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TETRAHEDRON: *ASYMMETRY*

Convergent syntheses of C(1→3)-linked disaccharides starting from isolevoglucosenone

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Abstract

Nucleophilic addition (Nu^-M^+) to isolevoglucosenone **1** generates enolates stereospecifically (*exo* face addition) that can be reacted with sugar-derived aldehydes to give C(1→3)-linked disaccharide precursors with high diastereoselectivity. Limitations of the method arising from unfavorable aldolate stability can be overcome by using Et_2AlI as the nucleophile. This leads to products of Baylis–Hillmann condensations. One example is presented and has led to the preparation of 2,3-anhydro-3-*C*-[(1*S*)-2,6-anhydro-D-*glycero*-D-*gulo*-heptitol-1-*C*-yl]-β-D-*gulo*-pyranose **5**. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

Carbohydrate mimics are potentially useful molecular tools for biology,[1] and may become leads for drug discovery.[2] In particular, C-linked disaccharides and oligosaccharides offer the advantage of being resistant to acidic and enzymatic hydrolysis.[3] They are potential inhibitors of glycosidases and glycosyltransferases.[4,5] They represent non-hydrolyzable epitopes.[6] Since the first synthesis of β-D-Glc*p*-CH_2(1→6)-D-Glc*p* by Rouzaud and Sinaÿ,[7] several approaches to *C*-disaccharides and C-linked oligosaccharides have been reported.[3,8,9] They are invariably multiple-step syntheses which do not always offer the necessary versatility for wide molecular diversity.[10] In a preliminary communication,[11] we have shown that isolevoglucosenone **1** (derived from D-glucose in four steps[12]) allows nucleophilic addition on the less hindered face of the bicyclic enone, generating enolates **2** that can react with 1,2:3,4-di-*O*-isopropylidene-α-D-galactohexodialdo-1,5-pyranose **3** giving the corresponding aldols **4** that were converted into C(1→3)-linked disaccharides with high stereoselectivity (Scheme 1). We present details of this convergent approach and disclose its application to the synthesis of **5**, a new kind of *C*-disaccharide in which β-D-glucopyranose is attached at C(3) of 2,3-anhydro-3-*gulo*-pyranose through a hydroxymethylene linker.

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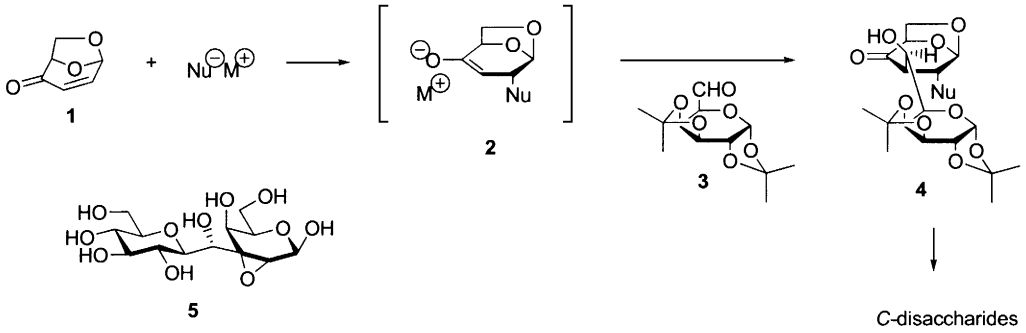
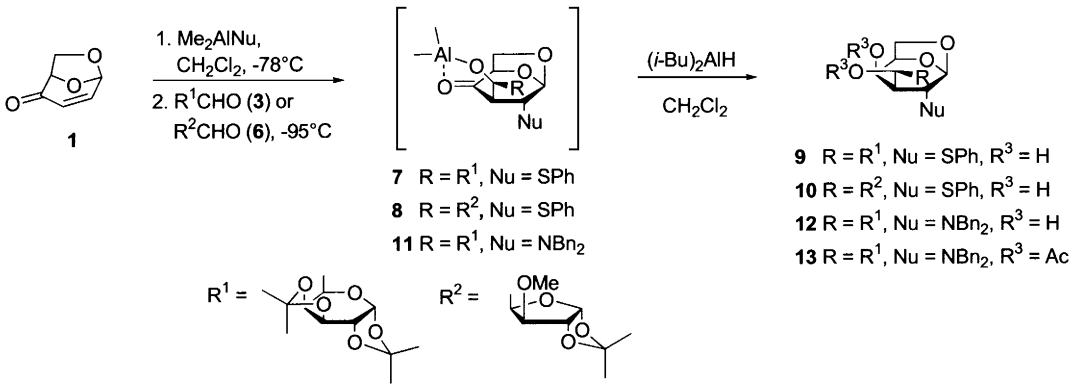


Scheme 1.

2. Synthesis and structural analysis

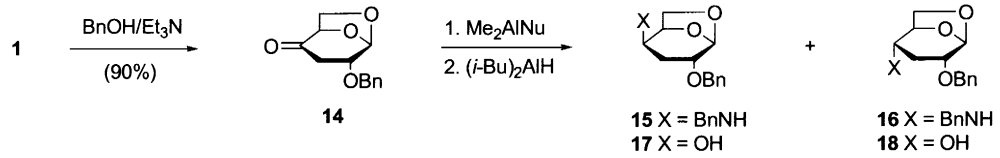
Oshima and co-workers have shown that conjugate addition of Me_2AlSPh to simple enones, followed by reaction of the aluminum enolates with aldehydes, allows the preparation of the corresponding aldols in one-pot procedures.[13] Me_2AlSPh added to isolevoglucosenone **1** at low temperature (−78°C, CH_2Cl_2), giving an enolate that reacted with aldehydes **3** and **6** (−95°C, 3 h), afforded the corresponding aluminum aldolates **7** and **8**. The aldolates so-obtained can be reduced in situ with $(i\text{-Bu})_2AlH$ (−78°C, CH_2Cl_2): after aqueous work-up, the *C*-disaccharides **9** (60% yield) and **10** (63% yield) were obtained as single diastereoisomers, respectively. The high diastereoselectivity of these reductions can be interpreted in terms of steric factors, the less hindered *exo* face of the bicyclic ketone, probably coordinated to the aluminum moiety of the aldolate, being attacked by the hydride (Scheme 2). This is in analogy with Paterson's $LiBH_4$ reduction of dicyclohexylboron aldolate.[14]



Scheme 2.

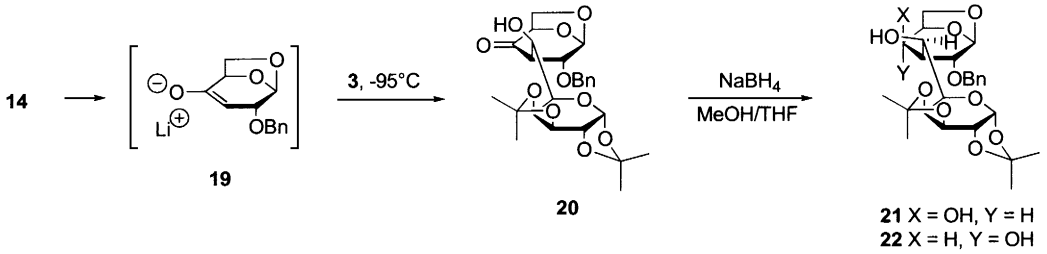
Replacing Me_2AlSPh by Me_2AlNBn_2 led to generation,[15] from **1** and **3**, of the corresponding *C*-glycoside of protected D-galactosamine **12** (40% yield) which was characterized as its diacetate **13** (Scheme 2). When using Et_2AlNBn_2 instead of Me_2AlNBn_2,[16] the yield of **12** dropped to 24%. With $Me_2AlN(Ac)Bn$ (prepared by addition of Me_3Al to benzyl isocyanate),[17] no *C*-disaccharide was obtained. The reaction of **1** with **3** with $Me_2AlN(SiMe_3)Bn$,[18] followed by treatment with $(i\text{-Bu})_2AlH$, failed to produce a *C*-disaccharide, probably because $Me_2AlN(SiMe_3)Bn$ is able to undergo facile 1,2-addition with generation of the corresponding imines that are reduced with $(i\text{-Bu})_2AlH$ into the corresponding *N*-alkyl-*N*-benzylamines. This hypothesis is supported by our observation that **14**, the adduct of benzyl alcohol to isolevoglucosenone, reacted with $Me_2AlN(SiMe_3)Bn$ (CH_2Cl_2, −78°C) and then with $(i\text{-Bu})_2AlH$ (CH_2Cl_2, −78°C) affording a 1.1:1 mixture of benzylamines **15** and **16** (52% yield).

Under the same conditions, **14** reacted with Me_2AlNBn_2 and then with $(i\text{-}Bu)_2AlH$ giving a mixture of alcohols **17** and **18** (56% yield) (Scheme 3). In the latter case, Me_2AlNBn_2 cannot generate a benzyl imine resulting from a 1,2-addition to the ketone.



Scheme 3.

The one-pot synthesis of *C*-disaccharides (Scheme 2) could not be applied to prepare *C*-glycosides of D-galactose itself (Nu=OR) as the reaction of **1** with **3** with Me_2AlOBn (prepared by the addition of Me_3Al to BnOH in CH_2Cl_2 at 0°C), followed by reduction with $(i\text{-}Bu)_2AlH$, failed to produce any trace of products of coupling between **1** and **3**. The lithium enolate **19** of ketone **14**, obtained on treatment with 1 equivalent of $(Me_3Si)_2NLi$ (THF, −78°C), did not eliminate lithium benzylate at low temperature and could be reacted with aldehyde **3** (and other aldehydes[11]) at −95°C, affording a single aldol **20** that could be isolated in 79% yield. Its reduction with $NaBH_4$ (MeOH/THF, 0°C) was less stereoselective than the reductions of the aluminum aldolates **7**, **8** and **11** with $(i\text{-}Bu)_2AlH$ (Scheme 4). It gave a 5:1 mixture of diols **21** (75% yield) and **22** (15% yield).



Scheme 4.

The relative configuration of the hydroxy group of the hydroxymethylene linker and that at C(4) of the D-galactose moiety of **9**, **12** and **21** were established by ^1H NMR of their acetonides **23**, **24** and **25**, respectively (Fig. 1), obtained on treatment with $(MeO)_2CMe_2$/acetone/*p*TsOH/Drierite. The pyranose ring of the 1,6-anhydro-D-galactose units of **23** and **25** adopts chair conformations, whereas a boat conformation is preferred in the case of **24**. The NOESY ^1H NMR spectrum of **23** showed cross-peaks for a signal pair at δ_H=3.95 (H-2′)/4.38 ppm (H_{endo}-6′), on the one hand, and for a signal pair at δ_H=4.08 (H-6)/4.38 ppm (H_{endo}-6′), on the other. The *trans* relationship between protons H-3′ and H-6 was proven by ^3J(H-3′, H-6)=9.1 Hz. The observation of ^3J(H-3′, H-4′)=9.1 Hz, ^3J(H-2′, H-3′)=3.0 Hz and ^3J(H-4′, H-5′)=6.1 Hz proved the *galacto* configuration. Smaller values (<2 Hz) for ^3J(H-4′, H-5′) would have been expected if this system had the *gluco* configuration. The ^1H NMR data for **25** were similar to those for **23**, ^3J(H-3′, H-6)=10.3 Hz and NOEs between H-2′(3.84 ppm)/H_{endo}-6′ (4.36 ppm), H-6 (4.44 ppm)/H_{endo}-6′ (4.36 ppm) were observed. The NOESY ^1H NMR spectrum of **24** showed a strong NOE between proton pair H-2′ (3.02 ppm)/H_{endo}-6′ (4.23 ppm). Such NOE was not observed for **23** and **25**, in agreement with the boat conformation of the *galacto* pyranoside moiety of **24**. NOEs between proton pairs Me_a (1.31 ppm)/H-5 (3.95 ppm), Me_a/H-4′ (4.45 ppm), Me_b (1.04 ppm)/H-2′ (3.02 ppm), Me_b/H-6 (4.30 ppm) and H-6/H_{endo}-6′ (4.23 ppm) were also observed. The *trans* relationship of H-2′ and H-3′ was given by ^3J(H-2′, H-3′)=10.0 Hz.

The high diastereoselectivity observed for the cross-aldol reactions reported above can be interpreted in terms of steric factors that make the face of the intermediate enolate (e.g. **19**) *anti* with respect to the

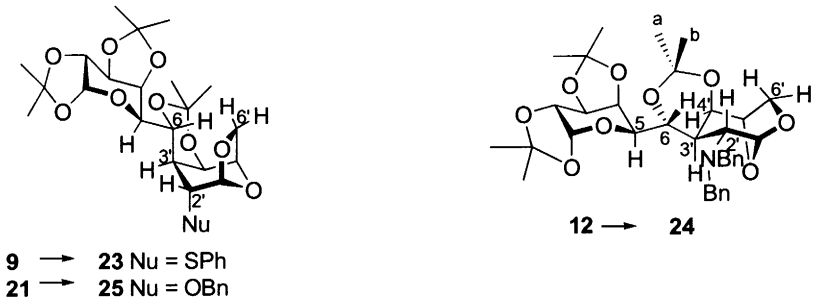


Fig. 1.

substituent at C(2) more accessible than the *syn* face (*exo* face of the bicyclo[3.2.1]octane system) for the aldehydes. With aluminum and lithium enolates, 'closed transition states' are preferred over 'open transition states', and for steric reasons, lead to aldol following the Zimmermann–Traxler model **26** (Fig. 2).[19]

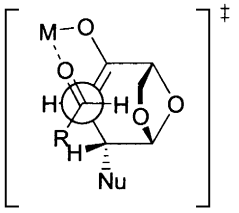


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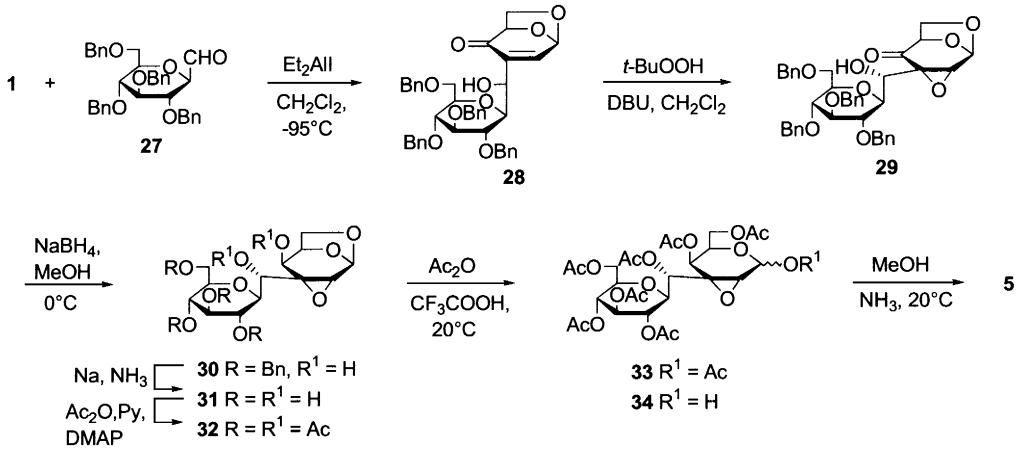
Fig. 2.

