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Efficient routes to glucosamine-*myo*-inositol derivatives, key building blocks in the synthesis of glycosylphosphatidylinositol anchor substances

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Abstract—Short synthetic routes to protected derivatives of 2-amino-2-deoxy-α-D-glucopyranosyl-(1→6)-D-*myo*-inositol are described. Various 2-azido-2-deoxy-glucosyl donors were synthesized, starting from D-glucal or glucosamine hydrochloride. Derivatives of 1,2- and 2,3- D-*myo*-inositol-camphanylidene acetals were prepared to function as glycosyl acceptors. The subsequent glycosylations produced useful building blocks for the synthesis of GPI-anchor substances. © 2002 Elsevier Science Ltd. All rights reserved.

1. Introduction

The glycosyl phosphatidylinositol (GPI) anchoring system (Fig. 1) attaches proteins to the cell surface.[1] This system is widely distributed among eucaryotes, especially in lower organisms, such as protozoa. All GPI-anchors characterized up to date contain an ethanolamine-PO_4-6Man*p*(α1-2)Man*p*(α1-6)Man*p*(α1-4)GlcN*p*(α1-6)Ins backbone (Fig. 1), and several of these have been synthesized, both as complete GPI-anchors[2] and lipid-free inositol containing oligosaccharides.[3]

Protein-free inositol phosphoglycans (IPGs) have also been proposed as second messengers to insulin. Two second messengers, diacylglycerol and a *myo*-inositol-1,2-cyclic phosphate-containing oligosaccharide are supposed to be released by the action of a phosphatidylinositol specific phospholipase C.[4] The α-D-glucosamine (1→6) *myo*-inositol-1,2-cyclic

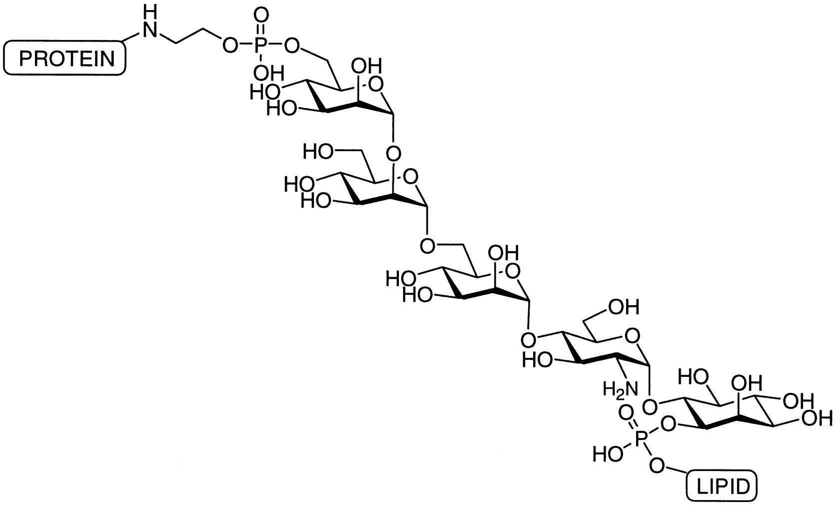

Figure 1. Common structure for GPI-anchors.

Keywords: glucosamine-*myo*-inositol; glycosylphosphatidylinositol; anchoring system.

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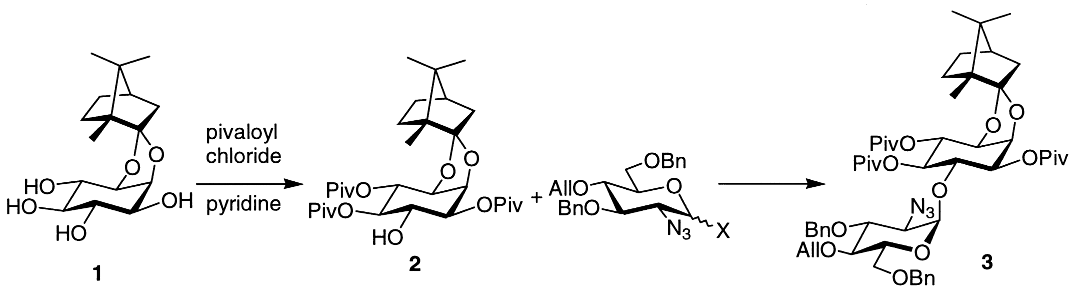


Scheme 1.

phosphate have been shown to be the minimum structural motif for the IPGs to possess insulin-mimetic activity.[5]

This work focuses on short routes to appropriately protected *myo*-inositol glycosyl acceptors, efficient routes to suitable glycosyl donors and subsequent glycosylation reactions. In the previously reported synthesis of 'disaccharide' **3**[6] (Scheme 1) the yield in the glycosylation step was not satisfactory. Pivaloylation of **1** produces the 1,4,5-pivaloyl derivative **2**, having a single free OH group in the 6-position of the D-*myo*-inositol derivative.[7] Position 6 is the intended site for glycosylation (Fig. 3). This constitutes a two-step procedure to a chiral glycosyl acceptor from *myo*-inositol. One disadvantage is that since the remaining OH group of **2** reacts slowly in the esterification step, it is likely to be an unreactive glycosyl acceptor as well. Another disadvantage is that using the pivaloyl derivative requires further synthetic manipulation after the glycosylation step. This has led us to investigate other glycosylation methods, glycosyl donors, glycosyl acceptors, solvents and combinations thereof.

For rational syntheses of these types of compounds (i.e. IPGs) it is necessary to find efficient routes to properly protected derivatives of α-D-glucosamine (1→6) *myo*-inositol as depicted in Fig. 2. Such derivatives should have persistent protecting groups R^1 and a selectively removable protecting group R^2. Furthermore, R^3 should be easily removed in the presence of the other protecting groups.

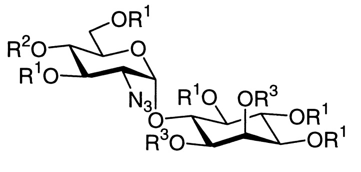


Figure 2.

The inositol acceptors were synthesized using the *myo*-inositol camphanylidene acetals described by Pietrusiewicz et al.[7] This method provides rapid entry into chiral *myo*-inositol derivatives. D-camphor is an inexpensive chiral auxilliary and the comparably more expensive L-camphor can be prepared in large scale from the less expensive L-borneol by sodium hypochlorite oxidation.[8] Resolution and regioselective protection is performed in one-step by reacting *myo*-inositol with D- or L-camphor dimethyl acetal and precipitating the *myo*-inositol-2,3- or 1,2-camphor acetal (**1** or **4**) from the reaction mixture. This camphor acetal, besides acting as a chiral auxilliary, also moderates the individual reactivity of the remaining hydroxyl groups, making regioselective protecting group manipulations possible (Fig. 3).

Derivative **4**, which has been used in syntheses of IPGs,[9,10] has the 1- and 2-hydroxyl groups protected by an acetal. This acetal can be selectively removed later in the syntheses. Conversion of **4** into an appropriately protected acceptor by differential protection of the 6-OH and the 3, 4 and 5-hydroxyls, respectively, provides an acceptor suitable for synthesis of 1,2-cyclic phosphate derivatives. This type of inositol derivatives can also, after deprotection of the camphor acetal, be regioselectively phosphorylated at the 1-OH.[9,11] This constitutes a starting point for syntheses of phospholipid containing GPI-substances.

2. Results and discussion

The methods described for preparing **1** and **4** involve preparation and purification of the camphor dimethyl acetal, and subsequent *trans*-acetalization with *myo*-inositol.[7] The camphor dimethyl acetal can be prepared from camphor and trimethyl orthoformate and then purified by distillation from sodium.[12]

When preparing the *myo*-inositol 1,2-camphor acetal we

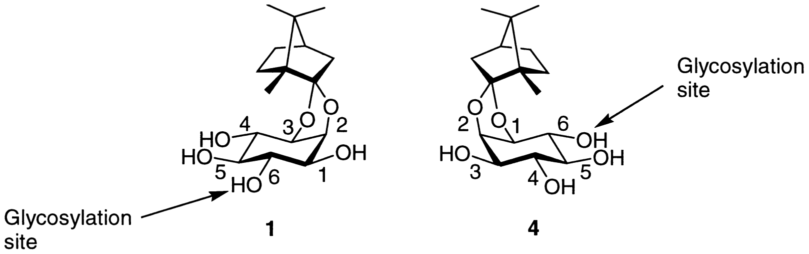
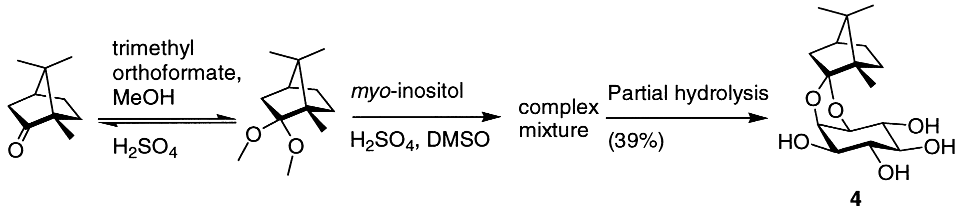
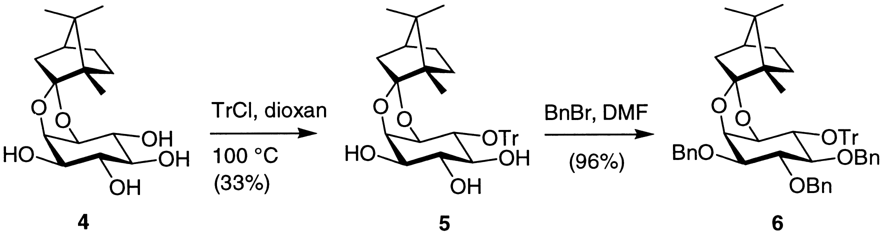


Figure 3. 2,3-D- and 1,2-L-camphanylidene acetals of D-*myo*-inositol.

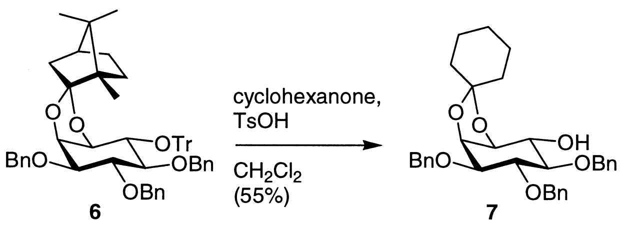


Scheme 2.



Scheme 3.

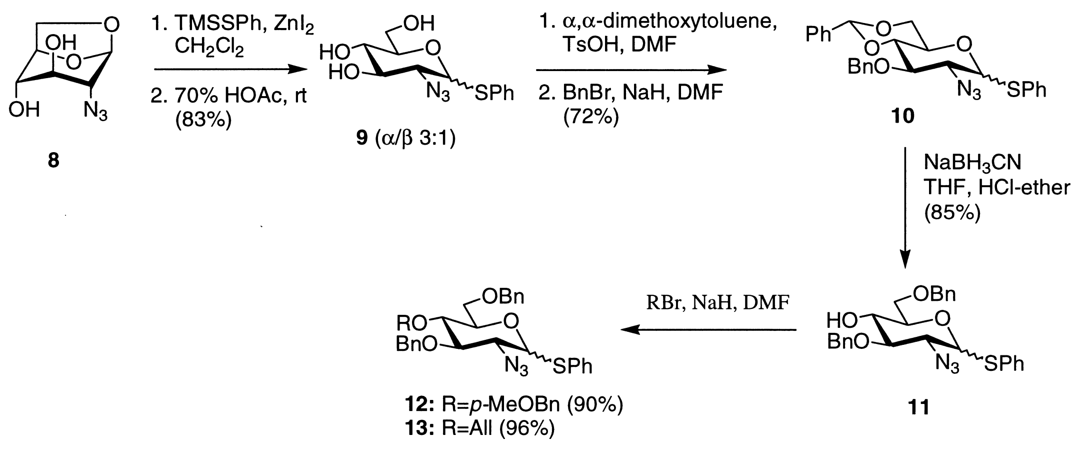
experienced difficulties in reproducing the results obtained by the original procedure (Scheme 2). We found that residual DMSO from the first step, producing a complex mixture of *myo*-inositol camphor acetals, was crucial for the result. In order to simplify the method, we have developed an in situ preparation of the camphor dimethyl acetal and subsequent reaction with *myo*-inositol, thus avoiding the laborious purification of the dimethyl acetal. Using 7 equiv. of trimethyl orthoformate gives $>$95% conversion of camphor into the dimethyl acetal. Evaporation of solvent and excess trimethyl orthoformate gives a crude camphor dimethyl acetal. Reaction with *myo*-inositol without any further purification provides an efficient method for preparing the chiral inositol derivatives **1** and **4**.



