.50° (6835 measured reflections, 6823 unique data), $R_1 = 0.0312$, $wR_2 = 0.0752$ for 6233 observed reflections [$\geqslant 4\sigma(F_0)$], goodness-of-fit $S = 1.023$. The residual electron density was found between −0.151 and 0.185 e Å^{-3}. In the crystal, only van der Waals' contact are observed.

All crystallographic data (included cif-files) for the structures reported herein have been deposited with the Cambridge Crystallographic Data Centre as a supplementary publication. Copies of this data (CCDC 203383 for **19** and CCDC 230423 for **20**) can be obtained free of charge on application to CCDC, e-mail: deposit@ccdc.cam.ac.uk.

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