Under the same conditions of Scheme 4, the cross-aldolization of the lithium enolate **19** with the β-glucopyranose-derived carbaldehyde **27**[20] led to a mixture of products that was reduced with $(i\text{-Bu})_2NH$ affording less than 7% of the desired *C*-disaccharide, the other products deriving from the reduction of ketone **14** and aldehyde **27**. This failure is not explained yet. No better success was attained with our one-pot method (Scheme 2) using Me_2AlSPh with **1** and **27**. Therefore, we explored the possibility of carrying out a condensation between **1** and **27** analogous to the Baylis–Hillmann reaction.[21]

When Et_2AlI (1 M in toluene) was added to a mixture of **1** and **27** (CH_2Cl_2, −95°C),[13] the product of coupling **28** was obtained in 80% yield. Treatment of enone **28** with *t*-BuOOH (CH_2Cl_2, DBU, 20°C) afforded epoxide **29** as single product (82% yield). Its relative configuration was given by the relatively small coupling constant ^3J(H-1, H-2)=1.3 Hz. Thus, the less sterically hindered *exo* face of the bicyclo[3.2.1]octenone moiety was preferred for the epoxidation (1,4-addition, elimination). The configuration of the hydroxymethylene linker will be established as shown below. Reduction of ketone **29** with $NaBH_4$ in MeOH (0°C) also prefers the *exo* face of the bicyclic system, producing alcohol **30** in 95% yield. Debenzylation of **30** with Na/NH_3 at −78°C provided hexol **31** in 83% yield. Hydrolysis of the 1,6-anhydrohexose appeared to be a difficult operation with **31**. We thus protected it as polyacetate **32** under standard conditions (Ac_2O, pyridine, DMAP, 25°C, 95% yield). Treatment of **32** with CF_3COOH in Ac_2O led to a mixture of peracetate **33** (single α-anomer, 37%) and β-pyranose **34** (38%), together with unreacted starting material **32** (16%). Methanolysis of **33** (NH_3/MeOH, 20°C) afforded *C*-disaccharide **5** (single β-pyranose) in 45% yield after chromatographic purification (Scheme 5).

The configurations of the hydroxymethylene linker and of the 4-hydroxy group in **30**–**34** (and **5**) were established in the following way. Treatment of **30** with $(MeO)_2CMe_2$, acetone and *p*TsOH as catalyst produced the corresponding acetonide **35** in 82% yield. Debenzylation of **35** with Na/NH_3 in THF (−78°C) afforded **36** (75% yield), the NOESY ^1H NMR spectrum of which showed cross-peaks for the



Scheme 5.

proton pairs H-1′ (4.61 ppm)/H$_{endo}$-6 (4.23 ppm), H-1′/Me$_a$ (1.42 ppm), Me$_b$ (1.51 ppm)/H-4 (4.29 ppm), Me$_a$/H-3′ (3.36 ppm) and H-2 (2.99 ppm)/H-2′ (2.95 ppm) consistently with the conformation shown for **36** (Fig. 3). The latter was confirmed by the coupling constants ^3J(H-1, H-2)=1 Hz, ^3J(H-1′, H-2′) ≃0 Hz. As for the aldol condensations of Schemes 2 and 4, a closed transition state (Zimmermann–Traxler model) similar to **26** is adopted for reaction **1**+Et$_2$AlI+**27**→**28** (Scheme 5). Distinction between α- and β-anomers for the *gulo*-pyranoses **5**, **34** and pyranoside **33** was based on their ^3J(H-1, H-2) and, in the case of **5**, on the NOESY ^{1}H NMR spectra, and by comparison with data reported for other 2,3-anhydropyranosides.[22]

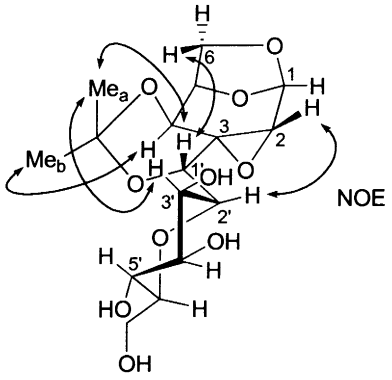


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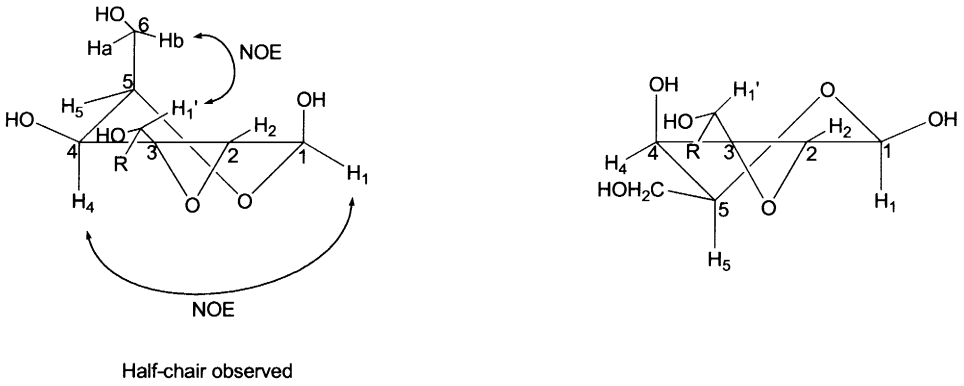
Fig. 3.

3. Conformational analysis of 5

The 600 MHz ^{1}H NMR spectrum of **5** (CD_3OD) was recorded at several temperatures between −20 and +60°C. Changes in δ_H of **5** (versus CHD_2OD) were insignificant. The largest variation was 0.06 ppm observed for H-4. The coupling constants ^3J(H-1′, H-2′)=2.0 Hz and ^3J(H-4, H-5)=3.6 Hz did not vary between −20 and +60°C. We can therefore conclude that **5** adopts a major half-chair conformation for the anhydro-*gulo*-pyranose moiety and a major staggered conformation about σ(C-1′, C-2′). The NOESY ^{1}H NMR (600 MHz, CD_3OD, 303 K) of **5** showed significant cross-peaks for proton signals assigned to

H-1 (5.25 ppm) and H-4 (4.26 ppm). This proves the β-pyranose and the half-chair conformation shown in Fig. 4. This was confirmed by the observation of an NOE between signals assigned to H-1′ (4.53 ppm) and H_b-6 (3.02 ppm) and by the absence of cross-peak for signals attributed to H-1 and H-5 (3.96 ppm).



Half-chair observed

Fig. 4.

The strong NOEs observed between signals assigned to H-2′ (3.58 ppm), H-6′ (3.32 ppm), and H-4 demonstrates that the most stable staggered configuration of the *C*-disaccharide maintains antiperiplanar bonds for σ(C-1′, C-3)/σ(C-2′, C-3′) and for σ(C-1′, C-2′)/σ(C-2, C-3) as predicted by Kishi and co-workers[23] for related C-linked disaccharides. These conclusions were further confirmed by the non-observation of NOEs between signals assigned to H-3′, H-4′, H-5′, H_a-7′, H_b-7′ and signals assigned to H-1, H-2, H-4, H-5, H_a-6, H_b-6, and by the fact that the coupling constant ^3J(H-1′, H-2′)=2.0 Hz, meaning that the value of the corresponding dihedral angle is not far from 90° (Fig. 5).

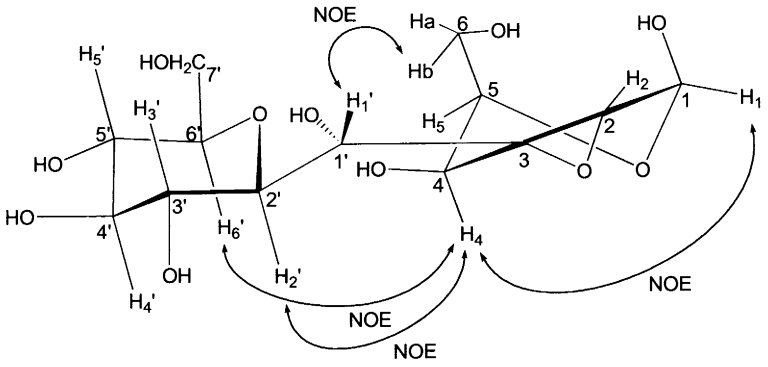


Fig. 5.

4. Conclusion

The Oshima coupling of enone and aldehydes has been applied to isolevoglucosenone and sugar-derived aldehydes. It allows generation of (1→3)-C-linked disaccharides in a few synthetic steps with high stereoselectivity. Unfortunately, the method is not general yet as the yield depends strongly on the nature of the aluminum reagent and of the aldehyde. In order to avoid retro-aldolization, a fast elimination generating 3-substituted isolevoglucosenone can be useful (Baylis–Hillmann type of condensation). An example has been described using Et_2AlI to induce the coupling. It has allowed the preparation of 2,3-

anhydro-3-*C*-[(1*S*)-2,6-anhydro-D-*glycero*-D-*gulo*-heptitol-1-*C*-yl]-β-D-gulopyranose (**5**), a β-*C*-(1→3)-glucopyranoside of a 2,3-anhydrohexopyranose.

5. Experimental

5.1. General

See Ref. 4. ^{1}H NMR assignments were confirmed by 2D-COSY and NOESY spectra.

5.2. (6R)-6-C-*[1,6-Anhydro-3-deoxy-2*-S-*phenyl-2-thio-β*-D-galacto-*pyranos-3-yl]-1,2:3,4-di*-O-*isopropylidene-α*-D-galacto-*pyranose* ***9***

Me_3Al (2 M solution in toluene, 100 μL, 0.20 mmol) was added to a solution of PhSH (20 μL, 0.20 mmol) in 0.1 mL of CH_2Cl_2 at 0°C. After 30 min, the mixture was cooled to −78°C and a 0.5 M CH_2Cl_2 solution of isolevoglucosenone **1**[12] (400 μL, 0.20 mmol) was added. Stirring was continued for 1 h. THF (0.5 mL) was added and the mixture was cooled to −95°C. A solution of 1,2:3,4-di-*O*-isopropylidene-α-D-galactohexodialdo-1,5-pyranose **3**[24] (54 mg, 0.21 mmol) in THF (0.2 mL) was added and the resulting solution was stirred for 3 h. A CH_2Cl_2 solution of (*i*-Bu)$_2$AlH (1 M, 400 μL, 0.40 mmol) was added dropwise. The mixture was slowly warmed to 20°C and stirred for 1 h, and then quenched with aq. NH_4Cl solution. A 2 M HCl solution (1 mL) was added to dissolve the gel. The aq. phase was extracted with CH_2Cl_2. The combined organic phases were dried (Na_2SO_4) and concentrated in vacuo. The residue was chromatographed on silica gel (3:7, EtOAc:light petroleum ether) to afford a colorless oil (59 mg, 60%): $[\alpha]^{25}_{589}=-45$, $[\alpha]^{25}_{577}=-47$, $[\alpha]^{25}_{546}=-53$, $[\alpha]^{25}_{435}=-89$, $[\alpha]^{25}_{405}=-107$ (*c* 0.4, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.49–7.43, 7.35–7.29, 7.28–7.23 (m, 5H, Ph), 5.62 (s, H-1′), 5.54 (d, ^3J(H-1, H-2)=5.1 Hz, H-1), 4.67 (t, ^3J(H-4′, H-5′)=^3J(H-3′, H-4′)=6.6 Hz, H-4′), 4.59 (dd, ^3J(H-4′, H-5′)=6.6 Hz, ^3J(H-5′, H$_{exo}$-6′)=4.8 Hz, H-5′), 4.54 (dd, ^3J(H-3, H-4)=7.9 Hz, ^3J(H-4, H-5)=2.1 Hz, H-4), 4.52 (dd, ^3J(H-3, H-4)=7.9 Hz, ^3J(H-2, H-3)=2.7 Hz, H-3), 4.38 (d, ^2J=7.6 Hz, H$_{endo}$-6′), 4.32 (dd, ^3J(H-1, H-2)=5.1 Hz, ^3J(H-2, H-3)=2.7 Hz, H-2), 4.11 (dd, ^3J(H-5, H-6)=7.9 Hz, ^3J(H-6, H-3′)=1.8 Hz, H-6), 3.94 (dd, ^3J(H-5, H-6)=7.9 Hz, ^3J(H-4, H-5)=2.1 Hz, H-5), 3.52 (dd, ^2J=7.6 Hz, ^3J(H-5′, H$_{exo}$-6′)=4.8 Hz, H$_{exo}$-6′), 3.38 (d, ^3J(H-2′, H-3′)=7.9 Hz, H-2′), 2.23 (m, H-3′), 1.54, 1.46, 1.34, 1.32 (4s, 4 Me); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 134.1, 131.8, 129.2, 127.2 (Ph), 109.6, 108.8 (*C*(O)$_2$Me$_2$), 103.4 (C1′), 96.6 (C1), 74.8 (C5), 71.3 (C4), 70.8 (C6, C3), 70.3 (C2), 67.0 (C5), 66.9 (C4), 62.8 (C6′), 49.1 (C2′), 38.2 (C3′), 25.9, 25.9, 24.9, 24.4 (4 Me); CI-MS (NH_3): *m/z* 497 ([M+H]$^+$, 9), 496 (M$^{+\cdot}$, 2), 449 (11), 448 (16), 432 (13), 277 (10), 250 (11), 85 (67), 83 (100).