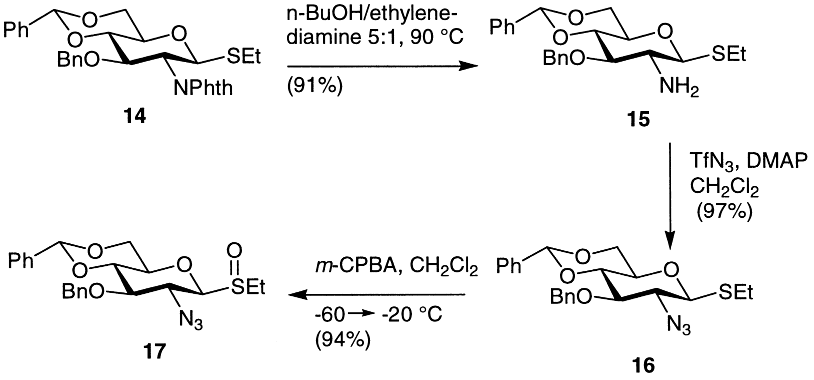
Scheme 4.

Conversion of **4** into a glycosyl acceptor was effected by a two-step sequence involving regioselective tritylation of the 6-OH (the glycosylation site) and benzylation of the remaining hydroxyls. Usually the 3-OH of **4** is the most reactive towards bulky reagents.[13] Surprisingly, the 6-OH was found to be the most reactive towards triphenylmethyl chloride in 1,4-dioxan, producing **5** as the major isomer in 33% yield, along with minor amounts of regioisomers and multiply tritylated derivatives. Subsequent benzylation produced **6** in 96% yield (Scheme 3).

The trityl group has been shown to activate secondary alcohols in glycosylation reactions[14] and has been used in highly stereoselective glycosylations with thiocyano donors.[15] The selectively removable camphor acetal protects the 1- and 2-hydroxyls to be phosphorylated later in the syntheses. This strategy avoids the drawback of protecting group manipulations in later stages of the syntheses. The moderate yield in the tritylation step is more than compensated for by the short route and the ready chromatographic separability of the isomers. Evidence for the configuration of **6** was provided by treatment with cyclohexanone and a catalytic amount of TsOH to produce the known derivative **7**[16] (Scheme 4).



Scheme 5.



Scheme 6.

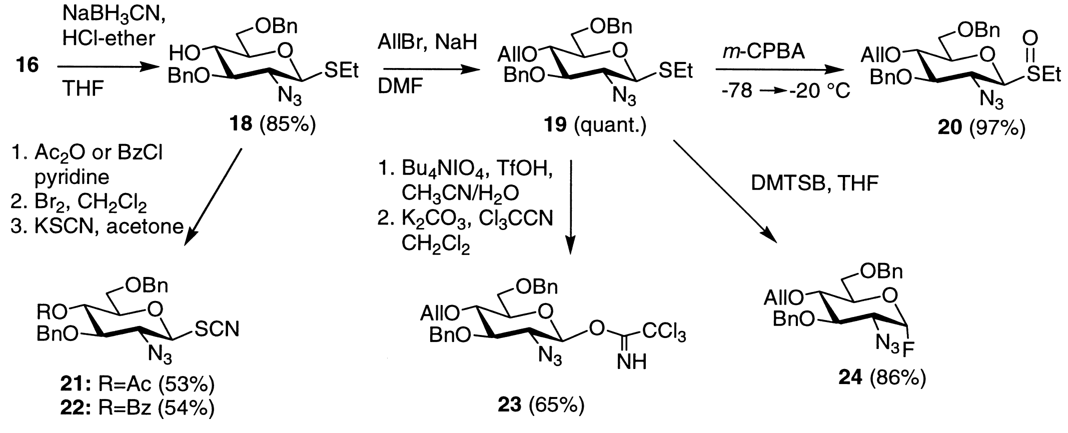
Since glucosamine had to be α-linked to the inositol, a nonparticipating azido-deoxy group, containing a masked amino-functionality, was used at C-2 of the glycosyl donor. Syntheses of such donors are shown in Schemes 5–7.

Thiophenyl donors **12** and **13** were synthesized from D-glucal, which can be transformed into the derivative 2-azido-1,6-anhydroglucopyranose **8**.[17] Heating a mixture of the diol **8** with trimethylthiophenylsilane (TMSSPh) in dichloromethane, followed by addition of ZnI_2 and molecular sieves (4 Å) gave **9** in 83% yield (α/β=2.2:1, determined by NMR). Compound **9** was then converted to a 4,6-*O*-benzylidene derivative, followed by benzylation, to produce **10** in 72% yield. Subsequent reductive opening of the 4,6-*O*-benzylidene acetal gave **11**, which was either *p*-methoxybenzylated or allylated to give **12** and **13** in an overall yield of 55 and 59%, respectively. Alternative routes, benzylation of **8** followed by either regioselective removal of the 4-*O*-benzyl protecting group with $TiCl_4$, or conversion to a phenylthio-glycoside have been developed by others.[18]

The syntheses of donors **16**, **17** and **19–24** are outlined in Schemes 6 and 7. Syntheses of donors **16**, **19** and **24** have been accomplished earlier by us, using the diazo-transfer protocol developed by Vasella et al.,[19] for introduction of the 2-azido-2-deoxy-functionality. In order to make more efficient use of the potentially hazardous trifluoromethanesulfonyl azide (TfN_3),[19,20] a different route to these donors was developed. Phthalimide **14**, readily available from glucosamine hydrochloride by standard transformations,[21] was transformed into the glycosyl donors **16** and **17** (Scheme 6), and **19–24** (Scheme 7).

Removal of the phthalimido protecting group using ethylene diamine in *n*-butanol[22] gave **15** in 91% yield. Subsequent diazotransfer produced glycosyl donor **16** in 97% yield. Reductive opening of the benzylidene acetal followed by allylation yielded donor **19**.[5] The thioglycosides **16** and **19** were converted into the corresponding sulfoxide donors **17** and **20** by oxidation with *m*-CPBA. No epoxidation of the allyl group was observed. Azide **18** was converted into the thiocyano donors **21** and **22**, the intention being to take advantage of the tritylated inositol derivative by utilizing the stereoselective glycosylation protocol developed by Kochetkov et al.[15] Acetylation or benzoylation, and conversion of the resulting derivative to the corresponding bromo sugar, followed by substitution with potassium thiocyanate produced **21** and **22** in 53 and 54% yield, respectively. Hydrolysis of the thioglycoside[23] **19** and subsequent reaction with trichloroacetonitrile[24] produced donor **23**. Reaction of **19** with dimethyl(methylthio)sulfonium tetrafluoroborate (DMTSB)[25] produced donor **24**.[6] Attempts to convert **19** into the bromo sugar by treatment with bromine failed, because of addition of the formed ethylsulfenyl bromide to the allylic double bond.

The results from the glycosylations of acceptors **2** and **6** with the various donors are outlined in Table 1. The



Scheme 7.

Table 1.

Entry	Donor	Acceptor	Promoter	Solvent	Result
i	**24**	**2**	$SnCl_2$/AgOTf	Ether	**3** (34%)
ii	**12**	**2**	DMTST	CH_2Cl_2	Decomposition
iii	**13**	**2**	DMTST	CH_2Cl_2	Decomposition
iv	**19**	**2**	DMTST	CH_2Cl_2	**3** (17%)
v	**19**	**2**	MeOTf	Ether	**3** (48%)
vi	**23**	**2**	TMSOTf	Ether	**3** (43%)
vii	**20**	**2**	Tf_2O	Toluene	**3** (63%)
viii	**19**	**6**	DMTST	Ether	**25** (25%)
ix	**19**	**6**	MeOTf	Ether	**25** (58%)
x	**16**	**6**	DMTST	Ether	**26** (traces)
xi	**16**	**6**	DMTST	CH_2Cl_2	Decomposition
xii	**16**	**6**	MeOTf	CH_2Cl_2	**26** (57%)
xiii	**17**	**6**	Tf_2O	Toluene	**26** (traces)
xiv	**20**	**6**	Tf_2O	Toluene	**25** (traces)
xv	**21**	**6**	$TrClO_4$	CH_2Cl_2	Decomposition
xvi	**22**	**6**	$TrClO_4$	CH_2Cl_2	Decomposition

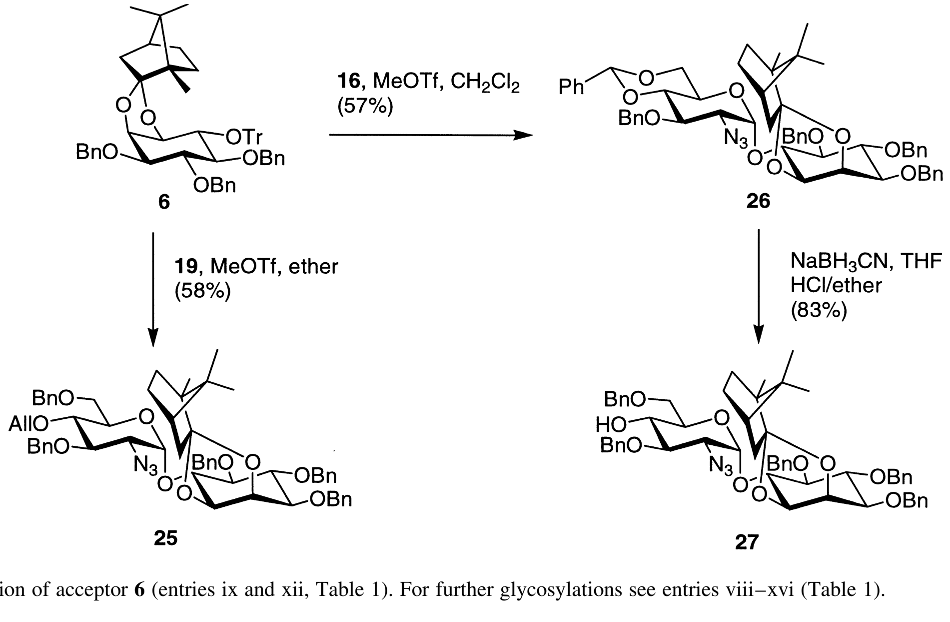
glycosylation of acceptor **2** (Scheme 1) with the glycosyl fluoride **24**, has previously been reported using dicyclopentadienylzirconium dichloride (Cp_2ZrCl_2) in ether to produce the disaccharide **3** in 48% yield.[6] A threefold excess of acceptor was used to achieve acceptable yields. The anomeric glycosyl fluoride **24** can also be activated with $SnCl_2$/AgOTf in diethyl ether[26] (entry i) This promoter system gave a lower yield (34%). Azides **12** and **13** with the unreactive thiophenyl anomeric group did not give any product with dimethyl(methylthio)sulfonium trifluoromethanesulfonate (DMTST) as promoter (entries ii and iii). The thioethyl donor **19** was, as expected, found to be more reactive than the thiophenyl donor **13**. Glycosylation with DMTST as promoter in dichloromethane gave the disaccharide in 17% yield along with decomposed products (entry iv). When **19** was activated with MeOTf in ether the yield was raised to 48% (entry v). Glycosylation of **2** with **23**, promoted by TMSOTf (entry vi), gave **3** in 43% yield together with the *N*-trichloroacetamido glucoside (25%). Sulfoxide donors activated with trifluoromethanesulfonic anhydride at low temperatures have been used with good results in glycosylations of unreactive hydroxyl groups.[27] The stereochemical outcome has also been shown to be controllable by varying the solvent and temperature for the glycosylation.[27,28] The best yield of **3** (entry vii), 63% together with traces of the β-glycoside, were obtained when the sulfoxide donor **20** was activated in toluene at −70°C, following the original procedure by Kahne et al.

Glycosylation of acceptor **6** (Scheme 8, Table 1) was tested using the donors **16**, **17** and **19–22**. Activation of **19** with DMTST in ether gave **25** in 25% yield along with decomposed products (entry viii). Activation with MeOTf in ether gave **25** in an acceptable yield of 58% (entry ix). The use of dichloromethane in these glycosylations only resulted in decomposition of the donor. When the benzylidene derivative **16** was used in the glycosylation of **6**, the reaction was very slow in ether, even when the strong thiophilic promoter DMTST was used. Changing the solvent to dichloromethane resulted in a significant improvement. DMTST gave mainly decomposition (entry xi), but with MeOTf as promoter, disaccharide **26** was produced in 57% yield (entry xii). Subsequent reductive opening of the benzylidene acetal gave the building block **27** in 83% yield. The sulfoxide donors **17** and **20** and the thiocyano donors **21** and **22** were also tested with this acceptor in toluene and dichloromethane, but the only products isolated were the β-glycosides in low yields (entries xiii–xvi).