5.3. *1,6-Anhydro-3-deoxy-3-[(5*R*)-1,2*-O-*isopropylidene-3*-O-*methyl-α*-D-xylo-*furanos-5*-C-*yl]-2*-S-*phenyl-2-thio-β*-D-galacto-*pyranose* ***10***

Me_3Al (2 M solution in toluene, 100 μL, 0.20 mmol) was added to a solution of PhSH (20 μL, 0.20 mmol) in 0.1 mL of CH_2Cl_2 at 0°C. After 30 min, the mixture was cooled to −78°C, to which a 0.5 M CH_2Cl_2 solution of **1** (400 μL, 0.20 mmol) was added. Stirring was continued for 1 h. THF (0.5 mL) was added and the mixture was cooled to −95°C. A solution of 1,2-*O*-isopropylidene-3-*O*-methyl-α-D-*xylo*-pentodialdo-1,4-furanose **6** (42 mg, 0.21 mmol) in THF (0.2 mL) was added and the resulting solution was stirred for 3 h. A CH_2Cl_2 solution of (*i*-Bu)$_2$AlH (1 M, 400 μL, 0.40 mmol) was added dropwise. The mixture was slowly warmed to 20°C and stirred for 1 h. It was then quenched with aq. NH_4Cl solution.

A 2 M HCl solution (1 mL) was added to dissolve the gel. The aq. phase was extracted with CH_2Cl_2. The combined organic phases were dried (Na_2SO_4) and concentrated in vacuo. Chromatography on silica gel (2:3, EtOAc:light petroleum ether) afforded a white solid (55 mg, 63%): mp 178–180°C; $[\alpha]^{25}_{589}=-38$, $[\alpha]^{25}_{577}=-39$, $[\alpha]^{25}_{546}=-44$, $[\alpha]^{25}_{435}=-76$, $[\alpha]^{25}_{405}=-89$ (*c* 1.77, $CHCl_3$); UV (CH_3CN): λ_{max} 252 (ε=7720), 196 (15810); IR (KBr): ν 3163, 1385, 1376, 1217, 1166, 1114, 1075, 1058, 1028 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.44–7.21 (m, 5H, Ph), 5.91 (d, ^3J(H-1′, H-2′)=4.0 Hz, H-1′), 5.58 (s, H-1), 5.11 (d, ^3J(OH, H-4)=4.3 Hz, OH), 4.67-4.59 (m, 2H, H-4, 5′), 4.57 (dd, ^3J(H-4, H-5)=5.5 Hz, ^3J(H-5, H_{exo}-6)=4.8 Hz, H-5), 4.57 (d, ^3J(H-1′, H-2′)=4.0 Hz, H-2′), 4.32 (d, ^2J=7.7 Hz, H_{endo}-6), 4.20 (dd, ^3J(H-4′, H-5′)=6.3 Hz, ^3J(H-3′, H-4′)=3.3 Hz, H-4′), 3.86 (d, ^3J(OH, H-5′)=7.0 Hz, OH), 3.59 (dd, ^2J=7.7 Hz, ^3J(H-5, H_{exo}-6)=4.8 Hz, H_{exo}-6), 3.56 (d, ^3J(H-3′, H-4′)=3.3 Hz, H-3′), 3.43 (d, ^3J(H-2, H-3)=5.6 Hz, H-2), 3.37 (s, OCH_3), 2.30 (ddd, ^3J(H-5′, H-3)=6.8 Hz, ^3J(H-3, H-4)=6.3 Hz, ^3J(H-2, H-3)=5.6 Hz, H-3) 1.46, 1.32 (2s, 2 Me); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 134.2, 132.0, 129.3, 127.5 (Ph), 111.6 ($C(O)_2Me_2$), 104.8 (C1′), 102.5 (C1), 84.8 (C3′), 80.7 (C2′), 79.6 (C4′), 75.4 (C5), 71.1 (C5′), 67.3 (C4), 63.3 (C6), 57.4 (OMe), 49.5 (C2), 41.3 (C3), 26.8, 26.1 (2 CH_3); CI-MS (NH_3): *m/z* 441 ($[M+H]^+$, 7), 440 ($M^{+\cdot}$, 7), 383 (4), 323 (8), 203 (7), 173 (17), 165 (14), 164 (24), 110 (100), 109 (36); anal. calcd for $C_{21}H_{28}O_8S$: C, 57.25; H, 6.41; found: C, 57.17; H, 6.50.

*5.4. (6*R*)-6-*O*-Acetyl-6-*C*-[4-*O*-acetyl-1,6-anhydro-2-dibenzylamino-2,3-dideoxy-β-*D*-galacto-pyranos-3-yl]-1,2:3,4-di-*O*-isopropylidene-α-*D*-galacto-pyranose **13***

To a solution of Bn_2NH (38 μL, 0.20 mmol) in 0.1 mL of CH_2Cl_2 was added Me_3Al (2 M solution in toluene, 100 μL, 0.20 mmol) at 0°C. The mixture was warmed to 20°C and stirred for 30 min. After being cooled down to −78°C, a 0.5 M CH_2Cl_2 solution of **1** (400 μL, 0.20 mmol) was added. Stirring was continued for 1 h. THF (0.5 mL) was added and the mixture was cooled to −95°C. A solution of **3** (54 mg, 0.21 mmol) in THF (0.2 mL) was added and the resulting solution was stirred for 3 h. A CH_2Cl_2 solution of $(i\text{-Bu})_2AlH$ (1 M, 400 μL, 0.40 mmol) was added dropwise. The mixture was slowly warmed to 20°C and stirred for 1 h, and then quenched with a 6 M aq. NaOH solution (0.5 mL) at 0°C. The mixture was stirred at 20°C for 2 h. The aq. phase was extracted with CH_2Cl_2. The combined organic phases were dried (Na_2SO_4) and concentrated in vacuo. Chromatography on silica gel (3:7, EtOAc:light petroleum ether) afforded a colorless oil (72 mg, containing 46 mg of pure **12**, 40%).

Data for **12**: ^1H NMR (400 MHz, $CDCl_3$): δ 7.40–7.20 (m, 5H, Ph), 5.71 (s, H-1′), 5.54 (d, ^3J(H-1, H-2)=5.2 Hz, H-1), 4.68 (dd, ^3J(H-3, H-4)=7.9 Hz, ^3J(H-2, H-3)=2.4 Hz, H-3), 4.60 (dd, ^3J(H-4′, H-5′)=7.9 Hz, ^3J(H-5′, H_{exo}-6′)=4.5 Hz, H-5′), 4.54 (m, H-6), 4.39 (dd, ^3J(H-4′, H-5′)=7.9 Hz, ^3J(H-3′, H-4′)=2.1 Hz, H-4′), 4.34 (dd, ^3J(H-1, H-2)=5.2 Hz, ^3J(H-2, H-3)=2.4 Hz, H-2), 4.27 (dd, ^3J(H-3, H-4)=7.9 Hz, ^3J(H-4, H-5)=1.5 Hz, H-4), 4.00 (dd, ^3J(H-5, H-6)=10.0 Hz, ^3J(H-4, H-5)=1.5 Hz, H-5), 3.90 (d, ^2J=13.6 Hz, $PhCH_2$), 3.84 (d, ^2J=6.7 Hz, H_{endo}-6′), 3.51 (d, ^2J=13.3 Hz, $PhCH_2$), 3.36 (dd, ^2J=6.7 Hz, ^3J(H-5′, H_{exo}-6′)=4.5 Hz, H_{exo}-6′), 2.81 (d, ^3J(H-2′, H-3′)=11.2 Hz, H-2′), 2.08 (ddd, ^3J(H-2′, H-3′)=11.2 Hz, ^3J(H-6, H-3′)=6.1 Hz, ^3J(H-3′, H-4′)=2.1 Hz, H-3′), 1.63, 1.56, 1.44, 1.33 (4s, 4 Me).

To a CH_2Cl_2 solution (1 mL) of the above product (0.079 mmol) were added Ac_2O (0.10 mL, 1.06 mmol), Et_3N (0.20 mL, 1.44 mmol) and DMAP (1 mg, 0.008 mmol). The mixture was stirred at 20°C for 5 h and concentrated in vacuo. Chromatography (3:7, EtOAc:light petroleum ether) afforded **13** (47 mg, 89%) as a white solid: mp 80–82°C; $[\alpha]^{25}_{589}=6.1$, $[\alpha]^{25}_{577}=4.4$, $[\alpha]^{25}_{546}=4.8$, $[\alpha]^{25}_{435}=7.3$, $[\alpha]^{25}_{405}=8.5$ (*c* 0.75, $CHCl_3$); UV (CH_3CN): λ_{max} 260 (ε=1290), 208 (14190); IR (KBr): ν 3028, 2987, 1744, 1454, 1382, 1257, 1212, 1106, 1068 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.40–7.20 (m, 10H), 5.57 (s, H-1′), 5.54 (d, ^3J(H-1, H-2)=5.5 Hz, H-1), 5.44 (dd, ^3J(H-4′, H-5′)=8.2 Hz, ^3J(H-3′, H-4′)=6.4 Hz, H-4′), 4.92 (dd, ^3J(H-4′, H-5′)=8.2 Hz, ^3J(H-5′, H_{exo}-6′)=4.5 Hz, H-5′), 4.65 (dd, ^3J(H-3, H-4)=7.9

Hz, ^3J(H-2, H-3)=2.1 Hz, H-3), 4.62 (m, H-6), 4.45 (dd, ^3J(H-3, H-4)=7.9 Hz, ^3J(H-4, H-5)=1.8 Hz, H-4), 4.34 (dd, ^3J(H-1, H-2)=5.5 Hz, ^3J(H-2, H-3)=2.1 Hz, H-2), 3.94 (d, 2H, ^2J=13.6 Hz, $PhCH_2$), 3.67 (dd, ^3J(H-5, H-6)=9.7 Hz, ^3J(H-4, H-5)=1.8 Hz, H-5), 3.64 (d, ^2J=8.2 Hz, H_{endo}-6′), 3.57 (d, 2H, ^2J=13.6 Hz, $PhCH_2$), 3.36 (dd, ^2J=8.2 Hz, ^3J(H-5′, H_{exo}-6′)=4.5 Hz, H_{exo}-6′), 3.12 (d, ^3J(H-2′, H-3′)=11.2 Hz, H-2′), 2.29 (ddd, ^3J(H-2′, H-3′)=11.2 Hz, ^3J(H-3′, H-4′)=6.4 Hz, ^3J(H-6, H-3′)=3.0 Hz, H-3′), 2.05, 2.03 (2s, 2 CH_3CO), 1.59, 1.44, 1.42, 1.32 (4s, 4 Me); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 170.1, 139.2, 129.2, 128.1, 127.0, 108.8, 108.2, 100.2, 96.4, 72.1, 70.8, 70.4, 70.3, 67.4, 66.9, 62.4, 60.4, 58.8, 32.8, 26.2, 25.8, 24.6, 24.5, 21.1, 21.0; CI-MS (NH_3): *m/z* 626 (7), 610 (10), 534 (9), 280 (8), 253 (11), 252 (58), 91 (100); anal. calcd for $C_{36}H_{45}O_{11}N$: C, 64.75; H, 6.79; N, 2.10; found: C, 64.25; H, 6.84; N, 2.17.

5.5. *1,6-Anhydro-2-*O*-benzyl-3-deoxy-*D-erythro-*hexopyrano-4-ulose* **14**

A mixture of **1** (185 mg, 1.47 mmol), benzyl alcohol (8.2 mL) and Et_3N (0.10 mL, 1.0 mmol) was stirred at 20°C for 15 h. Et_3N was then eliminated by evaporation. Excess of BnOH was recovered by bulb-to-bulb distillation in vacuo. Chromatography on silica gel (15:85, EtOAc:light petroleum ether) afforded a colorless syrup (310 mg, 90%): $[\alpha]^{25}_{589}=-57$, $[\alpha]^{25}_{577}=-58$, $[\alpha]^{25}_{546}=-67$, $[\alpha]^{25}_{435}=-133$, $[\alpha]^{25}_{405}=-176$ (*c* 1.2, $CHCl_3$); UV (CH_3CN): λ_{max} 207 (ε=9444), 194 (13480); IR (film): ν 3032, 2899, 1736, 1497, 1455, 1133, 1095, 999 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.45–7.22 (m, 5H, Ph), 5.62 (s, H-1), 4.63, 4.57 (2d, ^2J=12.0 Hz, $PhCH_2$), 4.55 (d, ^3J(H-5, H_{exo}-6)=5.0 Hz, H-5), 3.92 (d, ^2J=8.0 Hz, H_{endo}-6), 3.84 (dd, ^2J=8.0 Hz, ^3J(H-5, H_{exo}-6)=5.0 Hz, H_{exo}-6), 3.78 (ddd, ^3J(H-2, H-3b)=6.5 Hz, ^3J(H-2, H-3a)=3.5 Hz, ^3J(H-2, H-1)=1.2 Hz, H-2), 2.68 (dd, ^2J=12.5 Hz, ^3J(H-2, H-3b)=6.5 Hz, H-3b), 2.61 (dd, ^2J=12.5 Hz, ^3J(H-2, H-3a)=3.5 Hz, H-3a); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 204.1 (s, C4), 137.2 (s, Ph), 128.6, 128.1, 127.7 (3d, *J*=160 Hz, Ph), 101.5 (d, ^1J(C, H)=175 Hz, C1), 79.1 (d, ^1J(C, H)=161 Hz, C5), 75.5 (d, ^1J(C, H)=146 Hz, C2), 71.6 (t, ^1J(C, H)=142 Hz, C6), 66.8 (t, ^1J(C, H)=155 Hz, Ph*C*H_2), 39.2 (t, ^1J(C, H)=131 Hz, C3); CI-MS (NH_3): *m/z* 253 (16), 252 (18, $[M+NH_4]^+$), 170 (8), 126 (61), 108 (47), 105 (22), 97 (25), 91 (100), 83 (41); anal. calcd for $C_{13}H_{14}O_4$: C, 66.66; H, 6.02; found: C, 66.56; H, 6.01.

5.6. *4-Amino-1,6-anhydro-2-*O*,4-*N*-dibenzyl-3,4-dideoxy-β-*D-xylo-*hexopyranose* **15** *and 4-amino-1,6-anhydro-2-*O*,4-*N*-dibenzyl-3,4-dideoxy-β-*D-ribo-*hexopyranose* **16**

A 2 M heptane solution of Me_3Al (120 μL, 0.235 mmol) was added dropwise to a CH_2Cl_2 solution (0.2 mL) of Bn(TMS)NH (50 μL, 0.235 mmol) at 20°C. After 30 min, the mixture was cooled to −78°C and a solution of **14** (50 mg, 0.214 mmol) in 0.3 mL of CH_2Cl_2 was added dropwise. Stirring was continued for 1 h and (i-Bu)$_2$AlH (400 μL, 0.40 mmol) was added dropwise. The reaction mixture was stirred at −78°C for 2 h and quenched by careful addition of 6 M NaOH (2 mL). The mixture was stirred vigorously for 30 min and extracted with CH_2Cl_2. The organic extract was washed with brine, dried (Na_2SO_4) and concentrated. Chromatography (1:1, EtOAc:light petroleum ether, then EtOAc) afforded colorless oils **15** (19 mg, 27%) and **16** (17 mg, 25%).

Data for **15**: $[\alpha]^{25}_{589}=-41$, $[\alpha]^{25}_{577}=-40$, $[\alpha]^{25}_{546}=-46$, $[\alpha]^{25}_{435}=-81$, $[\alpha]^{25}_{405}=-97$ (*c* 0.90, $CHCl_3$); UV (CH_3CN): λ_{max} 263 (ε=880), 258 (890), 251 (870), 212 (8660); IR (film): ν 2957, 2895, 1494, 1454, 1365, 1142, 1096, 1061, 1027, 987 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.42–7.24 (m, 10H, Ph), 5.36 (s, H-1), 4.63, 4.54 (2d, ^2J=11.6 Hz, $PhCH_2$), 4.40 (m, H-5), 4.08 (d, ^2J=7.7 Hz, H_{endo}-6), 3.84, 3.77 (2d, ^2J=12.3 Hz, $PhCH_2$), 3.65 (dd, ^2J=7.7 Hz, ^3J(H-5, H_{exo}-6)=5.1 Hz, H_{exo}-6), 3.43 (dd, ^3J(H-2, H-3a)=4.4 Hz, ^3J(H-2, H-3e)=1.6 Hz, H-2), 3.30 (ddd, ^3J(H-3a, H-4)=11.9 Hz, ^3J(H-3e,

H-4)=5.6 Hz, ^3J(H-4, H-5)=3.5 Hz, H-4), 1.98 (ddd, ^2J=14.0 Hz, ^3J(H-3e, H-4)=5.6 Hz, ^3J(H-2, H-3e)=1.6 Hz, H-3e), 1.48 (ddd, ^2J=14.0 Hz, ^3J(H-3a, H-4)=11.9 Hz, ^3J(H-2, H-3a)=4.4 Hz, H-3a); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 141.5, 136.7, 128.5, 128.4, 127.9, 127.7, 127.7, 127.1 (Ph), 99.8 (C1), 74.7, 74.1, 71.4, 63.1, 51.7, 51.5, 28.6; CI-MS (NH_3): *m/z* 326 (26, $[M+H]^+$), 282 (4), 252 (10), 234 (3), 175 (5), 133 (15), 106 (45), 91 (100); anal. calcd for $C_{20}H_{23}O_3N$: C, 73.82, H, 7.12; N, 4.30; found: C, 73.78; H, 7.17; N, 4.29.

Data for **16**: $[\alpha]^{25}_{589}=-47$, $[\alpha]^{25}_{577}=-47$, $[\alpha]^{25}_{546}=-54$, $[\alpha]^{25}_{435}=-90$, $[\alpha]^{25}_{405}=-107$ (*c* 0.75, $CHCl_3$); UV (CH_3CN): 263 (1620), 212 (7730); IR (film): ν 2953, 2892, 1494, 1454, 1146, 1118, 1062, 1024, 923 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.45–7.22 (m, 10H, Ph), 5.44 (s, H-1), 4.67 (dd, ^3J(H-5, H_{exo}-6)=5.4 Hz, ^3J(H-5, H_{endo}-6)=0.9 Hz, H-5), 4.65 and 4.57 (2d, ^2J=12.3 Hz, $PhCH_2$), 3.89 (s, 2H, $PhCH_2$), 3.85 (dd, ^2J=7.2 Hz, ^3J(H-5, H_{exo}-6)=5.4 Hz, H_{exo}-6), 3.81 (dd, ^2J=7.2 Hz, ^3J(H-5, H_{endo}-6)=0.9 Hz, H_{endo}-6), 3.40 (dd, ^3J(H-2, H-3a)=4.6 Hz, ^3J(H-2, H-3e)=2.1 Hz, H-2), 2.60 (dd, ^3J(H-3a, H-4)=5.4 Hz, ^3J(H-3e, H-4)=1.5 Hz, H-4), 2.23 (br s, NH), 2.07 (ddd, ^2J=15.4 Hz, ^3J(H-2, H-3e)=2.1 Hz, ^3J(H-3e, H-4)=1.5 Hz, H-3e), 1.88 (ddd, ^2J=15.4 Hz, ^3J(H-3a, H-4)=5.4 Hz, ^3J(H-2, H-3a)=4.6 Hz, H-3a); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 140.8, 136.7, 128.4, 128.3, 128.1, 127.7, 127.7, 126.8 (Ph), 100.6 (C1), 75.1, 73.5, 71.4, 66.4, 53.1, 50.5, 24.0; CI-MS (NH_3): *m/z* 326 (20, $[M+H]^+$), 282 (4), 252 (10), 234 (3), 219 (3), 191 (6), 175 (4), 133 (16), 106 (46), 91 (100); anal. calcd for $C_{20}H_{23}O_3N$: C, 73.82; H, 7.12; N, 4.30; found: C, 73.78; H, 7.12; N, 4.26.

*5.7. 1,6-Anhydro-2-*O*-benzyl-3-deoxy-β-*D*-xylo-hexopyranose **17** and 1,6-anhydro-2-*O*-benzyl-3-deoxy-β-*D*-ribo-hexopyranose **18***

A 2 M heptane solution of Me_3Al (90 μL, 0.183 mmol) was added dropwise to a CH_2Cl_2 solution (0.2 mL) of Bn_2NH (35 μL, 0.183 mmol) at 20°C. After 30 min, the mixture was cooled to −78°C and a solution of **14** (39 mg, 0.167 mmol) in 0.3 mL of CH_2Cl_2 was added dropwise. Stirring was continued for 1 h and (*i*-Bu)$_2$AlH (310 μL, 0.312 mmol) was added dropwise. The reaction mixture was stirred at −78°C for 2 h and quenched by careful addition of 6 M NaOH (2 mL). The mixture was stirred vigorously for 30 min and extracted with CH_2Cl_2. The organic extract was washed with brine, dried (Na_2SO_4) and concentrated in vacuo. Chromatography (2:3, EtOAc:light petroleum ether) afforded a colorless oil (22 mg, 56%, **17**:**18**=1.1:1):[25] ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.42–7.22 (m, 5H, Ph), 5.44 (s, 0.48H, H-1 of **18**), 5.35 (s, 0.52H, H-1 of **17**), 4.65, 4.47 (2d, ^2J=12.4 Hz, 0.96H, $PhCH_2$ of **18**), 4.63 and 4.54 (2d, ^2J=12.4 Hz, 1.04H, $PhCH_2$ of **17**), 4.52 (m, 0.48H, H-5 of **18**), 4.37 (m, 0.52H, H-5 of **17**), 4.22 (ddd, ^3J(H-3a, H-4)=10.9 Hz, ^3J(H-3e, H-4)=5.5 Hz, ^3J(H-4, H-5)=3.9 Hz, 0.52H, H-4 of **17**), 4.08 (d, ^2J=7.6 Hz, 0.52H, H_{endo}-6 of **17**), 3.83 (dd, ^2J=7.6 Hz, ^3J(H-5, H_{exo}-6)=4.8 Hz, 0.48H, H_{exo}-6 of **18**), 3.78 (dd, ^2J=7.6 Hz, ^3J(H-5, H_{endo}-6)=1.2 Hz, 0.48H, H_{endo}-6 of **18**), 3.50 (dd, ^2J=7.6 Hz, ^3J(H-5, H_{exo}-6)=5.1 Hz, 0.52H, H_{exo}-6 of **17**), 3.63 (m, 0.48H, H-4 of **18**), 3.47 (dd, ^3J(H-2, H-3a)=4.5 Hz, ^3J(H-2, H-3e)=1.5 Hz, 0.52H, H-2 of **17**), 3.45 (m, 0.48H, H-2 of **18**), 2.11 (ddd, ^2J=14.2 Hz, ^3J(H-3e, H-4)=5.5 Hz, ^3J(H-2, H-3e)=1.5 Hz, 0.52H, H-3e of **17**), 1.96 (m, 0.96H, H-3 of **18**), 1.59 (ddd, ^2J=14.2 Hz, ^3J(H-3a, H-4)=10.9 Hz, ^3J(H-2, H-3a)=4.5 Hz, 0.52H, H-3a of **17**).

*5.8. (6*R*)-6-*C*-[1,6-Anhydro-2-*O*-benzyl-3-deoxy-β-*D*-xylo-hexopyrano-4-ulos-3-yl]-1,2:3,4-di-*O*-isopropylidene-α-*D*-galacto-pyranose **20***

A solution of *n*BuLi in hexane (1.6 M, 280 μL, 0.450 mmol) was added dropwise to a stirred solution of $(Me_3Si)_2NH$ (140 μL, 0.654 mmol) in THF (0.6 mL) at −10°C. After 20 min, the mixture was cooled to −78°C and a solution of **14** (90 mg, 0.385 mmol) in THF (1 mL) was added dropwise over a period

of 30 min. At the end of the addition, the mixture was left at −78°C for 30 min then cooled to −95°C. A solution of **3** (130 mg, 0.504 mmol) in THF (0.5 mL) was added dropwise and the mixture was stirred at −95°C for 3.5 h before a 10% solution of AcOH in THF (20 mL) was added dropwise at −78°C. After being warmed up to −10°C, the mixture was quenched with a saturated aq. solution of $NaHCO_3$ (15 mL) and extracted with CH_2Cl_2 (20 mL, three times). The combined organic phases were dried over Na_2SO_4 and concentrated in vacuo. Chromatography on silica gel (2:3, EtOAc:light petroleum ether) afforded a white solid (150 mg, 79%): ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.37–7.24 (m, 5H, Ph), 5.66 (s, H-1′), 5.46 (d, ^3J(H-1, H-2)=4.8 Hz, H-1), 4.71 (d, ^2J=11.8 Hz, $PhCH_2$), 4.64 (dd, ^3J(H-3, H-4)=7.9 Hz, ^3J(H-2, H-3)=2.7 Hz, H-3), 4.60 (d, ^2J=11.8 Hz, $PhCH_2$), 4.51 (d, ^3J(H-5′, H_{exo}-6′)=5.1 Hz, H-5′), 4.47 (dd, ^3J(H-3, H-4)=7.9 Hz, ^3J(H-4, H-5)=1.8 Hz, H-4), 4.30 (dd, ^3J(H-1, H-2)=4.8 Hz, ^3J(H-2, H-3)=2.7 Hz, H-2), 4.27 (dd, ^3J(H-5, H-6)=9.7 Hz, ^3J(H-6, H-3′)=1.5 Hz, H-6), 3.95 (dd, ^3J(H-5, H-6)=9.7 Hz, ^3J(H-4, H-5)=1.8 Hz, H-5), 3.84 (d, ^2J=7.6 Hz, H_{endo}-6′), 3.68 (dd, ^2J=7.6 Hz, ^3J(H-5′, H_{exo}-6′)=5.1 Hz, H_{exo}-6′), 3.60 (d, ^3J(H-2′, H-3′)=7.0 Hz, H-2′), 3.23 (dd, ^3J(H-2′, H-3′)=7.0 Hz, ^3J(H-6, H-3′)=1.5 Hz, H-3′), 1.51, 1.44, 1.35, 1.28 (4s, 4 CH_3); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 210.5 (s, C4′), 137.3 (s, Ph), 128.3 (d, ^1J(C, H)=158 Hz, Ph), 127.8 (d, ^1J(C, H)=158 Hz, Ph), 109.2, 108.7 (2s, 2 $Me_2C(O)_2$), 102.5 (d, ^1J(C, H)=177 Hz, C1′), 96.3 (d, ^1J(C, H)=178 Hz, C1), 78.4 (d, ^1J(C, H)=162 Hz, C3), 78.3 (d, ^1J(C, H)=149 Hz, C2′),72.1 (t, ^1J(C, H)=143 Hz, PhCH_2), 70.6 (d, ^1J(C, H)=157 Hz, C5′), 70.5 (d, ^1J(C, H)=152 Hz, C2), 67.6 (d, ^1J(C, H)=146 Hz, C4, C6), 67.2 (d, ^1J(C, H)=144 Hz, C5), 60.3 (t, ^1J(C, H)=147 Hz, H-6′), 49.7 (d, ^1J(C, H)=128 Hz, C3′), 25.9, 25.5, 24.9, 24.5 (4q, ^1J(C, H)=127 Hz, 4 Me).

*5.9. (6*R*)-6-*C*-(1,6-Anhydro-2-*O*-benzyl-3-deoxy-β-*D*-galacto-pyranos-3-yl)-1,2:3,4-di-*O*-isopropylidene-α-*D*-galacto-pyranose **21** and (6*R*)-6-*C*-[1,6-anhydro-2-*O*-benzyl-3-deoxy-β-*D*-galacto-pyranos-3-yl]-1,2:3,4-di-*O*-isopropylidene-α-*D*-gluco-pyranose **22***

$NaBH_4$ (11 mg, 0.30 mmol) was added to a stirred solution of **20** (49 mg, 0.10 mmol) in 1:1 THF:MeOH (3 mL) at 0°C. After 0.5 h at 0°C, the reaction mixture was quenched with a saturated aq. solution of NH_4Cl. The aq. phase was extracted with CH_2Cl_2 (10 mL, three times). The combined organic phases were dried (Na_2SO_4) and concentrated. Chromatography on silica gel (1:1, EtOAc:light petroleum ether) afforded white solids **21** (37 mg, 75%) and **22** (7 mg, 15%).