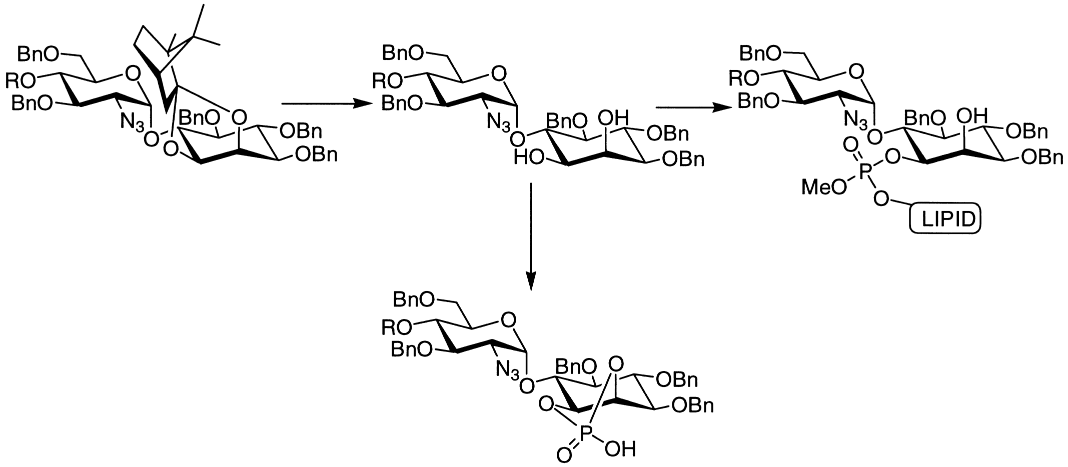
3. Conclusions

The glycosylation of acceptor **2** was most successful using the sulfoxide donor **20** giving the protected compound **3**. The stereoselectivity was highest when toluene was used as solvent. The donors **19**, **23** and **24** also gave acceptable and similar yields (43–48%) when ether was used as solvent. When dichloromethane was used as solvent these donors decomposed rather than reacting with the acceptor.

The glycosylation of acceptor **6** was most successful with the donors **16** and **19** using MeOTf as promoter, producing the derivatives **25** and **26**. The more reactive donor **19** gave the best yields in ether, while the less reactive **16** gave the



Scheme 8. Glycosylation of acceptor **6** (entries ix and xii, Table 1). For further glycosylations see entries viii–xvi (Table 1).



Scheme 9.

best yields in dichloromethane, being unreactive when ether was used as solvent. **26** was converted to the useful building block **27**, ready for further elongation at the 4-OH of the glucose unit. The moderate yields in the glycosylation steps is compensated for by the very short route to the glucosyl acceptors **2** and **6**.

In conclusion both acceptors can be glycosylated to produce appropriately protected glucosamine-inositol derivatives. The route, using **6** as acceptor, gives a building block **27** with a protecting group pattern which enables both further glycosylation of the 4-OH followed by selective deprotection of the camphanylidene acetal, and phosphorylation to give a 1,2-cyclic phosphate on the *myo*-inositol ring (Scheme 9),[9,10] without any protecting group manipulations. Regioselective phosphorylation of the 1-OH to produce phospholipid-containing GPI-substances is also an option.[9,11] The route using **2** as an acceptor gives a building block **3**, which after further protecting group manipulations[6] has been used in the syntheses of the core heptasaccharyl-*myo* inositol[29] found in *Leishmania* parasites and fragments thereof.[30]

4. Experimental

4.1. General methods

Organic phases were dried over $MgSO_4$, filtered and concentrated in vacuo below 40°C. NMR spectra were recorded on Varian Mercury 300 (^{1}H 300 MHz and ^{13}C 75.4 MHz and Varian Inova 600 (^{1}H 600 MHz) instruments at 25°C in $CDCl_3$ with TMS as internal standard (δ=0.00 ppm). Signals were assigned by means of DEPT, NOE difference and 2D spectra (COSY, DQF-PS COSY, HETCOR, MHQC, HMBC and NOESY). TLC was performed on Silica Gel F_{254} (E. Merck) with detection by UV light and/or by charring with 8% aqueous H_2SO_4 or AMC [ammonium molybdate 10 g, cerium(IV)sulfate 2 g, dissolved in 10% H_2SO_4 (200 mL)] followed by heating at ~250°C. Silica gel MERCK 60 (0.040–0.063 mm) was used for Flash Chromatography (FC). Silanized silica gel (Kieselgel 60 silanisiert, 0.063–0.200 mm, E. Merck) was used for reversed phase flash chromatography. Optical rotations were recorded at room temperature with a Perkin–Elmer 241 polarimeter. Melting points were recorded with a Gallenkamp melting point apparatus. FAB-mass spectra were recorded on a JEOL SX 102 Mass Spectrometer using a 3-nitrobenzyl alcohol matrix. IR spectra were recorded as films on CaF_2 crystals (syrups) or as KBr pellets (solids) on a Perkin–Elmer SPECRUM 1000 FT-IR Spectrometer.

4.1.1. 1,2-*O*-(L-1,7,7-Trimethyl[2,2,1]bicyclohept-6-ylidene)-D-*myo*-inositol (4). To a solution of L-camphor (31.0 g, 0.204 mol) in trimethyl orthoformate (155 mL, 1.41 mol) and methanol (31 mL) was added H_2SO_4 (0.30 mL). After 48 h, the mixture was neutralized with NaOMe (650 mg) and concentrated. The residue was dissolved in toluene (150 mL), the precipitated Na_2SO_4 filtered off and the filtrate concentrated to give crude L-camphor dimethyl acetal (41.8 g). To this crude camphor acetal and *myo*-inositol (16.0 g, 88.8 mmol) in DMSO (175 mL) was added H_2SO_4 (0.9 mL). The resulting mixture was stirred for 3 h at 75°C, neutralized with NEt_3 (6 mL) and concentrated under vacuum at 80°C. To the residue was added DMSO to a total weight of 78 g, and $CHCl_3$ (270 mL), MeOH (17 mL), H_2O (5.4 mL) and $TsOH\cdot H_2O$ (60 mg) were added. The mixture was stirred for 17 h, neutralized with NEt_3 (2 mL) and the resulting precipitate was filtered off and washed with $CHCl_3$ (2×200 mL) to give crude **4** (18.5 g). The crude product was recrystallized from MeOH (0.1% NEt_3) to give **4** (11.2 g) containing minor impurities of *myo*-inositol and the diastereomeric 2-*endo*-1-*exo*-isomer. A second recrystallization from MeOH (0.1% NEt_3)/H_2O gave pure **4** (10.9 g, 34.7 mmol, 39%). Mp 260–262°C; $[\alpha]_D=-44.0$ (*c* 1.0, pyridine), Lit. for the enantiomer.[13] mp 231–232°C; $[\alpha]_D=+44.3$ (*c* 1.9, pyridine); ^{1}H and ^{13}C NMR were in accordance with those previously reported.[7]

4.1.2. 6-*O*-Triphenylmethyl-1,2-*O*-(L-1,7,7-trimethyl-[2,2,1]bicyclohept-6-ylidene)-D-*myo*-inositol (5). Acetal **4** (5.00 g, 15.9 mmol), triphenylmethyl chloride (6.00 g, 21.5 mmol) and *N*,*N*-diisopropylethylamine (6 mL) were refluxed in 1,4-dioxan (200 mL). After 24 h, the mixture was concentrated and dissolved in MeOH containing 1% NEt_3 (400 mL). Toluene (100 mL) and H_2O (300 mL) was added. The phases were separated and the aqueous phase was extracted twice with toluene (100 mL). The combined organic layers were dried and concentrated. FC (toluene/acetone 4:1, 0.1% NEt_3) gave **5** (2.93 g, 5.26 mmol, 33%) as a colorless syrup. R_f 0.15 (toluene/acetone 4:1); $[\alpha]_D=+33$ (*c* 1.0, $CHCl_3$); IR ν_{max} cm^{-1} 1036, 1046, 1109, 1448, 2952, 3418; NMR: ^1H (600 MHz, $CDCl_3$), δ 0.67 (3H, s, CH_3), 0.78 (3H, s, CH_3), 0.92 (3H, s, CH_3), 0.98 (1H, ddd, $J=12.2$, 9.3, 4.7 Hz), 0.99 (1H, d, $J=14.0$ Hz), 1.25 (1H, ddd, $J=12.2$, 12.2, 4.7 Hz), 1.53–1.64 (2H, m), 1.66 (1H, dd, $J=4.7$, 4.7 Hz), 1.79 (1H, ddd, $J=12.9$, 5.0, 2.9 Hz), 3.47 (1H, dd, $J=7.3$, 3.9 Hz, H-1), 3.64–3.70 (2H, m, H-3, 4), 3.93 (1H, dd, $J=9.1$, 4.3 Hz, H-5), 3.96 (1H, dd, $J=3.9$, 3.9 Hz, H-2), 4.29 (1H, dd, $J=7.2$, 4.3 Hz, H-6), 7.10–7.52 (15H, m, Ph); ^{13}C (75 MHz, $CDCl_3$), δ 10.2 (CH_3), 20.2 (CH_3), 20.5 (CH_3), 26.9 (CH_2), 29.8 (CH_2), 43.0 (CH_2), 44.9 (CH), 48.0 (C_q), 51.2 (C_q), 70.4 (C-5), 73.8 (C-6), 74.4 (C-1), 74.5 (C-4), 74.8 (C-2), 77.5 (C-3), 88.8 (Ph_3C), 117.5 (OCO), 127.5–129.3 (Ph), 144.2 (Ph); Anal. Calcd for $C_{35}H_{40}O_6$: C, 75.5; H, 7.2 Found: C, 75.3; H, 7.3.

4.1.3. 3,4,5-Tri-*O*-benzyl-6-*O*-triphenylmethyl-1,2-*O*-(L-1,7,7-trimethyl[2,2,1]bicyclohept-6-ylidene)-D-*myo*-inositol (6). **5** (5.46 g, 9.81 mmol) in DMF (85 mL) was added dropwise over 20 min to 60% NaH (2.8 g, 70 mmol) at 0°C under N_2. The mixture was stirred for an additional 20 min at 0°C, benzyl bromide (7.7 mL, 65 mmol) was added and the mixture were stirred at rt for 14 h. MeOH (5 mL) was added dropwise and the mixture was diluted with toluene, washed with H_2O, dried, filtered and concentrated. FC (toluene) gave **6** (7.77 g, 9.39 mmol, 96%) as a colorless syrup. R_f 0.51 (toluene); $[\alpha]_D=-3.2$ (*c* 1.4, $CHCl_3$); IR ν_{max} cm^{-1} 1070, 1096, 1453, 1496, 2928; NMR: ^1H (600 MHz, $CDCl_3$), δ 0.78 (3H, s, CH_3), 0.82 (3H, s, CH_3), 0.87–0.98 (2H, m), 0.99 (3H, s, CH_3), 1.18–1.32 (1H, m), 1.55–1.80 (4H, m), 3.30 (1H, dd, $J=7.9$, 3.9 Hz, H-1), 3.82–3.84 (1H, m, H-3), 4.03 (1H, dd, $J=9.3$, 5.0 Hz, H-4), 4.09 (1H, dd, $J=9.3$, 3.6 Hz, H-5), 4.11 (1H, dd, $J=3.8$, 2.9 Hz, H-2), 4.13 (1H, d, $J=12.2$ Hz, C*H*$_2$Ph), 4.30 (1H, dd, $J=7.9$, 3.6 Hz, H-6), 4.33 (1H, d, $J=11.8$ Hz, C*H*$_2$Ph), 4.58 (1H, d, $J=11.5$ Hz, C*H*$_2$Ph), 4.70 (1H, d, $J=12.2$ Hz, C*H*$_2$Ph), 4.78 (1H, d, $J=11.8$ Hz, C*H*$_2$Ph), 4.79 (1H, d, $J=11.5$ Hz, C*H*$_2$Ph), 7.05–7.45 (30H, m, Ph); ^{13}C (75 MHz, $CDCl_3$), δ 10.0 (CH_3), 20.2 (CH_3), 20.6 (CH_3), 27.0 (CH_2), 29.7 (CH_2), 42.5 (CH_2), 44.9 (CH), 47.8 (C_q), 51.2 (C_q), 71.2 (*C*H$_2$Ph), 71.7 (*C*H$_2$Ph), 72.2 (C-2), 72.4 (C-6), 73.4 (C-1), 73.5 (*C*H$_2$Ph), 76.4 (C-5), 79.5 (C-4), 86.0 (C-3), 88.5 (Ph_3*C*O), 116.7 (OCO), 126.8–129.2 (Ph), 138.2 (Ph), 138.9 (Ph), 139.1 (Ph), 139.2 (Ph), 144.2 (Ph); Anal. Calcd for $C_{56}H_{58}O_6$: C, 81.3; H, 7.1 Found: C, 81.4; H, 7.0.