Data for **21**: mp 155–156°C; $[\alpha]^{25}_{589}$=−27, $[\alpha]^{25}_{577}$=−29, $[\alpha]^{25}_{546}$=−33, $[\alpha]^{25}_{435}$=−56, $[\alpha]^{25}_{405}$=−66 (*c* 0.65, $CHCl_3$); IR (KBr): ν 3283, 2989, 1455, 1384, 1260, 1213, 1065, 1003 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.43–7.29 (m, 5H), 5.56 (d, ^3J(H-1, H-2)=5.1 Hz, H-1), 5.47 (s, H-1′), 4.72, 4.53 (2d, ^2J=11.8 Hz, $PhCH_2$), 4.67–4.58 (m, 3H, H-3, H-4′, H-5′), 4.42 (dd, ^3J(H-3, H-4)=7.9 Hz, ^3J(H-4, H-5)=1.8 Hz, H-4), 4.35 (dd, ^3J(H-1, H-2)=5.1 Hz, ^3J(H-2, H-3)=2.4 Hz, H-2), 4.34 (d, ^2J=7.6 Hz, H_{endo}-6′), 4.25 (dd, ^3J(H-5, H-6)=8.5 Hz, ^3J(H-6, H-3′)=4.5 Hz, H-6), 3.98 (dd, ^3J(H-5, H-6)=8.5 Hz, ^3J(H-4, H-5)=1.8 Hz, H-5), 3.53 (d, ^3J(H-2′, H-3′)=8.2 Hz, H-2′), 3.46 (dd, ^2J=7.6 Hz, ^3J(H-5′, H_{exo}-6′)=4.5 Hz, H_{exo}-6′), 2.18 (m, H-3′), 1.54, 1.49, 1.37, 1.34 (4s, 4 Me); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 137.9 (s, Ph), 128.5 (d, ^1J(C, H)=159 Hz, Ph), 128.1 (d, ^1J(C, H)=158 Hz, Ph), 127.9 (d, ^1J(C, H)=158 Hz, Ph), 109.5, 108.7 (2s, 2 $C(O)_2Me_2$), 102.0 (d, ^1J(C, H)=177 Hz, C1′), 96.5 (d, ^1J(C, H)=179 Hz, C1), 77.1 (d, ^1J(C, H)=145 Hz, C2′), 73.9 (d, ^1J(C, H)=156 Hz, C3), 71.6 (t, ^1J(C, H)=155 Hz, $PhCH_2$), 71.0 (d, ^1J(C, H)=150 Hz, C4), 70.8 (d, ^1J(C, H)=152 Hz, C5′), 70.4 (d, ^1J(C, H)=154 Hz, C2), 70.1 (d, ^1J(C, H)=147 Hz, C6), 67.6 (d, ^1J(C, H)=141 Hz, C5), 65.3 (d, ^1J(C, H)=148 Hz, C4′), 61.9 (t, ^1J(C, H)=150 Hz, C6′), 38.7 (d, ^1J(C, H)=131 Hz, C3′), 26.0, 25.9, 24.9, 24.6 (4q, ^1J(C, H)=125 Hz, 4 Me); CI-MS (NH_3): *m/z* 512 ($[M+NH_4]^+$, 15), 496 (10), 495 ($[M+H]^+$, 25), 479 (5), 277 (18), 276 (19), 100 (33), 91 (100); anal. calcd for $C_{25}H_{34}O_{10}$: C, 60.72; H, 6.93; found: C, 60.85; H, 6.95.

Data for **22**: ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.42–7.22 (m, 5H, Ph), 5.58 (d, ^3J(H-1, H-2)=5.1 Hz, H-1), 5.50 (s, H-1′), 4.68 (d, ^2J=11.9 Hz, $PhCH_2$), 4.62 (dd, ^3J(H-3, H-4)=7.8 Hz, ^3J(H-2, H-3)=2.4 Hz, H-3), 4.57 (d, ^2J=11.9 Hz, $PhCH_2$), 4.56 (d, ^3J(H-5′, H_{exo}-6′)=5.4 Hz, H-5′), 4.43 (dd, ^3J(H-3, H-4)=7.8 Hz, ^3J(H-4, H-5)=1.9 Hz, H-4), 4.35 (dd, ^3J(H-1, H-2)=5.1 Hz, ^3J(H-2, H-3)=2.4 Hz, H-2), 3.97 (m, H-6), 3.81 (dd, ^3J(H-5, H-6)=8.1 Hz, ^3J(H-4, H-5)=1.9 Hz, H-5), 3.80 (d, ^3J(H-3′, H-4′)=4.9 Hz, H-4′), 3.74 (d, ^2J=7.6 Hz, H_{endo}-6′), 3.70 (dd, ^2J=7.6 Hz, ^3J(H-5′, H_{exo}-6′)=5.4 Hz, H_{exo}-6′), 3.25 (d, ^3J(H-2′, H-3′)=5.4 Hz, H-2′), 2.19 (dt, ^3J(H-2′, H-3′)=5.4 Hz, ^3J(H-3′, H-4′)=^3J(H-6, H-3′)=4.9 Hz, H-3′), 1.54, 1.47, 1.37, 1.33 (4s, 4 Me).

5.10. Acetonide **23**

A mixture of **9** (62 mg, 0.137 mmol), 2,2-dimethoxypropane (0.6 mL), Drierite (3 g), dry acetone (3 mL) and *p*TsOH (1 mg) was stirred at 20°C for 9 h. Et_3N (0.3 mL) was added and the solid was then filtered off. The filtrate was evaporated in vacuo. Chromatography on silica gel (8:92, EtOAc:light petroleum ether) afforded a colorless oil (35 mg, 48%): $[\alpha]^{25}_{589}=-69$, $[\alpha]^{25}_{577}=-78$, $[\alpha]^{25}_{546}=-85$, $[\alpha]^{25}_{435}=-146$, $[\alpha]^{25}_{405}=-168$ (*c* 0.17, $CHCl_3$); UV (CH_3CN): λ_{max} 255 (ε=5040), 202 (8176); IR (film): ν 2986, 2935, 1378, 1255, 1215, 1132, 1069, 1002 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.58–7.53, 7.31–7.19 (m, 5H, Ph), 5.53 (d, ^3J(H-1, H-2)=5.2 Hz, H-1), 5.27 (s, H-1′), 4.57 (dd, ^3J(H-3, H-4)=7.9 Hz, ^3J(H-2, H-3)=2.4 Hz, H-3), 4.50 (dd, ^3J(H-4′, H-5′)=6.1 Hz, ^3J(H-5′, H_{exo}-6)=5.1 Hz, H-5′), 4.45–4.38 (m, 3H, H-4′, 6′$_{endo}$, 4), 4.28 (dd, ^3J(H-1, H-2)=5.2 Hz, ^3J(H-2, H-3)=2.4 Hz, H-2), 4.08 (dd, ^3J(H-6, H-3′)=9.1 Hz, ^3J(H-5, H-6)=8.5 Hz, H-6), 3.95 (d, ^3J(H-2′, H-3′)=3.0 Hz, H-2′), 3.88 (dd, ^3J(H-5, H-6)=8.5 Hz, ^3J(H-4, H-5)=1.5 Hz, H-5), 3.58 (dd, ^2J=7.6 Hz, ^3J(H-5′, H_{exo}-6′)=5.1 Hz, H_{exo}-6′), 2.25 (dt, ^3J(H-6, H-3′)=^3J(H-3′, H-4′)=9.1 Hz, ^3J(H-2′, H-3′)=3.0 Hz, H-3′), 1.53, 1.47, 1.39, 1.35, 1.34, 1.29 (6s, 6 Me); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 134.5 (s, Ph), 131.9, 128.8, 127.0 (3d, ^1J(C, H)=160 Hz, Ph), 108.8, 108.7 (2s, $C(O)_2Me_2$), 102.1 (d, ^1J(C, H)=178 Hz, C1′), 100.2 (s, $C(O)_2Me_2$), 96.1 (d, ^1J(C, H)=180 Hz, C1), 73.1 (d, ^1J(C, H)=157 Hz, C5′), 70.7 (d, ^1J(C, H)=151 Hz, C2), 70.5 (d, ^1J(C, H)=155 Hz, C4′), 70.4 (d, ^1J(C, H)=154 Hz, C3), 70.1 (d, ^1J(C, H)=136 Hz, C5), 68.7 (d, ^1J(C, H)=145 Hz, C6), 63.8 (t, ^1J(C, H)=152 Hz, C6′), 63.3 (d, ^1J(C, H)=151 Hz, C4), 45.5 (d, ^1J(C, H)=147 Hz, C2′), 40.7 (d, ^1J(C, H)=133 Hz, C3′), 27.6, 26.1, 26.0, 25.4, 25.0, 24.4 (6q, ^1J=125 Hz, 6 Me); CI-MS (NH_3): *m/z* 538 (44), 537 ([M+H]$^+$, 100), 536 (M$^{+\cdot}$, 33), 479 (9), 430 (8), 429 (10), 370 (8), 320 (5), 81 (17); anal. calcd for $C_{27}H_{36}O_9S$: C, 60.43; H, 6.76; found: C, 60.41; H, 6.88.

5.11. Acetonide **24**

A mixture of **12** (41 mg, 0.071 mmol), 2,2-dimethoxypropane (1 mL), Drierite (1 g, powder), dry acetone (2 mL) and *p*TsOH (1 mg) was stirred at 20°C for 6 h. K_2CO_3 (10 mg) was added and the solid was then filtered off. The filtrate was evaporated in vacuo. Chromatography on silica gel (8:92, EtOAc:light petroleum ether) afforded a colorless oil (28 mg, 64%): $[\alpha]^{25}_{589}=-39$, $[\alpha]^{25}_{577}=-41$, $[\alpha]^{25}_{546}=-47$, $[\alpha]^{25}_{435}=-78$, $[\alpha]^{25}_{405}=-93$ (*c* 1.4, $CHCl_3$); UV (CH_3CN): λ_{max} 258 (ε=913), 213 (7724); IR (film): ν 2986, 1376, 1214, 1072, 997 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.44–7.18 (m, 5H, Ph), 5.54 (s, H-1′), 5.28 (d, ^3J(H-1, H-2)=5.2 Hz, H-1), 4.63 (dd, ^3J(H-3, H-4)=7.9 Hz, ^3J(H-2, H-3)=2.4 Hz, H-C3), 4.62 (m, H-C5′), 4.45 (dd, ^3J(H-4′, H-5′)=8.2 Hz, ^3J(H-3′, H-4′)=4.8 Hz, H-4′), 4.42 (dd, ^3J(H-3, H-4)=7.9 Hz, ^3J(H-4, H-5)=1.8 Hz, H-4), 4.30 (dd, ^3J(H-5, H-6)=9.7 Hz, ^3J(H-6, H-3′)=3.3 Hz, H-6), 4.27 (dd, ^3J(H-1, H-2)=5.2 Hz, ^3J(H-2, H-3)=2.4 Hz, H-2), 4.23 (d, ^2J=6.7 Hz, H_{endo}-6′), 3.98 (d, ^2J=13.6 Hz, $PhCH_2$), 3.95 (dd, ^3J(H-5, H-6)=9.7 Hz, ^3J(H-4, H-5)=1.8 Hz, H-5), 3.53 (d, ^2J=13.6 Hz, $PhCH_2$), 3.34 (dd, ^2J=6.7 Hz, ^3J(H-5′, H_{exo}-6′)=4.8 Hz, H_{exo}-6′), 3.02 (d, ^3J(H-2′, H-3′)=10.0 Hz,

H-2′), 2.03 (ddd, ^3J(H-2′, H-3′)=10.0 Hz, ^3J(H-3′, H-4′)=4.8 Hz, ^3J(H-6, H-3′)=3.3 Hz, H-3′), 1.65, 1.54, 1.40, 1.31, 1.28, 1.04 (6s, 6 Me); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 139.5 (s, Ph), 129.2, 128.0, 126.7 (3d, ^1J(C, H)=160 Hz, Ph), 108.9, 108.2 (2s, $C(O)_2Me_2$), 99.9 (d, ^1J(C, H)=169 Hz, C1′), 98.3 (s, $C(O)_2Me_2$), 96.2 (d, ^1J(C, H)=177 Hz, C1), 72.3 (d, ^1J(C, H)=161 Hz, C3), 70.7 (d, ^1J(C, H)=151 Hz, C5′), 70.7 (d, ^1J(C, H)=144 Hz, C4), 70.6 (d, ^1J(C, H)=152 Hz, C2), 68.3 (d, ^1J(C, H)=148 Hz, C5, C6), 62.8 (d, ^1J(C, H)=151 Hz, C4′), 61.9 (t, ^1J(C, H)=153 Hz, C6′), 60.7 (d, ^1J(C, H)=137 Hz, C2′), 53.5 (t, ^1J(C, H)=132 Hz, $PhCH_2$), 29.6 (d, ^1J(C, H)=129 Hz, C3′), 27.8, 26.3, 26.0, 25.6, 24.8, 24.2 (6q, ^1J(C, H)=125 Hz, 6 Me); CI-MS (NH_3): *m/z* 624 ($[M+H]^+$, 4), 623 ($M^{+\cdot}$, 3), 608 ($[M–Me]^+$, 5), 532 ($[M–PhCH_2]^+$, 8), 464 (8), 281 (13), 252 (29), 251 (10), 236 (12), 91 (100); anal. calcd for $C_{35}H_{45}NO_9$: C, 67.40; H, 7.27; found: C, 67.40; H, 7.20.

5.12. Acetonide **25**

A mixture of **21** (22 mg, 0.044 mmol), 2,2-dimethoxypropane (0.2 mL), Drierite (1 g), dry acetone (1.6 mL) and *p*TsOH (0.4 mg) was stirred at 20°C for 4 h. Et_3N (0.1 mL) was added and the solid was filtered off. The filtrate was evaporated in vacuo. Chromatography (1:9, EtOAc:petroleum ether) afforded white needles (12 mg, 50%): mp 158–160°C; $[\alpha]^{25}_{589}=-64$, $[\alpha]^{25}_{577}=-66$, $[\alpha]^{25}_{546}=-75$, $[\alpha]^{25}_{435}=-123$, $[\alpha]^{25}_{405}=-146$ (*c* 0.55, $CHCl_3$); UV (CH_3CN): λ_{max} 257 (ε=456), 251 (436), 208 (5650); IR (KBr): ν 2984, 2933, 1381, 1372, 1260, 1252, 1244, 1225, 1178, 1169, 1119, 1096, 1074, 1065, 1054 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.42–7.37, 7.35–7.29, 7.28–7.22 (m, 5H, Ph), 5.55 (d, ^3J(H-1, H-2)=5.2 Hz, H-1), 5.39 (s, H-1′), 4.75 (d, ^2J=11.5 Hz, $PhCH_2$), 4.58 and 4.56 (2d, ^2J=11.5 Hz, $PhCH_2$), 4.57 (dd, ^3J(H-3, H-4)=8.2 Hz, ^3J(H-2, H-3)=2.4 Hz, H-3), 4.54–4.47 (m, 2H, H-5′, 4′), 4.43 (dd, ^3J(H-3, H-4)=8.2 Hz, ^3J(H-4, H-5)=1.8 Hz, H-4), 4.36 (d, ^2J=7.3 Hz, H_{endo}-6′), 4.28 (dd, ^3J(H-1, H-2)=5.2 Hz, ^3J(H-2, H-3)=2.4 Hz, H-2), 4.04 (dd, ^3J(H-6, H-3′)=10.3 Hz, ^3J(H-5, H-6)=8.8 Hz, H-6), 3.85 (dd, ^3J(H-5, H-6)=8.8 Hz, ^3J(H-4, H-5)=1.8 Hz, H-5), 3.84 (d, ^3J(H-2′, H-3′)=2.7 Hz, H-2′), 3.56 (dd, ^2J=7.6 Hz, ^3J(H-5′, H_{exo}-6′)=4.8 Hz, H_{exo}-6′), 2.38 (ddd, ^3J(H-6, H-3′)=10.3 Hz, ^3J(H-3′, H-4′)=9.1 Hz, ^3J(H-2′, H-3′)=2.7 Hz, H-3′), 1.47, 1.42, 1.40, 1.35, 1.34, 1.28 (6s, 6 Me); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 138.9 (s, Ph), 128.1, 127.6, 127.3 (3d, ^1J(C, H)=160 Hz, Ph), 108.8, 108.5 (2s, $C(O)_2Me_2$), 100.8 (d, ^1J(C, H)=173 Hz, C1′), 99.8 (s, $C(O)_2Me_2$), 96.3 (d, ^1J(C, H)=183 Hz, C1), 75.9 (d, ^1J(C, H)=148 Hz, C2′), 72.6 (d, ^1J(C, H)=157 Hz, C5′), 71.4 (t, ^1J(C, H)=141 Hz, $PhCH_2$), 71.0 (d, ^1J(C, H)=140 Hz, C5), 70.6 (d, ^1J(C, H)=152 Hz, C2), 70.4 (d, ^1J(C, H)=150 Hz, C4), 70.4 (d, ^1J(C, H)=154 Hz, C3), 67.9 (d, ^1J(C, H)=145 Hz, C6), 63.3 (t, ^1J(C, H)=155 Hz, C6′), 62.8 (d, ^1J(C, H)=149 Hz, C4′), 41.9 (d, ^1J(C, H)=133 Hz, C3′), 27.2, 26.1, 26.0, 25.6, 24.9, 24.5 (6q, ^1J(C, H)=125 Hz, 6 Me); CI-MS (NH_3): *m/z* 536 (35), 535 ($[M+H]^+$, 78), 519 (7, $[M-Me]^+$), 428 (9), 427 (9), 376 (6), 385 (5), 91 (100); anal. calcd for $C_{28}H_{38}O_{10}$: C, 62.92; H, 7.16; found: C, 63.32; H, 7.21.

5.13. *1,6-Anhydro-3-*C*-[(1S)-2,6-anhydro-3,4,5,7-tetra-*O*-benzyl-*D*-glycero-*D*-gulo-heptitol-1-*C*-yl]-2,3-dideoxy-β-*D*-glycero-hex-2-en-4-ulopyranose **28**

1 M Et_2AlI in toluene (5.3 mL, 5.3 mmol) was added dropwise in 45 min to a stirred solution of **27**[20] (2.36 g, 4.3 mmol) and **1** (0.65 g, 5.1 mmol) in anhydrous CH_2Cl_2 (16 mL) cooled to −95°C under Ar atmosphere. After stirring at −95°C for 4 h, the cooling bath was removed and Et_2O (50 mL), then 1 M aq. HCl (6 mL) were added under vigorous stirring (red mixture becomes yellowish). After the addition of H_2O (50 mL), the aqueous phase was extracted with Et_2O (50 mL, three times). The combined org. phases were washed with brine (50 mL) and dried ($MgSO_4$). Solvent evaporation and flash chromatography on silica gel (3:1, light petroleum ether:EtOAc) afforded 2.32 g (80%) of white solid: mp

113–114°C (EtOH); $[\alpha]^{25}_{589}$=+45.3, $[\alpha]^{25}_{577}$=+48.3, $[\alpha]^{25}_{546}$=+67.4, $[\alpha]^{25}_{435}$=+289, $[\alpha]^{25}_{405}$=+706 (*c* 0.1, $CHCl_3$); UV (MeCN): λ_{max} 244 (ε=7000), 217 (11500); IR (KBr): ν 3415, 2865, 1695, 1495, 1455, 1355, 1100, 1060, 735, 700 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.38–7.12 (m, 20H), 7.07 (dd, ^3J(H-2, H-1)=3.5, ^4J(H-2, H-1′)=1.5 Hz, H-2), 5.78 (d, ^3J(H-1, H-2)=3.5 Hz, H-1), 4.96-4.74 (m, 5H), 4.63 (dd, ^3J(H-5, H_{exo}-6)=6.2, ^3J(H-5, H_{endo}-6)=1.2 Hz, H-5), 4.58 (br s, H-1′), 4.53–4.39 (m, 3H), 3.91 (dd, ^2J=8.2, ^3J(H_{exo}-6, H-5)=6.2 Hz, H_{exo}-6), 3.83 (t, ^3J(H-3′, H-4′)=^3J(H-3′, H-2′)=9.1 Hz, H-3′), 3.73 (t, ^3J(H-4′, H-5′)=^3J(H-4′, H-3′)=9.1 Hz, H-4′), 3.64 (dd, ^3J(H-2′, H-3′)=9.1, ^3J(H-2′, H-1′)=1.8 Hz, H-2′), 3.59 (d, ^3J(H-7′, H-6′)=3.4 Hz, H_2C(7′)), 3.55 (dd, ^2J=8.2, ^3J(H_{endo}-6, H-5)=1.2 Hz, H_{endo}-6), 3.52 (t, ^3J(H-5′, H-6′)=^3J(H-5′, H-4′)=9.1 Hz, H-5′), 3.34 (dt, ^3J(H-6′, H-5′)=9.1, ^3J(H-6′, H-7′)=3.4 Hz, H-6′); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 194.5 (s, C-4), 142.3 (d, ^1J(C, H)=166 Hz, C-2), 138.4, 138.1, 138.0, 137.9, 137.7 (5s), 128.4-127.8 (20d), 96.8 (d, ^1J(C, H)=177 Hz, C-1), 86.9 (d, ^1J(C, H)=141 Hz, C-4′), 79.2 (d, ^1J(C, H)=167 Hz, C-5), 78.6 (2d, ^1J(C, H)=141, C-2, ^1J(C, H)=139 Hz, C-2′, C-6′), 78.0 (d, ^1J(C, H)=138 Hz, C-5′), 77.6 (d, ^1J(C, H)=137 Hz, C-3′), 75.4, 74.9, 74.8, 73.3 (4t, ^{1}J(C, H)=142 Hz, CH_2 (Bn)), 69.2 (t, ^1J(C, H)=142 Hz, C-7′), 65.9 (d, ^1J(C, H)=146 Hz, C-1′), 62.1 (t, ^1J(C, H)=151 Hz, C-6); CI-MS (NH_3): *m/z* 697 (0.2, $[M+18]^+$), 663 (0.4), 441 (0.9), 256 (11.3), 191 (3.9), 91 (100); anal. calcd for $C_{41}H_{42}O_9$ (678.77): C, 72.55; H, 6.24; found: C, 72.64; H, 6.25.

*5.14. 1,6:2,3-Dianhydro-3-*C*-[(1*S*)-2,6-anhydro-3,4,5,7-tetra-*O*-benzyl-*D*-glycero-*D*-gulo-heptitol-1-*C*-yl]-β-*D*-ribo-hex-4-ulopyranose **29***

A 5.5 M *t*-BuOOH solution in nonane (870 μL, 4.78 mmol), DBU (434 μL, 2.90 mmol) and CH_2Cl_2 (13 mL) was added slowly to a stirred solution of **28** (1.32 g, 1.94 mmol) in CH_2Cl_2 (25 mL) cooled to 0°C. After stirring at 20°C for 5 h, CH_2Cl_2 (70 mL), H_2O (50 mL) and 0.5 M aq. $Na_2S_2O_3$ (50 mL) were added under vigorous stirring. After stirring at 20°C for 1 h, the aqueous layer was extracted with CH_2Cl_2 (50 mL, three times). The combined org. extracts were washed with 1 M aq. HCl (50 mL), then with brine (50 mL) and dried ($MgSO_4$). Solvent evaporation afforded 1.40 g (100%) of **29**, pure enough for the next step. Flash chromatography on silica gel (3:1, light petroleum ether:EtOAc) gave a white solid (82%): mp 47°C; $[\alpha]^{25}_{589}$=+10.3, $[\alpha]^{25}_{546}$=+4.5, $[\alpha]^{25}_{435}$=+12.5, $[\alpha]^{25}_{405}$=+21.0 (*c* 0.22, $CHCl_3$); UV (MeCN): λ_{max} 216 (ε=10400); IR (KBr): ν 3420, 3030, 2870, 1730, 1495, 1455, 1360, 1120, 1095, 1065, 1030, 990, 735, 700 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.34–7.15 (m, 20H), 5.82 (s, H-1), 4.92–4.77 (m, 5H), 4.64 (d, ^3J(H-1′, H-2′)=2.0 Hz, H-1′), 4.57–4.49 (m, 5H), 3.79 (t, ^3J(H-3′, H-4′)=^3J(H-3′, H-2′)=9.0 Hz, H-3′), 3.77–3.74 (m, H_2C(6)), 3.69 (t, ^3J(H-4′, H-5′)=^3J(H-4′, H-3′)=9.0 Hz, H-4′), 3.68 (d, ^3J(H-7′, H-6′)=2.8 Hz, H_2C(7′)), 3.57 (t, ^3J(H-5′, H-6′)=^3J(H-5′, H-4′)=9.0 Hz, H-5′), 3.57 (dd, ^3J(H-2, H-1)=1.3 Hz, H-2), 3.44 (dd, ^3J(H-2′, H-3′)=9.0, ^3J(H-2′, H-1′)=2.0 Hz, H-2′), 3.31 (dt, ^3J(H-6′, H-5′)=9.0, ^3J(H-6′, H-7′)=2.8 Hz, H-6′); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 199.0 (s, C-4), 138.4, 138.2, 138.0, 137.95 (4s), 128.4–127.6 (20d), 98.1 (d, ^1J(C, H)=178 Hz, C-1), 86.8 (d, ^1J(C, H)=145 Hz, C-4′), 79.4 (d, ^1J(C, H)=140 Hz, C-6′), 78.3 (d, ^1J(C, H)=158 Hz, C-5), 77.7 (d, ^1J(C, H)=141 Hz, C-5′), 77.2 (d, ^1J(C, H)=143 Hz, C-3′), 77.1 (d, ^1J(C, H)=143 Hz, C-2′), 75.5, 75.0, 74.9, 73.5 (4t, ^1J(C, H)=142 Hz, CH_2 (Bn)), 69.0 (t, ^1J(C, H)=142 Hz, C-7′), 65.4 (t, ^1J(C, H)=155 Hz, C-6), 63.2 (d, ^1J(C, H)=147 Hz, C-1′), 59.5 (s, C-3), 50.5 (d, ^1J(C, H)=188 Hz, C-2); CI-MS (NH_3): *m/z* 712 (0.6, $[M+18]^+$), 663 (2), 603 (1), 462 (0.5), 181 (2), 91 (100); anal. calcd for $C_{41}H_{42}O_{10}$ (694.78): C, 70.88; H, 6.09; found: C, 70.83; H, 6.06.

*5.15. 1,6:2,3-Dianhydro-3-*C*-[(1*S*)-2,6-anhydro-3,4,5,7-tetra-*O*-benzyl-*D*-glycero-*D*-gulo-heptitol-1-*C*-yl]-β-*D*-gulo-pyranose **30***

$NaBH_4$ (0.12 g, 3.2 mmol) was added portionwise to a stirred solution of **29** (1.4 g, 2.0 mmol) in MeOH (50 mL) cooled to 0°C. After stirring at 0°C for 1 h, CH_2Cl_2 (50 mL), H_2O (50 mL) and 1 M aq. HCl (5 mL) were added. The aqueous layer was extracted with CH_2Cl_2 (50 mL, three times), the combined org. extracts were washed with brine (50 mL) and dried ($MgSO_4$). Solvent evaporation and flash chromatography on silica gel (7:3, light petroleum ether:EtOAc) afforded 1.33 g (95%) of white solid: mp 48°C; $[\alpha]^{25}_{589}$=+8.7, $[\alpha]^{25}_{546}$=+23, $[\alpha]^{25}_{435}$=+30, $[\alpha]^{25}_{405}$=+38 (*c* 0.09, $CHCl_3$); UV (MeCN): λ_{max} 215 (ε=9100); IR (film): ν 3430, 3065, 2910, 1635, 1455, 1265, 1125, 1065, 735, 700 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.34–7.20 (m, 20H), 5.52 (d, ^3J(H-1, H-2)=0.9 Hz, H-1), 4.95-4.41 (m, 8H), 4.59 (d, ^3J(OH, H-4)=5.6 Hz, OH), 4.23 (dd, ^3J(H-4, OH)=5.6, ^3J(H-4, H-5)=4.9 Hz, H-4), 4.12 (dd, ^2J=8.2, ^3J(H_{endo}-6, H-5)=1.8 Hz, H_{endo}-6), 4.07 (ddd, ^3J(H-5, H_{exo}-6)=6.1, ^3J(H-5, H-4)=4.9, ^3J(H-5, H_{endo}-6)=1.8 Hz, H-5), 3.78-3.75 (m, 4H, H-3′, H-4′, H_{exo}-6, OH), 3.69 (dd, ^2J=9.7, ^3J(H_a-7′, H-6′)=2.9 Hz, H_a-7′), 3.65 (ddd, ^3J(H-6′, H-5′)=9.1, ^3J(H-6′, H_b-7′)=6.9, ^3J(H-6′, H_a-7′)=2.9 Hz, H-6′), 3.56 (d, ^3J(H-2′, H-3′)=8.2 Hz, H-2′), 3.46 (dd, ^2J(H_b-7′, H_a-7′)=9.7, ^3J(H_b-7′, H-6′)=6.9 Hz, H_b-7′), 3.43 (t, ^3J(H-5′, H-6′)=^3J(H-5′, H-4′)=9.1 Hz, H-5′), 3.19 (d, ^3J(H-1′, OH)=7.6 Hz, H-1′), 2.91 (br s, H-2); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 138.3, 138.0, 137.6, 137.0 (4s), 128.4–127.4 (20d), 97.0 (d, ^1J(C, H)=176 Hz, C-1), 86.7 (d, ^1J(C, H)=142 Hz, C-4′), 78.6 (d, ^1J(C, H)=142 Hz, C-5′), 78.3 (d, ^1J(C, H)=139 Hz, C-2′), 77.4 (d, ^1J(C, H)=144 Hz, C-3′), 77.0 (d, ^1J(C, H)=144 Hz, C-6′), 75.6, 75.0, 74.95, 73.5 (4t, ^1J(C, H)=143 Hz, CH_2 (Bn)), 74.8 (d, ^1J(C, H)=146 Hz, C-1′), 72.5 (d, ^1J(C, H)=159 Hz, C-5), 69.5 (t, ^1J(C, H)=140 Hz, C-7′), 67.0 (d, ^1J(C, H)=152 Hz, C-4), 63.4 (t, ^1J(C, H)=152 Hz, C-6), 57.0 (d, ^1J(C, H)=180 Hz, C-2), 56.9 (s, C-3); CI-MS (NH_3): *m/z* 714 (9, $[M+18]^+$), 697 (2), 605 (2), 481 (3), 391 (3), 253 (6), 181 (13), 91 (100); anal. calcd for $C_{41}H_{44}O_{10}$ (696.79): C, 70.67; H, 6.36; found: C, 70.66; H, 6.43.