4.1.4. 3,4,5-Tri-*O*-benzyl-1,2-*O*-cyclohexylidene-D-*myo*-inositol (7). **6** (410 mg, 0.50 mmol), cyclohexanone (2.0 mL, 19 mmol), trimethyl orthoformate (0.10 mL, 0.92 mmol) and *p*-toluene sulfonic acid monohydrate (20 mg, 0.11 mmol) was dissolved in CH_2Cl_2. After 18 h, the mixture was diluted with CH_2Cl_2, washed with $NaHCO_3$ (sat), dried, filtered and concentrated. FC (CH_2Cl_2/acetone 97:3) gave crystalline **7** (144 mg, 0.27 mmol, 55%). $[\alpha]_D=-20$ (*c* 1.0, $CHCl_3$), Lit.[16a] $[\alpha]_D=-18$ (*c* 1.1, $CHCl_3$); mp 96–98°C, Lit.[16b] 96–98°C; ^1H and ^{13}C NMR spectra were identical to those previously published for the racemic compound.[16b]

4.1.5. Phenyl 2-azido-2-deoxy-1-thio-D-glucopyranoside (9). To a solution of **8** (410 mg, 2.19 mmol) in CH_2Cl_2 (15 mL) was added Me_3SiSPh (1.44 mL, 7.60 mmol). The mixture was heated until a clear solution was obtained and then 4 Å molecular sieves and ZnI_2 (2.10 g, 6.58 mmol) were added. The mixture was stirred at rt for 3 h, filtered through Celite and concentrated. The residue was dissolved in 70% aqueous HOAc (30 mL) and stirred at rt for 30 min, concentrated and purified on a silica gel column (toluene/EtOAc 1:1→1:3) to give **9** (598 mg, 2.01 mmol, 92%, ($\alpha/\beta=2.2:1$, determined by NMR) as a colorless syrup. $[\alpha]_D=+134$ (*c* 1.0, $CHCl_3$); IR ν_{max} cm^{-1} 1067, 1263, 2111, 3358; The ^1H and ^{13}C NMR spectra were in accordance with those previously reported.[31]

4.1.6. Phenyl 2-azido-3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-1-thio-D-glucopyranoside (10). To a mixture of **9** (310 mg, 0.104 mmol) and α,α-dimethoxytoluene (172 μL, 1.15 mmol) in DMF (6 mL), a catalytic amount of *p*-toluenesulfonic acid was added. The reaction mixture was heated to 50°C and stirred overnight. The solution was diluted with CH_2Cl_2 (20 mL), washed with aqueous saturated $NaHCO_3$ and water, dried, filtered and concentrated. Purification on a silica gel column (toluene/EtOAc 10:1) gave phenyl *2-azido-4,6-O-benzylidene-2-deoxy-1-thio-D-glucopyranoside* (330 mg, 0.8 mmol, 75%) as a white solid. R_f 0.47 (toluene/EtOAc 9:1); $[\alpha]_D=+165$ (*c* 1.2, $CHCl_3$); IR ν_{max} cm^{-1} 976, 1008, 1101, 1262, 1370, 2101, 3333; NMR: ^1H (300 MHz, $CDCl_3$) α-anomer, δ 3.49 (1H, dd, $J=9.3$, 9.3 Hz, H-4), 3.69 (1H, dd, $J=10.3$, 10.3 Hz, H-6a), 3.81 (1H, dd, $J=9.9$, 5.5 Hz, H-2), 3.95 (1H, dd, $J=9.5$, 9.5 Hz, H-3), 4.18 (1H, dd, $J=10.4$, 5.0 Hz, H-6b), 4.33 (1H, ddd $J=9.9$, 9.9, 4.9 Hz, H-5), 5.49 (1H, d, $J=5.5$ Hz, H-1), 5.50 (1H, s, C*H*Ph), 7.22–7.52 (10H, m, Ph); β-anomer, δ 3.30 (1H, dd, $J=10.2$, 9.1 Hz, H-2), 3.38 (1H, ddd, $J=9.6$, 9.6, 4.9 Hz, H-5), 3.43 (1H, dd, $J=9.3$, 9.3 Hz, H-6a), 3.68 (1H, dd, $J=9.1$, 9.1 Hz, H-3), 3.73 (1H, dd, $J=9.6$, 9.6 Hz, H-4), 4.34 (1H, dd, $J=10.6$, 4.8 Hz, H-6b), 4.47 (1H, d, $J=10.2$ Hz, H-1), 5.49 (1H, s, C*H*Ph), 7.34–7.58 (10H, m, Ph); ^{13}C (75 MHz, $CDCl_3$) α-anomer, δ 63.4 (C-5), 63.7 (C-2), 68.4 (C-6), 70.6 (C-3), 81.6 (C-4), 87.7 (C-1), 102.1 (*C*HPh), 126.3–136.8 (Ph); β-anomer, δ 65.1 (C-2), 68.4 (C-6), 70.2 (C-5), 74.0 (C-3), 80.2 (C-4), 86.8 (C-1), 101.9 (*C*HPh), 126.3–136.7 (Ph). A solution of phenyl 2-azido-4,6-*O*-benzylidene-2-deoxy-1-thio-D-glucopyranoside (230 mg, 0.6 mmol) and benzyl bromide (142 μL, 1.2 mmol) in DMF (4.5 mL) was added dropwise to a cold (0°C) stirred slurry of 50% sodium hydride (55 mg, 1.2 mmol) in DMF (3 mL). After 50 min the reaction was quenched with methanol (5 mL), diluted with toluene, washed with aqueous saturated $NaHCO_3$ and water, dried, filtered, concentrated and purified on a silica gel column (toluene/EtOAc 20:1) to give **10** (273 mg, 0.57 mmol, 96%) as a white solid. R_f 0.67 (toluene/EtOAc 9:1); $[\alpha]_D=+59$ (*c* 1.0, $CHCl_3$); IR ν_{max} cm^{-1} 1005, 1086, 1374, 2102, 2902; NMR: ^1H (300 MHz, $CDCl_3$) α-anomer, δ 3.74–3.80 (2H, m, H-4, 6a), 3.92–4.01 (2H, m, H-2, 3), 4.22, (1H, dd, $J=10.4$, 4.9 Hz, H-6b), 4.42 (1H, ddd, $J=9.7$, 9.7, 4.8 Hz, H-5), 4.83 (1H, d, $J=11.0$ Hz, C*H*$_2$Ph), 4.98 (1H, d, $J=10.7$ Hz, C*H*$_2$Ph), 5.57 (1H, d, $J=3.8$ Hz, H-1), 5.60 (1H, s, C*H*Ph), 7.29–7.52 (15H, m, Ph); β-anomer, δ 3.31–3.50 (2H, m, H-2, 5), 3.60–3.69 (2H, m, H-3, 4), 3.79 (1H, dd, *J*=10.3, 10.3 Hz, H-6a), 4.80 (1H, dd, *J*=10.6, 5.1 Hz, H-6b), 4.49 (1H, d, *J*=10.2 Hz, H-1), 4.78 (1H, d, *J*=11.0 Hz, CH_2Ph), 4.91 (1H, d, *J*=11.0 Hz, CH_2Ph), 5.57 (1H, s, C*H*Ph), 7.28–7.58 (15H, m, Ph); ^{13}C (75 MHz, $CDCl_3$) α-anomer, δ 63.6 (C-2), 63.8 (C-5), 68.6 (C-6), 75.2 (*C*H$_2$Ph), 77.9 (C-3), 82.7 (C-4), 87.9 (C-1), 101.5 (C*H*Ph), 126.0–137.7 (Ph); β-anomer, δ 64.7 (C-2), 68.5 (C-6), 70.5 (C-5), 75.2 (*C*H$_2$Ph), 81.0 (C-3), 81.3 (C-4), 86.7 (C-1), 101.3 (C*H*Ph 126.0–137.1 (Ph); HRMS Calcd for $C_{26}H_{25}O_4N_3S$: $[M+Na]^+$ 498.1463 Found: $[M+Na]^+$ 498.1468.

4.1.7. Phenyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-1-thio-D-glucopyranoside (11). Sodium cyanoborohydride (800 mg, 13 mmol) was added to a stirred solution of **10** (280 mg, 0.59 mmol) in THF (15 mL). After 2 h, the mixture was treated with etheral HCl until gas evolution ceased. After an additional 30 min, the mixture was filtered through Celite. The filtrate was concentrated and purified on a silica gel column (toluene/EtOAc 10:1) to give **11** (240 mg, 0.50 mmol, 85%) as a colorless syrup. R_f 0.53 (toluene/EtOAc 4:1); $[\alpha]_D=+76$ (*c* 1.1, $CHCl_3$); IR ν_{max} cm^{-1} 1066, 2108; NMR: ^{1}H (300 MHz, $CDCl_3$) α-anomer, δ 3.62–3.77 (4H, m, H-3, 4, 6a, 6b), 3.89 (1H, dd, *J*=9.9, 5.5 Hz, H-2), 4.33 (1H, ddd, *J*=9.1, 4.5, 4.5 Hz, H-5), 4.49 (1H, d, *J*=12.1 Hz, CH_2Ph), 4.58 (1H, d, *J*=12.1 Hz, CH_2Ph), 4.84 (1H, d, *J*=11.3 Hz, CH_2Ph), 4.94 (1H, d, *J*=11.3 Hz, CH_2Ph), 5.56 (1H, d, *J*=5.5 Hz, H-1), 7.24–7.52 (15H, m, Ph); β-anomer, δ 3.31 (1H, dd, *J*=9.5, 9.5 Hz, H-2), 3.37 (1H, dd, *J*=8.8, 8.8 Hz, H-3), 3.46 (1H, ddd, *J*=9.3, 4.9, 4.9 Hz, H-5), 3.63 (1H, dd, *J*=9.6, 9.6 Hz, H-4), 3.75 (1H, dd, *J*=9.7, 4.6 Hz, H-6a), 3.78 (1H, dd, *J*=10.2, 4.8 Hz, H-6b), 4.44 (1H, d, *J*=8.5 Hz, H-1), 4.55 (1H, d, *J*=11.8 Hz, CH_2Ph), 4.61 (1H, d, *J*=11.8 Hz, CH_2Ph), 4.81 (1H, d, *J*=11.0 Hz, CH_2Ph), 4.90 (1H, d, *J*=11.0 Hz, CH_2Ph), 7.25–7.58 (15H, m, Ph); ^{13}C (75 MHz, $CDCl_3$) α-anomer, δ 63.6 (C-2), 69.7 (C-6), 71.0 (C-5), 72.3 (C-4), 73.6 (*C*H$_2$Ph), 75.4 (*C*H$_2$Ph), 81.4 (C-3), 87.3 (C-1), 127.7–137.9 (Ph); β-anomer, δ 64.5 (C-2), 70.3 (C-6), 72.0 (C-4), 73.8 (*C*H$_2$Ph), 75.5 (*C*H$_2$Ph), 78.0 (C-5), 84.6 (C-3), 86.3 (C-1), 127.7–137.9 (Ph); Anal. Calcd for $C_{26}H_{27}N_3O_4S$: C, 65.4; H, 5.7 Found: C, 65.0; H, 5.5.

4.1.8. Phenyl 2-azido-3,6-di-*O*-benzyl-2-deoxy-4-*O*-*p*-methoxybenzyl-1-thio-D-glucopyranoside (12). A solution of **11** (180 mg, 0.37 mmol) and *p*-methoxybenzyl bromide (101 μL, 0.76 mmol) in DMF (4.5 mL) was added dropwise to a cold (0°C), stirred slurry of 50% sodium hydride (40 mg, 0.76 mmol) in DMF (5 mL). The reaction was quenched with methanol after 1 h, diluted with toluene, washed with aqueous saturated $NaHCO_3$ and water, dried, filtered and concentrated. The residue was first purified on a silica gel column (toluene/EtOAc 24:1), followed by purification on a reversed phase gel column using a gradient of acetone/water (2:1→4:1). The residue was concentrated, diluted with CH_2Cl_2, washed with water, dried, filtered and concentrated to give **12** (204 mg, 0.34 mmol, 90%) as a colorless syrup. R_f 0.56 (toluene/EtOAc 12:1); $[\alpha]_D=+64$ (*c* 1.0, $CHCl_3$); IR ν_{max} cm^{-1} 1082, 1250, 1514, 2109; NMR ^{1}H (300 MHz, $CDCl_3$) α-anomer, δ 3.62 (1H, dd, *J*=10.7, 1.9 Hz, H-6a), 3.73 (1H, dd, *J*=9.2, 9.2 Hz, H-4), 3.79 (1H, dd, *J*=10.5, 3.6 Hz, H-6b), 3.80 (1H, dd, *J*=9.0, 9.0 Hz, H-3), 3.79 (3H, s, CH_3O), 3.94 (1H, dd, *J*=9.9, 5.5 Hz, H-2), 4.34 (1H, ddd, *J*=9.5, 3.6, 1.8 Hz, H-5), 4.44 (1H, d, *J*=11.8 Hz, CH_2Ph), 4.47 (1H, d, *J*=10.4 Hz, CH_2Ph), 4.60 (1H, d, *J*=12.1 Hz, CH_2Ph), 4.73 (1H, d, *J*=10.4 Hz, CH_2Ph), 4.91 (2H, s, CH_2Ph), 5.60 (1H, d, *J*=5.5 Hz, H-1), 6.82 (2H, d, *J*=8.8 Hz, Ph), 7.08 (2H, d, *J*=8.8 Hz, Ph), 7.24–7.52 (15H, m, Ph); β-anomer, δ 3.33 (1H, dd, *J*=9.6, 9.6 Hz, H-2), 3.42–3.47 (1H, ddd, *J*=9.6, 3.6, 2.0 Hz, H-5), 3.48 (1H, dd, *J*=9.1, 9.1 Hz, H-3), 3.58 (1H, dd, *J*=9.2, 9.2 Hz, H-4), 3.69–3.81 (2H, m, H-6a, 6b), 3.78 (3H, s, CH_3O), 4.40 (1H, d, *J*=9.9 Hz, H-1), 4.51 (1H, d, *J*=10.7 Hz, CH_2Ph), 4.54 (1H, d, *J*=11.8 Hz CH_2Ph), 4.62 (1H, d, *J*=11.8 Hz, CH_2Ph), 4.71 (1H, d, *J*=10.4 Hz, CH_2Ph), 4.85 (2H, s, CH_2Ph), 6.82 (2H, d, *J*=8.5 Hz, Ph), 7.11 (2H, d, *J*=8.8 Hz, Ph), 7.23–7.61 (15H, m, Ph); ^{13}C (75 MHz, $CDCl_3$) α-anomer, δ 55.3 (CH_3O), 64.1 (C-2), 68.3 (C-6), 71.9 (C-5), 73.5 (*C*H$_2$Ph), 74.8 (*C*H$_2$Ph), 75.7 (*C*H$_2$Ph), 78.0 (C-4), 81.8 (C-3), 87.3 (C-1), 113.9 (Ph), 127.6–137.8 (Ph), 159.4 (CH_3O*Ph*); β-anomer, δ 55.3 (CH_3O), 65.1 (C-2), 68.8 (C-6), 73.4 (*C*H$_2$Ph), 74.7 (*C*H$_2$Ph), 75.9 (*C*H$_2$Ph), 77.3 (C-4), 79.4 (C-5), 85.1 (C-3), 86.0 (C-1), 113.9 (Ph), 127.6–138.2 (Ph), 159.4 (CH_3O*Ph*); HRMS Calcd for $C_{34}H_{35}O_4N_3S$: $[M+Na]^+$ 620.2195 Found: $[M+Na]^+$ 620.2177.

4.1.9. Phenyl 4-allyl-2-azido-3,6-di-*O*-benzyl-2-deoxy-1-thio-D-glucopyranoside (13). A solution of **11** (220 mg, 0.46 mmol) and allyl bromide (78 μL 0.92 mmol) in DMF (3 mL) was added dropwise to a cold (0°C), stirred slurry of 50% sodium hydride (50 mg, 0.92 mmol) in DMF (5 mL). The reaction was quenched with methanol after 40 min, diluted with toluene, washed with aqueous saturated $NaHCO_3$, water, dried, filtered, concentrated and purified on a silica gel column (toluene/EtOAc 10:1) to give **13** (230 mg, 0.44 mmol, 96%) as a white solid. R_f 0.82 (toluene/EtOAc 12:1); $[\alpha]_D=+95$ (*c* 1.0, $CHCl_3$); IR ν_{max} cm^{-1} 696, 746, 1054, 1072, 1151, 2107; NMR: ^{1}H (300 MHz, $CDCl_3$) α-anomer, δ 3.60 (1H, dd, *J*=9.9, 8.8 Hz, H-4), 3.64 (1H, dd, *J*=10.8, 2.1 Hz, H-6a), 3.76 (1H, dd, *J*=9.5, 9.5 Hz, H-3), 3.77 (1H, dd, *J*=11.0, 3.6 Hz, H-6b), 3.90 (1H, dd, *J*=10.3, 5.4 Hz, H-2), 4.02 (1H, dd, *J*=12.4, 5.7, 1.4, 1.4 Hz, CHCH_2O), 4.26 (1H, dddd, *J*=12.4, 5.5, 1.4, 1.4 Hz, CHCH_2O), 4.32 (1H, ddd, *J*=9.9, 3.6, 1.9 Hz, H-5), 4.46 (1H, d, *J*=11.8 Hz, CH_2Ph), 4.62 (1H, d, *J*=12.1 Hz, CH_2Ph), 4.85 (1H, d, *J*=10.4 Hz, CH_2Ph), 4.89 (1H, d, *J*=10.7 Hz, CH_2Ph), 5.11–5.24 (2H, m, CH_2=CH), 5.58 (1H, d, *J*=5.2 Hz, H-1), 5.77–5.90 (1H, m, CH_2=C*H*), 7.24–7.54 (15H, m, Ph); β-anomer, δ 3.27–3.48 (4H, m, H-2, H-3, H-4, H-5), 3.70–3.81 (2H, m, H-6a, 6b), 4.07 (1H, dddd, *J*=12.4, 5.5, 1.4, 1.4 Hz, CHCH_2O), 4.24 (1H, dddd, *J*=12.4, 5.8, 1.4, 1.4 Hz, CHCH_2O), 4.40 (1H, d, *J*=10.2 Hz, H-1), 4.56 (1H, d, *J*=12.1 Hz, CH_2Ph), 4.64 (1H, d, *J*=11.8 Hz, CH_2Ph), 4.82 (2H, s, Ph), 5.10–5.23 (2H, m, CH_2=CH), 5.78–5.91 (1H, m, CH_2=CH), 7.21–7.61 (15H, m, Ph); ^{13}C (75 MHz, $CDCl_3$) α-anomer, δ 63.9 (C-2), 68.3 (C-6), 71.9 (C-5), 73.5 (*C*H$_2$Ph), 73.9 (CH*C*H$_2$O), 75.7 (*C*H$_2$Ph), 78.1 (C-4), 81.7 (C-3), 87.3 (C-1), 117.1 (*C*H$_2$=CH), 127.7–137.8 (Ph), 134.4 (CH_2=*C*H); β-anomer, δ 64.9 (C-2), 68.8 (C-6), 73.5 (*C*H$_2$Ph), 73.8 (CH*C*H$_2$O), 75.9 (*C*H$_2$Ph), 77.3 (C-3), 79.4 (C-5), 84.9 (C-4), 85.9 (C-1), 117.1 (*C*H$_2$=CH), 127.6–138.3 (Ph), 133.6 ($\mathrm{CH_2{=}}\mathit{C}\mathrm{H}$); Anal. Calcd for $C_{29}H_{31}N_3O_4S$: C, 67.3; H, 6.0 Found: C, 67.1; H, 6.1.

4.1.10. Ethyl 2-amino-3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-1-thio-β-D-glucopyranoside (15). **14**[21] (7.21 g, 13.6 mmol) in *n*-butanol/ethylenediamine 5:1 (480 mL) was stirred at 90°C for 14 h, after which the mixture was concentrated, dissolved in $CHCl_3$/MeOH 10:1 and passed through a short column of silica. FC (CH_2Cl_2/EtOAc 9:1) and recrystallization from EtOAc/hexane gave **15** (4.96 g, 12.4 mmol, 91%) as white needles. R_f 0.28 (CH_2Cl_2/EtOAc 9:1); mp 147–148°C; $[\alpha]_D=-45$ (*c* 1.5, $CHCl_3$); IR ν_{max} cm^{-1} 931, 1027, 1070, 1082, 1093, 1369, 1452, 1607, 2860; NMR: ^{1}H (300 MHz, $CDCl_3$), δ 1.30 (3H, dd, *J*=7.6, 7.6 Hz, $\mathrm{C}H_3\mathrm{CH_2}$), 2.74 (2H, m, $\mathrm{CH_3C}H_2$), 2.96 (1H, dd, *J*=10.0, 10.0 Hz, H-2), 3.51 (1H, ddd, *J*=9.7, 9.7, 4.8 Hz, H-5), 3.57 (1H, dd, *J*=9.1, 9.1 Hz, H-3), 3.78 (1H, dd, *J*=9.1, 9.1 Hz, H-6a), 3.79 (1H, dd, *J*=10.2, 10.2 Hz, H-4), 4.35 (1H, dd, *J*=10.5, 5.2 Hz, H-6b), 4.42 (1H, d, *J*=10.1 Hz, H-1), 4.71 (1H, d, *J*=11.5 Hz, $\mathrm{C}H_2\mathrm{Ph}$), 5.03 (1H, d, *J*=11.5 Hz, $\mathrm{C}H_2\mathrm{Ph}$), 5.63 (1H, s, $\mathrm{C}H\mathrm{Ph}$), 7.20–7.65 (10H, m, Ph); ^{13}C (75 MHz, $CDCl_3$), δ 15.3 ($C\mathrm{H_3CH_2}$), 24.6 ($\mathrm{CH_3}C\mathrm{H_2}$), 56.1 (C-2), 68.7 (C-6), 70.6 (C-3), 74.9 ($C\mathrm{H_2Ph}$), 82.2 (C-4), 82.3 (C-5), 87.6 (C-1), 101.2 ($C\mathrm{HPh}$), 126.0 (Ph), 127.9 (Ph), 128.2 (Ph), 128.3 (Ph), 128.5 (Ph), 129.0 (Ph), 137.4 (Ph), 138.3 (Ph); Anal. Calcd for $C_{22}H_{27}NO_4S$: C, 65.8; H, 6.8 Found: C, 66.0; H, 6.8.