*5.16. 1,6:2,3-Dianhydro-3-*C*-[(1*S*)-2,6-anhydro-*D*-glycero-*D*-gulo-heptitol-1-*C*-yl]-β-*D*-gulo-pyranose **31***

Metallic Na (1.2 g, 52 mmol) was added to liquid NH_3 (30 mL, condensed at −78°C). A solution of **30** (1.32 g, 1.9 mmol) in anhydrous THF (10 mL) was added dropwise under stirring. After stirring at −78°C for 40 min, solid NH_4Cl (4 g) was added and the cooling bath removed. Once at 20°C, the residue was taken in MeOH and purified by flash chromatography on silica gel (3:1, CH_2Cl_2:MeOH) affording 0.53 g (83%) of hygroscopic white solid: $[\alpha]^{25}_{589}$=−11, $[\alpha]^{25}_{546}$=−13, $[\alpha]^{25}_{435}$=−23, $[\alpha]^{25}_{405}$=−29 (*c* 0.36, MeOH); IR (KBr): ν 3415, 2925, 1640, 1415, 1125, 1085, 1015, 620 cm^{-1}; ^{1}H NMR (400 MHz, CD_3OD): δ 5.56 (d, ^3J(H-1, H-2)=1.1 Hz, H-1), 4.30 (ddd, ^3J(H-5, H_{exo}-6)=6.1, ^3J(H-5, H-4)=4.9, ^3J(H-5, H_{endo}-6)=1.8 Hz, H-5), 4.24 (d, ^3J(H-4, H-5)=4.9 Hz, H-4), 4.19 (br s, H-1′), 4.06 (dd, ^2J=8.0, ^3J(H_{endo}-6, H-5)=1.8 Hz, H_{endo}-6), 3.87 (dd, ^2J=11.9, ^3J(H_a-7′, H-6′)=1.8 Hz, H_a-7′), 3.78 (dd, ^3J(H-2′, H-3′)=9.1, ^3J(H-2′, H-1′)=1.3 Hz, H-2′), 3.72 (m, 2H, H_{exo}-6, H_b-7′), 3.55 (t, ^3J(H-3′, H-4′)=^3J(H-3′, H-2′)=9.1 Hz, H-3′), 3.39 (t, ^3J(H-4′, H-5′)=^3J(H-4′, H-3′)=9.1 Hz, H-4′), 3.33–3.30 (m, 2H, H-5′, H-6′), 3.19 (br s, H-2); ^{13}C NMR (100.6 MHz, CD_3OD): δ 98.6 (d, ^1J(C, H)=175 Hz, C-1), 81.4 (d, ^1J(C, H)=142 Hz, C-6′), 80.2 (d, ^1J(C, H)=142 Hz, C-2′), 79.6 (d, ^1J(C, H)=140 Hz, C-4′), 74.6 (d, ^1J(C, H)=158 Hz, C-5), 71.0 (d, ^1J(C, H)=145 Hz, C-5′), 70.7 (d, ^1J(C, H)=144 Hz, C-3′), 68.2 (d, ^1J(C, H)=146 Hz, C-1′), 67.4 (d, ^1J(C, H)=148 Hz, C-4), 64.3 (t, ^1J(C, H)=152 Hz, C-6), 62.5 (t, ^1J(C, H)=143 Hz, C-7′), 60.0 (s, C-3), 55.1 (d, ^1J(C, H)=182 Hz, C-2); CI-MS (NH_3): *m/z* 354 (1.2, $[M+18]^+$), 247 (1), 126 (94), 95 (100), 83 (81).

5.17. 4-O-*Acetyl-1,6:2,3-dianhydro-3*-C-*[(1*S*)-1,3,4,5,7-penta*-O-*acetyl-2,6-anhydro*-D-glycero-D-gulo-*heptitol-1*-C-*yl]-β*-D-gulo-*pyranose* ***32***

A mixture of **31** (530 mg, 1.57 mmol), Ac_2O (6 mL), pyridine (10 mL) and 4-dimethylaminopyridine (0.5 mg) was stirred at 20°C for 15 h. Solvent evaporation in vacuo gave a residue that was taken in toluene (10 mL) and the solvent was evaporated to dryness in vacuo. The latter operation was repeated and the residue purified by flash chromatography on silica gel (1:2, light petroleum ether:EtOAc) affording 878 mg (95%) of white solid: mp 66°C; $[\alpha]^{25}_{589}$=+12, $[\alpha]^{25}_{546}$=+13, $[\alpha]^{25}_{435}$=+22, $[\alpha]^{25}_{405}$=+25 (*c* 0.38, $CHCl_3$); IR (KBr): ν 1755, 1435, 1375, 1230, 1120, 1035, 910 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.59 (s, H-1), 5.34 (d, ^3J(H-4, H-5)=4.8 Hz, H-4), 5.22 (t, ^3J(H-4′, H-5′)=^3J(H-4′, H-3′)=9.7 Hz, H-4′), 5.10 (t, ^3J(H-3′, H-4′)=^3J(H-3′, H-2′)=9.7 Hz, H-3′), 5.07 (t, ^3J(H-5′, H-6′)=^3J(H-5′, H-4′)=9.7 Hz, H-5′), 4.86 (br s, H-1′), 4.48 (ddd, ^3J(H-5, H_{exo}-6)=5.9, ^3J(H-5, H-4)=4.8, ^3J(H-5, H_{endo}-6)=1.9 Hz, H-5), 4.33 (dd, ^2J=12.4, ^3J(H_a-7′, H-6′)=4.9 Hz, H_a-7′), 4.13 (dd, ^2J=12.4, ^3J(H_b-7′, H-6′)=2.0 Hz, H_b-7′), 4.02 (dd, ^3J(H-2′, H-3′)=9.7, ^3J(H-2′, H-1′)=1.9 Hz, H-2′), 3.84 (dd, ^2J=8.1, ^3J(H_{endo}-6, H-5)=1.9 Hz, H_{endo}-6), 3.80 (dd, ^2J=8.1, ^3J(H_{exo}-6, H-5)=5.9 Hz, H_{exo}-6), 3.75 (ddd, ^3J(H-6′, H-5′)=9.7, ^3J(H-6′, H_a-7′)=4.9, ^3J(H-6′, H_b-7′)=2.0 Hz, H-6′), 3.18 (s, H-2), 2.15, 2.11, 2.08, 2.04, 2.00, 1.99 (6s, 6 AcO). ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 170.5, 170.1, 169.5, 169.3, 169.0, 168.5 (6s), 96.9 (d, ^1J(C, H)=177 Hz, C-1), 76.6, 76.4 (2d, ^1J(C, H)=144, ^1J(C, H)=133 Hz, C-2′, C-6′), 74.1 (d, ^1J(C, H)=152 Hz, C-4′), 70.1 (d, ^1J(C, H)=160 Hz, C-5), 68.1, 67.6, 67.4 (3d, ^1J(C, H)=156, ^1J(C, H)=157, ^1J(C, H)=155 Hz, C-4, C-3′, C-5′), 66.4 (d, ^1J(C, H)=148 Hz, C-1′), 63.5 (t, ^1J(C, H)=156 Hz, C-6), 62.0 (t, ^1J(C, H)=149 Hz, C-7′), 53.9 (s, C-3), 52.6 (d, ^1J(C, H)=184 Hz, C-2), 20.7, 20.6, 20.4, 20.35, 20.3, 20.1 (6q, ^1J(C, H)=130 Hz, 6 Ac); CI-MS (NH_3): *m/z* 606 (15, $[M+18]^+$), 529 (2), 117 (5), 83 (100); anal. calcd for $C_{25}H_{32}O_{16}$ (588.52): C, 51.02; H, 5.48; found: C, 50.84; H, 5.30.

5.18. 1,4,6-Tri-O-*acetyl-2,3-anhydro-3*-C-*[(1*S*)-1,3,4,5,7-penta*-O-*acetyl-2,6-anhydro*-D-glycero-D-gulo-*heptitol-1-C-yl]-α*-D-gulo-*pyranose* ***33*** *and 4,6-di*-O-*acetyl-2,3-anhydro-3*-C-*[(1*S*)-1,3,4,5,7-penta*-O-*acetyl-2,6-anhydro*-D-glycero-D-gulo-*heptitol-1*-C-*yl]-β*-D-gulo-*pyranose* ***34***

A mixture of **32** (225 mg, 0.38 mmol), Ac_2O (1.35 mL) and CF_3COOH (1 mL) was stirred at 20°C for 25 h. This was poured into ice (10 mL) and neutralized with sat. aq. solution of $NaHCO_3$ (pH 8). The mixture was extracted with EtOAc (10 mL, three times). The combined organic extracts were washed with brine (30 mL) and dried ($MgSO_4$). Solvent evaporation and flash chromatography on silica gel (1:1, light petroleum ether:EtOAc) afforded 93 mg (37%) of pyranose **33**, 100 mg (38%) of pyranose **34** and 43 mg (16%) of **32**.

Data for **33**: white solid, mp 81°C; $[\alpha]^{25}_{589}$=+16, $[\alpha]^{25}_{546}$=+21, $[\alpha]^{25}_{435}$=+32, $[\alpha]^{25}_{405}$=+40 (*c* 0.22, $CHCl_3$); IR (KBr): ν 1750, 1435, 1375, 1230, 1165, 1100, 1035, 600 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.34 (d, ^3J(H-1, H-2)=2.9 Hz, H-1), 5.65 (d, ^3J(H-4, H-5)=1.1 Hz, H-4), 5.16 (dd, ^3J(H-4′, H-5′)=9.5, ^3J(H-4′, H-3′)=9.5 Hz, H-4′), 5.08 (dd, ^3J(H-3′, H-4′)=9.5, ^3J(H-3′, H-2′)=9.5 Hz, H-3′), 4.99 (dd, ^3J(H-5′, H-6′)=9.5, ^3J(H-5′, H-4′)=9.5 Hz, H-5′), 4.89 (d, ^3J(H-1′, H-2′)=2.0 Hz, H-1′), 4.30 (ddd, ^3J(H-5, H_a-6)=7.1, ^3J(H-5, H_b-6)=4.4, ^3J(H-5, H-4)=1.1 Hz, H-5), 4.26 (dd, ^2J=12.3, ^3J(H_a-7′, H-6′)=2.0 Hz, H_a-7′), 4.09 (dd, ^2J=12.3, ^3J(H_b-7′, H-6′)=7.8 Hz, H_b-7′), 4.07 (dd, ^2J=11.6, ^3J(H_b-6, H-5)=4.4 Hz, H_b-6), 3.88 (dd, ^2J=11.6, ^3J(H_a-6, H-5)=7.1 Hz, H_a-6), 3.74 (d, ^3J(H-2, H-1)=2.9 Hz, H-2), 3.70 (dd, ^3J(H-2′, H-3′)=9.5, ^3J(H-2′, H-1′)=2.0 Hz, H-2′), 3.68 (ddd, ^3J(H-6′, H-5′)=9.5, ^3J(H-6′, H_b-7′)=7.8, ^3J(H-6′, H_a-7′)=2.0 Hz, H-6′), 2.17, 2.14, 2.13, 2.10, 2.05, 2.03, 2.00, 2.00 (8s, 24H, 8 AcO); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 170.2–169.3 (8s), 87.5 (d, ^1J(C, H)=172 Hz, C-1), 76.6 (2d, ^1J(C, H)=144, ^1J(C, H)=144 Hz, C-2′, C-6′), 74.0 (d, ^1J(C, H)=154 Hz, C-4′), 68.4 (d, ^1J(C, H)=151

Hz, C-5′), 68.1 (d, ^1J(C, H)=148 Hz, C-5), 67.3 (d, ^1J(C, H)=155 Hz, C-3′), 67.1 (d, ^1J(C, H)=147 Hz, C-1′), 66.4 (d, ^1J(C, H)=151 Hz, C-4), 62.6 (t, ^1J(C, H)=149 Hz, C-7′), 61.6 (t, ^1J(C, H)=152 Hz, C-6), 55.7 (s, C-3), 55.1 (d, ^1J(C, H)=188 Hz, C-2), 20.9–20.4 (8q, ^1J(C, H)=130 Hz, 8 Ac); CI-MS (NH_3): *m/z* 708 (89, $[M+18]^+$), 663 (3), 631 (54), 606 (27), 83 (100); anal. calcd for $C_{29}H_{38}O_{19}$ (690.61): C, 50.44; H, 5.55; found: C, 50.48; H, 5.59.