4.1.11. Ethyl 2-azido-3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-1-thio-β-D-glucopyranoside (16). To a solution of NaN_3 (8.0 g, 123 mmol) in H_2O (20 mL) was added CH_2Cl_2 (25 mL). The resulting mixture was cooled to 0°C under N_2. Trifluoromethanesulfonic anhydride (4.0 mL, 23 mmol) was added over 30 min to the stirred two-phase mixture. After an additional 2 h at 0°C, the phases were separated and the aqueous phase was extracted with CH_2Cl_2 (2×10 mL). The combined organic layers were washed with sat. $NaHCO_3$ (20 mL) and H_2O (20 mL), dried with $MgSO_4$ and filtered. The resulting solution of triflyl azide was added dropwise to a stirred solution of **15** (5.03 g, 12.5 mmol) and DMAP (4.65 g, 38 mmol) in CH_2Cl_2 (50 mL). After 16 h, the mixture was diluted with EtOAc and concentrated. FC (toluene/EtOAc 12:1) and recrystallization from hexane gave **16** (5.18 g, 12.1 mmol, 97%). R_f 0.56 (toluene/EtOAc 12:1); IR ν_{max} cm^{-1} 995, 1062, 1084, 1101, 1278, 1376, 1452, 2111; ^{1}H and ^{13}C NMR spectra were identical to those previously reported.[6]

4.1.12. Ethyl 2-azido-3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-1-thio-β-D-glucopyranoside *S*-oxide (17). To a stirred solution of **16** (428 mg, 1.00 mmol) in CH_2Cl_2 (50 mL) at −60°C, was added *m*-CPBA (200 mg, 1.16 mmol). The mixture was allowed to warm up to −20°C over 25 min. The mixture was diluted with CH_2Cl_2, washed with aqueous $NaHCO_3$, dried, filtered and concentrated. FC (toluene/EtOAc 1:1) and recrystallization from EtOAc/hexane produced **17** as a mixture of (*R*)- and (*S*)-sulfoxides (419 mg, 0.94 mmol, 94%). R_f 0.46, 0.26 (toluene/EtOAc 1:1); mp 142–148°C (from EtOAc/hexane); $[\alpha]_D=-192$ (*c* 1.0, $CHCl_3$); IR ν_{max} cm^{-1} 1015, 1108, 1263, 1366, 1454, 2109, 2862; NMR: ^{1}H (300 MHz, $CDCl_3$) R_f 0.46, δ 1.37 (3H, dd, *J*=7.6, 7.6 Hz, $\mathrm{CH_2C}H_3$), 2.84 (1H, ddd, *J*=20.6, 7.6, 7.6 Hz, $\mathrm{CH_3C}H_2$), 3.08 (1H, ddd, *J*=20.6, 7.6, 7.6 Hz, $\mathrm{CH_3C}H_2$), 3.49 (1H, ddd, *J*=9.5, 9.5, 5.1 Hz, H-5), 3.74 (1H, dd, *J*=9.6, 9.6 Hz, H-4), 3.76 (1H, dd, *J*=10.1, 10.1 Hz, H-6a), 3.83 (1H, dd, *J*=8.9, 8.9 Hz, H-3), 3.99 (1H, dd, *J*=9.2, 9.2 Hz, H-2), 4.10 (1H, d, *J*=9.8 Hz, H-1), 4.35 (1H, dd, *J*=10.5, 5.1 Hz, H-6b), 4.82 (1H, d, *J*=11.3 Hz, $\mathrm{C}H_2\mathrm{Ph}$), 4.98 (1H, d, *J*=11.3 Hz, $\mathrm{C}H_2\mathrm{Ph}$), 5.53 (1H, s, $\mathrm{C}H\mathrm{Ph}$), 7.28–7.45 (10H, m, Ph); R_f 0.26, δ 1.32 (3H, dd, *J*=7.6, 7.6 Hz, $\mathrm{CH_2C}H_3$), 2.76 (1H, ddd, *J*=20.6, 7.6, 7.6 Hz, $\mathrm{CH_3C}H_2$), 3.08 (1H, ddd, *J*=20.6, 7.6, 7.6 Hz, $\mathrm{CH_3C}H_2$), 3.52 (1H, ddd, *J*=9.7, 9.7, 4.9 Hz, H-5), 3.79 (1H, d, *J*=10.5 Hz, H-1), 3.81–3.84 (2H, m, H-3, H-4), 3.88 (1H, dd, *J*=10.3, 10.3 Hz, H-6a), 4.05–4.11 (1H, m, H-2), 4.34 (1H, dd, *J*=10.5, 5.1 Hz, H-6b), 4.84 (1H, d, *J*=11.2 Hz, $\mathrm{C}H_2\mathrm{Ph}$), 4.99 (1H, d, *J*=11.6 Hz, $\mathrm{C}H_2\mathrm{Ph}$), 5.57 (1H, s, $\mathrm{C}H\mathrm{Ph}$), 7.26–7.49 (10H, m, Ph); ^{13}C (75 MHz, $CDCl_3$) R_f 0.46, δ 7.5 ($C\mathrm{H_3CH_2}$), 43.5 ($\mathrm{CH_3}C\mathrm{H_2}$), 59.5 (C-2), 68.2 (C-6), 71.0 (C-5), 75.0 ($C\mathrm{H_2Ph}$), 80.9 (C-3, 4), 90.7 (C-1), 101.4 ($C\mathrm{HPh}$), 126.0 (Ph), 128.0 (Ph), 128.3 (Ph), 128.4 (Ph), 128.5 (Ph), 129.2 (Ph), 136.9 (Ph), 137.5 (Ph); R_f 0.26, δ 7.4 ($C\mathrm{H_3CH_2}$), 41.3 ($\mathrm{CH_3}C\mathrm{H_2}$), 59.5 (C-2), 68.1 (C-6), 71.3 (C-5), 74.9 ($C\mathrm{H_2Ph}$), 80.7 (C-3), 81.0 (C-4), 88.0 (C-1), 101.4 ($C\mathrm{HPh}$), 126.0 (Ph), 128.0 (Ph), 128.2 (Ph), 128.4 (Ph), 128.5 (Ph), 129.2 (Ph), 136.9 (Ph), 137.5 (Ph); Anal. Calcd for $C_{22}H_{25}N_3O_5S$: C, 59.6; H, 5.7 Found: C, 59.6; H 5.3.

4.1.13. Ethyl 4-*O*-allyl-2-azido-3,6-di-*O*-benzyl-2-deoxy-1-thio-β-D-glucopyranoside *S*-oxide (20). To a stirred solution of **19**[6] (470 mg, 1.00 mmol) in CH_2Cl_2 (50 mL) at −78°C, was added *m*-CPBA (200 mg, 1.16 mmol). The mixture was allowed to warm up to −20°C over 30 min. The mixture was diluted with CH_2Cl_2, washed with aqueous $NaHCO_3$, dried, filtered and concentrated. FC (toluene/EtOAc 1:1) and recrystallization from hexane produced **20** as a mixture of (*R*)- and (*S*)-sulfoxides (470 mg, 0.97 mmol, 97%). R_f 0.25, 0.21 (toluene/EtOAc 2:1); mp 65–66°C (from hexane); $[\alpha]_D=-57$ (*c* 1.0, $CHCl_3$); IR ν_{max} cm^{-1} 1027, 1086, 1276, 1359, 1455, 2113, 2912; NMR: ^{1}H (300 MHz, $CDCl_3$) R_f 0.25, δ 1.37 (3H, dd, *J*=7.6, 7.6 Hz, $\mathrm{C}H_3\mathrm{CH_2}$), 2.82 (1H, ddd, *J*=10.6, 7.6, 7.6 Hz, $\mathrm{CH_3C}H_2$), 3.04 (1H, ddd, *J*=10.6, 7.6, 7.6 Hz, $\mathrm{CH_3C}H_2$), 3.43–3.48 (1H, m, H-5), 3.51 (1H, dd, *J*=8.7, 8.7 Hz, H-4), 3.60 (1H, dd, *J*=8.9, 8.9 Hz, H-3), 3.68 (1H, dd, *J*=11.0, 3.8 Hz, H-6a), 3.73 (1H, dd, *J*=11.0, 2.0 Hz, H-6b), 3.83 (1H, dd, *J*=9.4, 9.4 Hz, H-2), 3.99 (1H, dd, *J*=10.1, 10.1 Hz, H-1), 4.07 (1H, dddd, *J*=12.3, 5.8, 1.4, 1.4 Hz, $\mathrm{CHC}H_2\mathrm{O}$), 4.25 (1H, dddd, *J*=12.3, 5.8, 1.4, 1.4 Hz, $\mathrm{CHC}H_2\mathrm{O}$), 4.52 (1H, d, *J*=12.3 Hz, $\mathrm{C}H_2\mathrm{Ph}$), 4.59 (1H, d, *J*=12.3 Hz, $\mathrm{C}H_2\mathrm{Ph}$), 4.87 (2H, s, $\mathrm{C}H_2\mathrm{Ph}$), 5.11–5.23 (2H, m, $\mathrm{C}H_2\mathrm{{=}CH}$), 5.77–5.89 (1H, m, $\mathrm{CH_2{=}C}H$), 7.25–7.38 (10H, m, Ph); R_f 0.21, δ 1.30 (3H, dd, *J*=7.5, 7.5 Hz, $\mathrm{C}H_3\mathrm{CH_2}$), 2.80 (1H, ddd, *J*=10.6, 7.6, 7.6 Hz, $\mathrm{CH_3C}H_2$), 3.10 (1H, ddd, *J*=10.4, 7.6, 7.6 Hz, $\mathrm{CH_3C}H_2$), 3.44 (1H, dd, *J*=9.8, 8.7 Hz, H-4), 3.52 (1H, ddd, *J*=9.8, 5.1, 1.9 Hz, H-5), 3.64 (1H, dd, *J*=9.5, 8.7 Hz, H-3), 3.70 (1H, dd, *J*=10.9, 5.5 Hz, H-6a), 3.70 (1H, d, *J*=10.2 Hz, H-1), 3.77 (1H, dd, *J*=10.9, 2.2 Hz, H-6b), 3.96 (1H, dd, *J*=10.4, 9.6 Hz, H-2), 4.07 (1H, dddd, *J*=12.4, 5.8, 1.5, 1.5 Hz, $\mathrm{CHC}H_2\mathrm{O}$), 4.26 (1H, dddd, *J*=12.4, 5.8, 1.5, 1.5 Hz, $\mathrm{CHC}H_2\mathrm{O}$), 4.54 (1H, d, *J*=12.0 Hz, $\mathrm{C}H_2\mathrm{Ph}$), 4.60 (1H, d, *J*=12.0 Hz, $\mathrm{C}H_2\mathrm{Ph}$), 4.89 (2H, s, $\mathrm{C}H_2\mathrm{Ph}$), 5.12–5.24 (2H, m, $\mathrm{C}H_2\mathrm{{=}CH}$), 5.77–5.90 (1H, m, $\mathrm{CH_2{=}C}H$), 7.25–7.42

(10H, m, Ph); ^{13}C (75 MHz, CDCl$_3$) R_f 0.25, δ 7.2 (*C*H$_3$CH$_2$), 43.1 (CH$_3$*C*H$_2$), 61.0 (C-2), 68.4 (C-6), 73.6 (*C*H$_2$Ph), 73.8 (CH*C*H$_2$O), 75.8 (*C*H$_2$Ph), 77.0 (C-4), 80.1 (C-5), 84.8 (C-3), 90.7 (C-1), 117.3 (*C*H$_2$=CH), 127.7–128.5 (Ph), 134.2 (CH$_2$=*C*H), 137.6 (Ph), 137.9 (Ph); R_f 0.21, δ 7.2 (*C*H$_3$CH$_2$), 41.3 (CH$_3$*C*H$_2$), 59.9 (C-2), 69.0 (C-6), 73.6 (*C*H$_2$Ph), 74.0 (CH*C*H$_2$O), 75.7 (*C*H$_2$Ph), 77.5 (C-4), 80.6 (C-5), 84.9 (C-3), 87.7 (C-1), 117.6 (*C*H$_2$=CH), 127.7–128.5 (Ph), 134.1 (CH$_2$=*C*H), 137.9 (Ph), 138.0 (Ph); Anal. Calcd for $C_{25}H_{31}N_3O_5S$: C, 61.8; H, 6.4 Found: C, 62.0; H 6.3.