Data for **34**: white solid, mp 68°C; $[\alpha]^{25}_{589}$=+35, $[\alpha]^{25}_{546}$=+45, $[\alpha]^{25}_{435}$=+50, $[\alpha]^{25}_{405}$=+55 (*c* 0.02, $CHCl_3$); UV (MeCN): final absorbance: 191 (ε=3200); IR (KBr): ν 3475, 1750, 1375, 1235, 1040, 905, 600 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.61 (br s, H-4), 5.42 (br s, H-1), 5.16 (t, ^3J(H-4′, H-5′)=^3J(H-4′, H-3′)=9.5 Hz, H-4′), 5.08 (t, ^3J(H-3′, H-4′)=^3J(H-3′, H-2′)=9.5 Hz, H-3′), 5.02 (t, ^3J(H-5′, H-6′)=^3J(H-5′, H-4′)=9.5 Hz, H-5′), 4.86 (d, ^3J(H-1′, H-2′)=1.7 Hz, H-1′), 4.25–4.21 (m, 2H, H-5, H_a-7′), 4.14–4.09 (m, 2H, H_a-6, H_b-7′), 3.87 (dd, ^2J=11.5, ^3J(H_b-6, H-5)=7.1 Hz, H_b-6), 3.73–3.64 (m, 3H, H-2′, H-2, H-6′), 3.26 (br s, OH), 2.16, 2.11, 2.10, 2.05, 1.99 (7s, 21H, 7 AcO); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 170.6, 170.5, 170.2, 169.8, 169.5, 169.4, 169.3 (7s), 87.3 (d, ^1J(C, H)=169 Hz, C-1), 76.6 (d, ^1J(C, H)=146 Hz, C-2′, C-6′), 74.1 (d, ^1J(C, H)=152 Hz, C-4′), 68.4 (d, ^1J(C, H)=154 Hz, C-5′), 67.6 (d, ^1J(C, H)=147 Hz, C-1′), 67.4 (d, ^1J(C, H)=149 Hz, C-3′), 66.5 (d, ^1J(C, H)=151 Hz, C-4), 66.0 (d, ^1J(C, H)=148 Hz, C-5), 62.4 (t, ^1J(C, H)=149 Hz, C-7′), 62.2 (t, ^1J(C, H)=149 Hz, C-6), 57.5 (d, ^1J(C, H)=185 Hz, C-2), 57.3 (s, C-3), 20.8-20.3 (7q, ^1J(C, H)=130 Hz, 7 Ac); CI-MS (NH_3): *m/z* 666 (100, $[M+18]^+$), 631 (29), 228 (10), 169 (7), 97 (13).

5.19. 2,3-Anhydro-3-C-*[(1*S*)-2,6-anhydro*-D-glycero-D-gulo-*heptitol-1*-C-*yl]-β*-D-gulo-*pyranose* ***5***

A mixture of **33** (73 mg, 0.11 mmol) and sat. solution of NH_3 in MeOH (5 mL) was stirred at 20°C for 6 h. Solvent evaporation in vacuo afforded pure **5** and acetamide (by ^{1}H NMR). Chromatography on silica gel (2:1, $CHCl_3$:MeOH) afforded 16 mg (45%) of pure **5** (a single anomer): hygroscopic white solid, $[\alpha]^{25}_{589}$=+4.8, $[\alpha]^{25}_{546}$=+6.4, $[\alpha]^{25}_{435}$=+12.2, $[\alpha]^{25}_{405}$=+14.6 (*c* 0.31, MeOH); UV (MeCN): final absorbance: 194 (ε=3000); IR (KBr): ν 3390, 2925, 1640, 1415, 1090, 1040, 570 cm^{-1}; ^{1}H NMR (600 MHz, 323 K, CD_3OD): δ 5.25 (s, H-1), 4.53 (d, ^3J(H-1′, H-2′)=2.0 Hz, H-1′), 4.26 (d, ^3J(H-4, H-5)=3.6 Hz, H-4), 3.96 (ddd, ^3J(H-5, H_b-6)=6.9, ^3J(H-5, H_a-6)=4.4, ^3J(H-5, H-4)=3.6 Hz, H-5), 3.87 (dd, ^2J=11.9, ^3J(H_a-7′, H-6′)=2.1 Hz, H_a-7′), 3.74 (dd, ^2J=11.4, ^3J(H_a-6, H-5)=4.4 Hz, H_a-6), 3.71 (t, ^3J(H-3′, H-4′)=^3J(H-3′, H-2′)=9.2 Hz, H-3′), 3.65 (d, ^3J(H-2, H-1)=0.5 Hz, H-2), 3.62 (dd, ^2J=11.4, ^3J(H_b-6, H-5)=6.9 Hz, H_b-6), 3.60 (dd, ^2J=11.9, ^3J(H_b-7′, H-6′)=7.8 Hz, H_b-7′), 3.58 (dd, ^3J(H-2′, H-3′)=9.2, ^3J(H-2′, H-1′)=2.0 Hz, H-2′), 3.44 (t, ^3J(H-4′, H-5′)=^3J(H-4′, H-3′)=9.2 Hz, H-4′), 3.32 (ddd, ^3J(H-6′, H-5′)=9.2, ^3J(H-6′, H_b-7′)=7.8, ^3J(H-6′, H_a-7′)=2.1 Hz, H-6′), 3.18 (t, ^3J(H-5′, H-6′)=^3J(H-5′, H-4′)=9.2 Hz, H-5′). ^{13}C NMR (100.6 MHz, CD_3OD): δ 95.8 (d, ^1J(C, H)=172 Hz, C-1), 82.4 (d, ^1J(C, H)=142 Hz, C-6′), 79.9, 79.8 (2d, ^1J(C, H)=140 Hz, C-2′, C-4′), 75.9 (d, ^1J(C, H)=146 Hz, C-4), 72.7 (d, ^1J(C, H)=144 Hz, C-5), 72.1 (d, ^1J(C, H)=143 Hz, C-5′), 70.7 (d, ^1J(C, H)=146 Hz, C-3′), 68.1 (s, C-3), 65.4 (d, ^1J(C, H)=145 Hz, C-1′), 64.2 (t, ^1J(C, H)=143 Hz, C-6), 63.8 (t, ^1J(C, H)=144 Hz, C-7′), 60.3 (d, ^1J(C, H)=193 Hz, C-2). CI-MS (NH_3): *m/z* 372 (13, $[M+18]^+$), 354 (6), 282 (16), 252 (17), 210 (37), 192 (100), 127 (69), 92 (64). Electrospray-MS (+, 50:50:1, MeCN:H_2O:AcOH) *m/z* 396.1 (100, $[M+MeCN+1]^+$), 355.2 (20, $[M+1]^+$); anal. calcd: see **33**.

5.20. 1,6:2,3-Dianhydro-3-C-*[(1*S*)-2,6-anhydro-3,4,5,7-tetra*-O-*benzyl*-D-glycero-D-gulo-*heptitol-1*-C-*yl]-β*-D-gulo-*pyranose-1′,4-acetonide* ***35***

A mixture of **30** (223 mg, 0.32 mmol), 2,2-dimethoxypropane (6 mL), dry acetone (6 mL) and *p*TsOH (60 mg) was stirred at 20°C for 15 h. After the addition of EtOAc (10 mL) and H_2O (20 mL), the aq.

phase was extracted with EtOAc (10 mL, three times). The combined org. extracts were washed with a sat. aq. solution of $NaHCO_3$ (20 mL), brine (20 mL) and dried ($MgSO_4$). Solvent evaporation and flash chromatography on silica gel (4:1, light petroleum ether:EtOAc) afforded 193 mg (82%) of white solid: mp 38°C; $[\alpha]^{25}_{589}$=+18, $[\alpha]^{25}_{546}$=+21, $[\alpha]^{25}_{435}$=+34, $[\alpha]^{25}_{405}$=+42 (*c* 0.2, $CHCl_3$); UV (MeCN): λ_{max} 217 (ε=16600); IR (KBr): ν 3520, 3030, 2905, 2865, 1495, 1455, 1365, 1225, 1120, 1085, 1030, 925, 735, 700 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.41–7.15 (m, 20H), 5.54 (d, ^3J(H-1, H-2)=1.0 Hz, H-1), 4.97–4.61 (m, 8H), 4.47 (d, ^3J(H-1′, H-2′)=1.4 Hz, H-1′), 4.44 (ddd, ^3J(H-5, H_{exo}-6)=6.2, ^3J(H-5, H-4)=5.4, ^3J(H-5, H_{endo}-6)=1.7 Hz, H-5), 4.35 (d, ^3J(H-4, H-5)=5.4 Hz, H-4), 4.24 (dd, ^2J=8.2, ^3J(H_{endo}-6, H-5)=1.7 Hz, H_{endo}-6), 3.83 (t, ^3J(H-3′, H-4′)=^3J(H-3′, H-2′)=9.3 Hz, H-3′), 3.77 (dd, ^2J=8.2, ^3J(H_{exo}-6, H-5)=6.2 Hz, H_{exo}-6), 3.75 (d, ^3J(H-7′, H-6′)=2.7 Hz, $H_2C(7')$), 3.65 (2t, ^3J(H-4′, H-5′)=^3J(H-4′, H-3′)=^3J(H-5′, H-6′)=^3J(H-5′, H-4′)=9.3 Hz, H-4′, H-5′), 3.35 (br d, ^3J(H-6′, H-5′)=9.3 Hz, H-6′), 3.09 (br d, ^3J(H-2′, H-3′)=9.3 Hz, H-2′), 2.97 (br s, H-2), 1.44, 1.35 (2s, 2 Me); ^{13}C NMR (100.6 MHz, $CDCl_3$): δ 138.6, 138.4, 138.3, 138.1 (4s), 128.4–127.4 (20d), 101.6 (s), 97.6 (d, ^1J(C, H)=175 Hz, C-1), 87.5 (d, ^1J(C, H)=140 Hz, C-4′), 79.5 (d, ^1J(C, H)=146 Hz, C-6′), 78.2 (d, ^1J(C, H)=146 Hz, C-5′), 77.6 (d, ^1J(C, H)=151 Hz, C-3′), 75.4, 74.9, 74.85, 73.3 (4t, ^1J(C, H)=143 Hz, 4 CH_2 (Bn)), 75.3 (d, ^1J(C, H)=139 Hz, C-2′), 71.6 (d, ^1J(C, H)=158 Hz, C-5), 68.3 (t, ^1J(C, H)=142 Hz, C-7′), 65.3 (d, ^1J(C, H)=142 Hz, C-1′), 63.7 (d, ^1J(C, H)=151 Hz, C-4), 63.4 (t, ^1J(C, H)=152 Hz, C-6), 58.7 (s, C-3), 49.9 (d, ^1J(C, H)=181 Hz, C-2), 24.6, 24.2 (2q, ^1J(C, H)=126 Hz, 2 Me); CI-MS (NH_3): *m/z* 754 (95, $[M+18]^+$), 645 (4), 181 (9), 124 (21), 108 (62), 91 (100).

5.21. *1,6:2,3-Dianhydro-3-*C-*[(1*S*)-2,6-anhydro-*D-glycero-D-gulo-*heptitol-1-*C-*yl]-β-*D-gulo-*pyranose-1′,4-acetonide* **36**

Metallic Na (170 mg, 7.4 mmol) was added to liquid NH_3 (5 mL, condensed at −78°C). A solution of **35** (193 mg, 0.26 mmol) in anhydrous THF (1.4 mL) was added dropwise under stirring. After stirring at −78°C for 20 min, solid NH_4Cl (0.6 g) was added and the cooling bath removed. Once at 20°C, the residue was taken in MeOH and purified by flash chromatography on silica gel (5:1, CH_2Cl_2:MeOH) affording 74 mg (75%) of white solid: mp 135–138°C; $[\alpha]^{25}_{589}$=−22, $[\alpha]^{25}_{546}$=−32, $[\alpha]^{25}_{435}$=−52, $[\alpha]^{25}_{405}$=−67 (*c* 0.11, MeOH); UV (MeCN): final absorbance: 194 (ε=900); IR (KBr): ν 3385, 2920, 1655, 1385, 1225, 1125, 1080, 1030, 925, 875, 610, 510 cm^{-1}; ^1H NMR (400 MHz, CD_3OD): δ 5.57 (d, ^3J(H-1, H-2)=1.0 Hz, H-1), 4.61 (s, H-1′), 4.47 (ddd, ^3J(H-5, H_{exo}-6)=6.2, ^3J(H-5, H-4)=5.4, ^3J(H-5, H_{endo}-6)=1.8 Hz, H-5), 4.29 (d, ^3J(H-4, H-5)=5.4 Hz, H-4), 4.23 (dd, ^2J=8.2, ^3J(H_{endo}-6, H-5)=1.8 Hz, H_{endo}-6), 3.81 (dd, ^2J=12.1, ^3J(H_a-7′, H-6′)=2.4 Hz, H_a-7′), 3.76 (dd, ^2J=8.2, ^3J(H_{exo}-6, H-5)=6.2 Hz, H_{exo}-6), 3.65 (dd, ^2J=12.1, ^3J(H_b-7′, H-6′)=5.1 Hz, H_b-7′), 3.37–3.28 (m, 3H, H-3′, H-4′, H-5′), 3.13 (ddd, ^3J(H-6′, H-5′)=9.4, ^3J(H-6′, H_b-7′)=5.1, ^3J(H-6′, H_a-7′)=2.4 Hz, H-6′), 2.99 (br s, H-2), 2.95 (dd, ^3J(H-2′, H-3′)=9.4, ^3J(H-2′, H-1′)=0.7 Hz, H-2′), 1.51 (s, Me_b), 1.42 (s, Me_a); ^{13}C NMR (100.6 MHz, CD_3OD): δ 103.4 (s), 98.9 (d, ^1J(C, H)=176 Hz, C-1), 82.2 (d, ^1J(C, H)=138 Hz, C-6′), 80.3, 71.2, 70.5 (3d, ^1J(C, H)=143, ^1J(C, H)=143, ^1J(C, H)=146 Hz, C-3′, C-4′, C-5′), 76.1 (d, ^1J(C, H)=140 Hz, C-2′), 72.9 (d, ^1J(C, H)=160 Hz, C-5), 66.3 (d, ^1J(C, H)=142 Hz, C-1′), 65.4 (d, ^1J(C, H)=151 Hz, C-4), 64.2 (t, ^1J(C, H)=153 Hz, C-6), 62.7 (t, ^1J(C, H)=143 Hz, C-7′), 60.3 (s, C-3), 50.6 (d, ^1J(C, H)=181 Hz, C-2), 24.6, 24.2 (2q, ^1J(C, H)=127 Hz, 2 Me); CI-MS (NH_3): *m/z* 395 (3, $[M+18]^+$), 338 (5), 302 (4), 213 (17), 191 (7), 155 (12), 109 (100).

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