4.1.14. 4-*O*-Acetyl-2-azido-3,6-di-*O*-benzyl-2-deoxy-β-D-glucopyranosyl thiocyanate (21). To a stirred solution of **18**[6] (495 mg, 1.15 mmol) in pyridine (5 mL) was added acetic anhydride (0.25 mL, 2.6 mmol). After 10 min, the mixture was diluted with CH$_2$Cl$_2$, washed with H$_2$O and 0.1 M HCl, dried filtered and concentrated. FC (toluene/EtOAc 12:1) gave *ethyl 4-O-acetyl-2-azido-3,6-di-O-benzyl-2-deoxy-thio-β-D-glucopyranoside* (538 mg, 1.14 mmol, 99%) as a colorless syrup. R_f 0.68 (toluene/EtOAc 4:1); NMR: ^{1}H (300 MHz, CDCl$_3$), δ 1.32 (3H, dd, J=7.6, 7.6 Hz, *C*H$_3$CH$_2$), 1.84 (3H, s), 2.66–2.83 (2H, m, CH$_3$C*H*$_2$), 3.42–3.56 (5H, m, H-2, 3, 5, 6a, 6b), 4.28–4.34 (1H, m, H-1), 4.49 (2H, s, *C*H$_2$Ph), 4.65 (1H, d, J=11.3 Hz, *C*H$_2$Ph), 4.83 (1H, d, J=11.3 Hz, *C*H$_2$Ph), 4.96–5.04 (1H, m, H-4), 7.24–7.36 (10H, m, Ph); ^{13}C (75 MHz, CDCl$_3$), δ 15.1 (*C*H$_3$CH$_2$), 20.7 (*C*H$_3$CO), 24.7, (CH$_3$*C*H$_2$), 65.8 (C-2), 69.7, 70.8, 73.6, 75.2, 77.6, 82.5, 84.3, 127.7–128.5 (Ph), 137.5 (Ph), 137.8 (Ph), 169.6 (CH$_3$*C*O). To a stirred solution of this derivative (346 mg, 0.73 mmol) in CH$_2$Cl$_2$ (5 mL) was added bromine (124 mg, 0.78 mmol). After 10 min, cyclohexene was added to the mixture until the yellow color disappeared, and the mixture was concentrated. The resulting bromo sugar was stirred with KSCN (227 mg, 2.34 mmol) and 18-crown-6 ether (20 mg, 0.076 mmol) in dry acetone (3 mL) for 3 h. The mixture was filtered through Celite and concentrated. FC (toluene/EtOAc 20:1) gave **21** (184 mg, 0.39 mmol, 54%) as a colorless syrup. R_f 0.41 (toluene/EtOAc 12:1); $[\alpha]_D=-54$ (*c* 0.8, CHCl$_3$); IR ν_{max} cm^{-1} 1062, 1224, 1365, 1455, 1747, 2114, 2160, 2873; NMR: ^{1}H (300 MHz, CDCl$_3$), δ 1.85 (3H, s, C*H*$_3$CO), 3.48–3.66 (4H, m), 3.72 (1H, dd, J=9.6, 9.6 Hz), 4.48 (1H, d, J=9.9 Hz, H-1), 4.52 (2H, s, C*H*$_2$Ph), 4.67 (1H, d, J=11.3 Hz, C*H*$_2$Ph), 4.83 (1H, d, J=11.3 Hz, C*H*$_2$Ph), 5.07 (1H, dd, J=9.6, 9.6 Hz, H-4), 7.25–7.38 (10H, m, Ph); ^{13}C (75 MHz, CDCl$_3$), δ 20.7 (*C*H$_3$CO), 65.7 (C-2), 68.9, 70.1, 73.7, 75.5, 79.1, 82.1, 83.7, 107.8 (SCN), 127.9–128.6 (Ph), 137.0 (Ph), 137.5 (Ph), 169.3 (CH$_3$*C*O); HRMS Calcd for $C_{23}H_{24}N_4O_5S$: $[M+Na]^+$ 491.1365 Found: $[M+Na]^+$ 491.1383.

4.1.15. 2-Azido-4-*O*-benzoyl-3,6-di-*O*-benzyl-2-deoxy-β-D-glucopyranosyl thiocyanate (22). To a stirred solution of **18**[6] (371 mg, 0.86 mmol) in pyridine (5 mL) was added benzoyl chloride (0.20 mL, 1.7 mmol) and DMAP (20 mg, 0.16 mmol). After 30 min, the mixture was diluted with CH$_2$Cl$_2$, washed with H$_2$O and 0.1 M HCl, dried filtered and concentrated. FC (toluene/EtOAc 12:1) gave *ethyl 2-azido-4-O-benzoyl-3,6-di-O-benzyl-2-deoxy-thio-β-D-glucopyranoside* (448 mg, 0.84 mmol, 98%) as a colorless syrup. R_f 0.72 (toluene/EtOAc 4:1); NMR: ^{1}H (300 MHz, CDCl$_3$), δ 1.34 (3H, dd, J=7.4, 7.4 Hz, C*H*$_3$CH$_2$), 2.72–2.83 (2H, m, CH$_3$C*H*$_2$), 3.51–3.73 (5H, m, H-2, 3, 5, 6a, 6b), 4.39 (1H, d, J=10.2 Hz, H-1), 4.46 (2H, s, C*H*$_2$Ph), 4.63 (1H, d, J=11.0 Hz, C*H*$_2$Ph), 4.77 (1H, d, J=10.7 Hz, C*H*$_2$Ph), 5.29 (1H, dd, J=9.9, 9.3 Hz, H-4), 7.15–7.25 (10H, m, Ph), 7.41–7.46 (2H, m, Ph), 7.56–7.66 (1H, m, Ph), 7.94–7.98 (2H, m, Ph); ^{13}C (75 MHz, CDCl$_3$), δ 15.1 (*C*H$_3$CH$_2$), 24.7, (CH$_3$*C*H$_2$), 65.9 (C-2), 69.7, 71.4, 73.6, 75.3, 78.0, 82.4, 84.4, 127.6–129.8 (Ph), 133.4 (Ph), 137.1 (Ph), 137.7 (Ph), 165.2 (Ph*C*O). To a stirred solution of this derivative (353 mg, 0.66 mmol) in CH$_2$Cl$_2$ (5 mL) was added bromine (115 mg, 0.72 mmol). After 10 min, cyclohexene was added to the mixture until the yellow color disappeared, and the mixture was concentrated. The resulting bromo sugar was stirred with KSCN (210 mg, 2.16 mmol) and 18-crown-6 ether (23 mg, 0.087 mmol) in dry acetone (3 mL) for 3 h. The mixture was filtered through Celite and concentrated. FC (gradient toluene→toluene/EtOAc 20:1) gave **22** (193 mg, 0.36 mmol, 55%) as a colorless syrup. R_f 0.35 (toluene/EtOAc 12:1); $[\alpha]_D=-71$ (*c* 0.6, CHCl$_3$); IR ν_{max} cm^{-1} 1067, 1256, 1451, 1732, 2114, 2160, 2916; NMR: ^{1}H (300 MHz, CDCl$_3$), δ 3.62 (2H, d, J=4.4 Hz), 3.72–3.84 (3H, m), 4.49 (2H, s, C*H*$_2$Ph), 4.56 (1H, d, J=9.6 Hz, H-1), 4.65 (1H, d, J=10.7 Hz, C*H*$_2$Ph), 4.76 (1H, d, J=11.0 Hz C*H*$_2$Ph), 5.36 (1H, dd, J=9.9, 9.1 Hz, H-4), 7.13–7.26 (10H, m, Ph), 7.41–7.47 (2H, m, Ph), 7.57–7.63 (1H, m, Ph), 7.94–7.98 (2H, m, Ph); ^{13}C (75 MHz, CDCl$_3$), δ 65.8 (C-2), 68.9, 70.5, 73.8, 75.5, 79.4, 82.0, 83.9, 107.8 (SCN), 127.7–129.9 (Ph), 133.6 (Ph), 136.6 (Ph), 137.4 (Ph), 165.0 (Ph*C*O); HRMS Calcd for $C_{28}H_{26}N_4O_5S$: $[M+Na]^+$ 553.1522 Found: $[M+Na]^+$ 553.1495.

4.1.16. *O*-(4-*O*-Allyl-2-azido-3,6-di-*O*-benzyl-2-deoxy-β-D-glucopyranosyl) trichloroacetimidate (23). To a stirred mixture of **19**[6] (140 mg, 0.30 mmol), H$_2$O (10 μL) and TfOH (7 μL) in acetonitrile (25 mL) at 0°C was added a solution of tetrabutylammonium periodate (52 mg, 0.12 mmol) in acetonitrile (3 mL). After 1 h, aqueous NaHCO$_3$ (sat.) was added (15 mL) and the mixture was extracted with CH$_2$Cl$_2$. The organic layer was washed with 5% Na$_2$S$_2$O$_3$ and brine, dried, filtered and concentrated. FC (toluene/EtOAc 6:1) gave *4-O-allyl-2-azido-3,6-di-O-benzyl-2-deoxy-D-glucopyranose* (106 mg, 0.25 mmol, 84%). R_f 0.38 (toluene/EtOAc 4:1); ^{1}H NMR were in accordance with that previously published.[32] To a stirred solution of 4-*O*-allyl-2-azido-3,6-di-*O*-benzyl-2-deoxy-D-glucopyranose (127 mg, 0.30 mmol) in dry CH$_2$Cl$_2$ (4.5 mL) were added K$_2$CO$_3$ (413 mg, 3.0 mmol) and trichloroacetonitrile (0.60 mL, 6.0 mmol). After 3 h, the reaction mixture was diluted with dry toluene, filtered through Celite and concentrated. The residue was purified on a silica gel column (light petroleum 45–60/EtOAc 4:1, 1% NEt$_3$) to give **23** (132 mg, 0.23 mmol, 78%) as a colorless syrup. R_f 0.35 (light petroleum 40–65/EtOAc 4:1); IR ν_{max} cm^{-1} 1060, 1286, 1674, 2113; NMR: ^{1}H (300 MHz, CDCl$_3$), δ 3.48 (1H, dd, J=9.6, 8.8 Hz, H-3), 3.52–3.65 (2H, m, H-4, 5), 3.64 (1H, dd, J=9.1, 9.1 Hz, H-2), 3.69–3.78 (2H, m, H-6a, 6b), 4.11 (1H, dddd, J=12.4, 5.5, 1.4, 1.4 Hz, CHC*H*$_2$O), 4.29 (1H, dddd, J=12.4, 5.8, 1.4, 1.4 Hz, CHC*H*$_2$O), 4.57 (1H, d, J=12.1 Hz, C*H*$_2$Ph), 4.66 (1H, d, J=12.1 Hz, C*H*$_2$Ph), 4.86 (1H, d, J=11.0 Hz, C*H*$_2$Ph), 4.90 (1H, d, J=11.0 Hz, C*H*$_2$Ph), 5.14–5.25 (2H, m, C*H*$_2$=CH), 5.64 (1H, d, J=8.5 Hz, H-1), 5.80–5.93 (1H, m, CH$_2$=C*H*), 7.26–7.43

(10H, m, Ph), 8.76 (1H, s, NH); ^{13}C (75 MHz, CDCl$_3$), δ 65.7 (C-2), 67.9 (C-6), 73.4 (*C*H$_2$Ph), 73.8 (CH*C*H$_2$O), 75.6 (*C*H$_2$Ph), 76.1 (C-5), 77.0 (C-4), 82.8 (C-3), 90.6 (*C*Cl$_3$), 96.8 (C-1), 117.1 (*C*H$_2$=CH), 127.7–128.5 (Ph), 134.4 (CH$_2$=*C*H), 137.8 (Ph), 138.0 (Ph), 161.1 (Cl$_3$*C*NHO); Anal. Calcd for C$_{25}$H$_{27}$Cl$_3$N$_4$O$_5$: C, 52.7; H, 4.8 Found: C, 52.9; H, 4.8.

4.1.17. 6-*O*-(4-Allyl-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-glucopyranosyl)-1,4,5-tri-*O*-trimethylacetyl-2,3-*O*-(D-1,7,7-trimethyl[2.2.1]bicyclohept-6-ylidene)-D-*myo*-inositol (3). **20** (38 mg, 0.078 mmol) in toluene (1 mL) under argon was cooled to −78°C. Trifluoromethanesulfonic anhydride (0.014 mL, 0.083 mmol) was added, and the resulting mixture stirred for 5 min at −78°C. **2** (75 mg, 0.133 mmol) and di-*t*-butyl-methyl aminopyridine (19 mg, 0.093 mmol) dissolved in toluene (1 mL) were added. The reaction mixture was allowed to warm up to 0°C over 15 min. After an additional 30 min at 0°C, the mixture was diluted with toluene, washed with NaHCO$_3$, dried, filtered and concentrated. FC (toluene/EtOAc 25:1) gave **3** (48 mg, 0.049 mmol, 63%) as a colorless syrup. R_f 0.62 (toluene/EtOAc 12:1); ^{1}H and ^{13}C NMR spectra were identical to those previously reported.[6]

4.1.18. 6-*O*-(4-Allyl-2-azido-3,6-di-*O*-benzyl-2-deoxy-α-D-glucopyranosyl)-3,4,5-tri-*O*-benzyl-1,2-*O*-(L-1,7,7-trimethyl[2,2,1]bicyclohept-6-ylidene)-D-*myo*-inositol (25). To a stirred mixture of **19** (100 mg, 0.22 mmol), **6** (190 mg, 0.23 mmol) and 4 Å molecular sieves in diethyl ether (5 mL) under argon was added methyl trifluoromethanesulfonate (0.120 mL, 1.1 mmol). After 18 h, NEt$_3$ (0.4 mL) was added, and after an additional 15 min the mixture was filtered through Celite and concentrated. FC (petroleum ether 65–75/EtOAc gradient 19:1→9:1) gave **25** (116 mg, 0.12 mmol, 56%) as a colorless syrup. R_f 0.49 (toluene/EtOAc 12:1); $[\alpha]_D=+53$ (*c* 0.5, CHCl$_3$); IR ν_{max} cm^{-1} 1038, 1212, 1453, 1728, 1789, 2106, 2933; NMR: ^{1}H (600 MHz, CDCl$_3$), δ 0.84 (3H, s, CH$_3$), 0.87 (3H, s, CH$_3$), 1.06 (3H, s, CH$_3$), 1.21 (1H, ddd, J=12.0, 9.2, 4.6 Hz), 1.37 (1H, ddd, J=12.2, 12.2, 4.7 Hz), 1.46 (1H, d, J=12.9 Hz), 1.67–1.73 (1H, m), 1.74 (1H, dd, J=4.6, 4.6 Hz), 1.88–1.92 (2H, m), 3.33 (1H, dd, J=10.4, 3.6 Hz, H-2′), 3.37 (1H, dd, J=11.1, 2.0 Hz, H-6′a), 3.41 (1H, dd, J=11.1, 2.6 Hz, H-6′b), 3.42 (1H, dd, J=9.7, 7.4 Hz, H-4), 3.62 (1H, dd, J=10.0, 9.0 Hz, H-4′), 3.78 (1H, dd, J=8.1, 3.9 Hz, H-2), 3.80 (1H, dd, J=7.4, 7.4 Hz, H-3), 3.90 (1H, dd, J=10.4, 9.0 Hz, H-3′), 3.98 (1H, dd, J=9.9, 7.0 Hz, H-5), 3.99 (1H, dddd, J=12.6, 7.2, 1.6, 1.6 Hz, CHC*H*$_2$O), 4.01 (1H, ddd, J=9.7, 2.6, 2.0 Hz, H-5′), 4.01 (1H, dd, J=6.6 Hz, H-6), 4.22 (1H, dddd, J=12.6, 5.6, 1.5, 1.5 Hz, CHC*H*$_2$O), 4.28 (1H, dd, J=6.1, 4.6 Hz, H-1), 4.37 (1H, d, J=12.2 Hz, C*H*$_2$Ph), 4.55 (1H, d, J=12.2 Hz, C*H*$_2$Ph), 4.64 (1H, d, J=10.6 Hz, C*H*$_2$Ph), 4.68 (1H, d, J=12.0 Hz, C*H*$_2$Ph), 4.69 (1H, d, J=10.9 Hz, C*H*$_2$Ph), 4.72 (1H, d, J=10.9 Hz, C*H*$_2$Ph), 4.73 (1H, d, J=12.0 Hz, C*H*$_2$Ph), 4.79 (1H, d, J=10.9 Hz, C*H*$_2$Ph), 4.82 (1H, d, J=10.8 Hz, C*H*$_2$Ph), 4.85 (1H, d, J=10.8 Hz, C*H*$_2$Ph), 5.07–5.20 (2H, m, C*H*$_2$=CH), 5.55 (1H, d, J=3.6 Hz, H-1′), 5.75–5.88 (1H, m, CH$_2$=C*H*), 7.22–7.44 (25H, m, Ph); ^{13}C (75 MHz, CDCl$_3$), δ 9.8 (CH$_3$), 20.4 (CH$_3$), 20.6 (CH$_3$), 27.0 (CH$_2$), 29.9 (CH$_2$), 44.8 (CH$_2$), 45.1 (CH), 47.9 (C$_q$), 51.6 (C$_q$), 63.2 (C-2′), 67.8 (C-6′), 70.4 (C-5′), 72.5 (*C*H$_2$Ph), 73.3 (*C*H$_2$Ph), 73.5 (CH*C*H$_2$O), 73.9 (C-1), 74.7 (*C*H$_2$Ph), 75.2 (*C*H$_2$Ph), 75.2 (*C*H$_2$Ph), 76.1 (C-6), 77.0 (C-2), 78.1 (C-4′, 5), 79.8 (C-3′), 80.6 (C-3), 80.7 (C-4), 95.7 (C-1′), 116.0 (*C*H$_2$=CH), 118.0 (OCO), 127.6–128.5 (Ph), 135.0 (CH$_2$=*C*H), 138.0–138.6 (Ph); Anal. Calcd for C$_{60}$H$_{69}$N$_3$O$_{10}$: C, 72.6; H, 7.0 Found: C, 72.7; H 6.8.

4.1.19. 6-*O*-(2-Azido-3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-β-D-glucopyranosyl)-3,4,5-tri-*O*-benzyl-1,2-*O*-(L-1,7,7-trimethyl[2,2,1]bicyclohept-6-ylidene)-D-*myo*-inositol (26). To a stirred mixture of **16** (2.30 g, 5.38 mmol), **6** (5.20 g, 6.30 mmol) and 4 Å molecular sieves in CH$_2$Cl$_2$ (100 mL) under argon was added methyl trifluoromethanesulfonate (2.8 mL, 25 mmol). After 28 h, NEt$_3$ (7 mL) was added, and after an additional 15 min the mixture was filtered through Celite and concentrated. FC (petroleum ether 65–75/EtOAc gradient 19:1–9:1) gave **26** (2.97 g, 3.13 mmol, 58%) as a colorless syrup. R_f 0.57 (toluene/EtOAc 12:1); $[\alpha]_D=+47$ (*c* 0.9, CHCl$_3$); IR ν_{max} cm^{-1} 1035, 1094, 1453, 2107, 2872, 2941; NMR: ^{1}H (600 MHz, CDCl$_3$), δ 0.86 (3H, s, CH$_3$), 0.87 (3H, s, CH$_3$), 1.07 (3H, s, CH$_3$), 1.21 (1H, ddd, J=12.0, 9.3, 4.6 Hz), 1.39 (1H, ddd, J=12.2, 12.2, 4.7 Hz), 1.46 (1H, d, J=12.6 Hz), 1.68–1.74 (1H, m), 1.75 (1H, dd, J=4.5, 4.5 Hz), 1.86 (1H, ddd, J=12.9, 9.3, 3.6 Hz), 1.91 (1H, ddd, J=12.9, 4.7, 2.9 Hz), 3.35 (1H, dd, J=10.3, 3.6 Hz, H-2′), 3.42 (1H, dd, J=10.0, 7.5 Hz, H-4), 3.66–3.71 (2H, m, H-6′a, 4′), 3.78 (1H, dd, J=8.3, 3.9 Hz, H-2), 3.81 (1H, dd, J=8.1, 8.1 Hz, H-3), 3.99 (1H, dd, J=10.2, 7.0 Hz, H-5), 4.00 (1H, dd, J=7.0, 5.7 Hz, H-6), 4.01 (1H, dd, J=9.7, 9.7 Hz, H-3′), 4.16–4.21 (2H, m, H-5′, 6′b), 4.27 (1H, dd, J=5.7, 3.9 Hz, H-1), 4.67 (1H, d, J=10.8 Hz, C*H*$_2$Ph), 4.68 (1H, d, J=11.1 Hz, C*H*$_2$Ph), 4.69 (1H, d, J=11.8 Hz, C*H*$_2$Ph), 4.70 (1H, d, J=10.8 Hz, C*H*$_2$Ph), 4.73 (1H, d, J=11.8 Hz, C*H*$_2$Ph), 4.76 (1H, d, J=11.1 Hz, C*H*$_2$Ph), 4.78 (1H, d, J=10.8 Hz, C*H*$_2$Ph), 4.91 (1H, d, J=11.1 Hz, C*H*$_2$Ph), 5.56 (1H, s, C*H*Ph), 5.58 (1H, d, J=3.9 Hz, H-1′), 7.03–7.46 (25H, m, Ph); ^{13}C (75 MHz, CDCl$_3$), δ 9.7 (CH$_3$), 20.4 (CH$_3$), 20.6 (CH$_3$), 27.0 (CH$_2$), 29.8 (CH$_2$), 44.9 (CH$_2$), 45.2 (CH), 47.9 (C$_q$), 51.6 (C$_q$), 62.6 (C-5′), 63.0 (C-2′), 68.8 (C-6′), 72.6 (*C*H$_2$Ph), 74.0 (C-1), 74.7 (*C*H$_2$Ph), 74.8 (*C*H$_2$Ph), 75.4 (*C*H$_2$Ph), 75.4 (C-3′), 75.9 (C-6), 76.9 (C-2), 77.9 (C-5), 80.6 (C-3), 80.6 (C-4), 83.0 (C-4′), 95.9 (C-1′), 101.3 (*C*HPh), 118.1 (OCO), 126.2 (Ph), 127.5–128.4 (Ph), 137.5 (Ph), 137.8 (Ph), 137.9 (Ph), 138.3 (Ph), 138.5 (Ph); Anal. Calcd for C$_{57}$H$_{63}$N$_3$O$_{10}$: C, 72.0; H, 6.7 Found: C, 72.2; H 6.8.

4.1.20. 6-*O*-(2-Azido-3,6-di-*O*-benzyl-2-deoxy-β-D-glucopyranosyl)-3,4,5-tri-*O*-benzyl-1,2-*O*-(L-1,7,7-trimethyl-[2,2,1]bicyclohept-6-ylidene)-D-*myo*-inositol (27). To a mixture of **26** (1.92 g, 2.02 mmol) and NaBH$_3$CN (1.35 g, 21.5 mmol) in THF (30 mL) at 0°C was added ether saturated with HCl until only traces of starting material remained according to TLC. NEt$_3$ (5 mL) was added, the mixture filtered through Celite and concentrated. FC (toluene/EtOAc 20:1) gave **27** (1.59 g, 1.67 mmol, 83%) as a colorless syrup. R_f 0.37 (toluene/EtOAc 12:1); $[\alpha]_D=+33$ (*c* 1.1, CHCl$_3$); IR ν_{max} cm^{-1} 1037, 1111, 1453, 1729, 2105, 2918; NMR: ^{1}H (600 MHz, CDCl$_3$), δ 0.84 (3H, s, CH$_3$), 0.87 (3H, s, CH$_3$), 1.06 (3H, s, CH$_3$), (1H, ddd, J=12.2, 9.3, 4.7 Hz), 1.37 (1H, ddd, J=12.2, 12.2, 4.7 Hz), 1.46 (1H, d, J=12.9 Hz), 1.67–1.73 (1H, m), 1.74 (1H, dd, J=4.5, 4.5 Hz), 1.85–1.92 (2H, m), 3.30 (1H, dd, J=9.7, 3.6 Hz, H-2′), 3.43 (1H, dd, J=9.7, 7.5 Hz, H-4), 3.44 (1H, dd, J=10.7, 4.3 Hz, H-6′a), 3.49 (1H, dd, J=10.6, 3.8 Hz, H-6′b), 3.73 (1H, dd, J=9.2, 9.2 Hz, H-4′), 3.78 (1H, dd, J=9.9, 8.8 Hz, H-3′), 3.79–3.82 (2H, m, H-2, 3), 3.98 (1H, dd, J=9.7, 7.2 Hz, H-5), 4.00 (1H, ddd, J=9.2, 4.3, 3.8 Hz, H-5′), 4.02 (1H, dd, J=7.2, 6.1 Hz, H-6), 4.28 (1H, dd, J=6.1, 3.8 Hz, H-1), 4.40 (1H, d, J=12.2 Hz, CH_2Ph), 4.47 (1H, d, J=12.2 Hz, CH_2Ph), 4.64 (1H, d, J=10.8 Hz, CH_2Ph), 4.68 (1H, d, J=12.2 Hz, CH_2Ph), 4.69 (1H, d, J=10.8 Hz, CH_2Ph), 4.73 (1H, d, J=11.8 Hz, CH_2Ph), 4.77 (1H, d, J=10.8 Hz, CH_2Ph), 4.80 (1H, d, J=11.1 Hz, CH_2Ph), 4.83 (1H, d, J=11.1 Hz, CH_2Ph), 4.87 (1H, d, J=11.1 Hz, CH_2Ph), 5.56 (1H, d, J=3.6 Hz, H-1′), 7.16–7.42 (25H, m, Ph); ^{13}C (75 MHz, $CDCl_3$), δ 9.6 (CH_3), 20.3 (CH_3), 20.6 (CH_3), 26.9 (CH_2), 29.8 (CH_2), 44.8 (CH_2), 45.1 (CH), 47.9 (C_q), 51.5 (C_q), 62.7 (C-2′), 69.4 (C-6′), 69.5 (C-5′), 72.4 (C-4′), 72.5 (CH$_2$Ph), 73.3 (CH$_2$Ph), 73.8 (C-1), 74.7 (CH$_2$Ph), 74.8 (CH$_2$Ph), 75.1 (CH$_2$Ph), 76.0 (C-6), 76.9 (C-2), 77.8 (C-5), 79.2 (C-3′), 80.6 (C-3), 80.7 (C-4), 95.5 (C-1′), 118.0 (OCO), 127.6–129.0 (Ph), 137.9–138.4 (Ph); Anal. Calcd for $C_{57}H_{65}N_3O_{10}$: C, 71.9; H, 6.9 Found: C, 71.7; H 7.0.

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