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Direct chemical glycosylation with pentenyl- and thioglycoside donors of *N*-acetylglucosamine

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ABSTRACT

The use of pentenyl and thiophenyl glycosides of *N*-acetylglucosamine (GlcNAc) as glycosyl donors for the direct preparation of O-glycosides of GlcNAc promoted by *N*-iodosuccinimide (NIS) and metal triflates in dichloromethane has been investigated. Both glycosyl acceptors 1-octanol and (−)-menthol resulted in good glycosylation yields for both types of donors with pentenyl glycosides being somewhat superior in terms of yield. Carbohydrate-based acceptors were reacted with a benzylated GlcNAc-pentenyl donor but only provided disaccharides in poor to moderate yields. The results show that a variety of metal triflates are capable of acting as an activator for both NIS and the intermediate oxazoline.

1. Introduction

A recent statistical analysis has revealed that the most frequently encountered monosaccharide in mammalian oligosaccharide frameworks is the β-D-*N*-acetylglucosamine unit (β-D-GlcNAc) where it by far exceeds the occurrence of glucose.[1] This fact makes further development of glycosylation reactions with GlcNAc (GlcNAc-ylation), an important task in carbohydrate chemistry. It is well known that GlcNAc-ylation is hampered by the formation of an intermediate oxazoline which typically reacts only sluggishly as a glycosyl donor to form the glycoside product. For this reason other masking groups than the biologically relevant *N*-acetyl has been used extensively resulting in the lengthening of the synthetic sequence.[2,3]

We have recently shown that β-GlcNAc tetraacetate (**1**) is a useful donor in combination with rare earth metal triflates as catalytic promoters for the direct synthesis of β-glycosides of GlcNAc.[4] In this reaction, the catalyst acts as an activator for both oxazoline formation and oxazoline breakdown (Scheme 1A).[4,5] The present work describes our attempts to expand the previous results obtained with acetate donors to thiophenyl and pentenyl GlcNAc-donors using *N*-iodosuccinimide (NIS) promotion relying on a catalytic amount of metal triflates to act as an activator of both NIS[6,7] and the intermediate oxazoline. As hydroxyl-protecting groups, the use of both *O*-acetyl and *O*-benzyl has been investigated (Scheme 1B).

2. Results and discussion

Thioglycosides have become one of the preferred donor types[8] in modern glycosylation chemistry[9] owing to their stability under protecting group manipulations and many modes of activation. Traditional 'van Boom-activation' employing *N*-iodosuccinimide (NIS) in combination with catalytic amounts of triflic acid (TfOH)[10] or other harsh catalysts like TMSOTf is still widely used with success. Silver triflate (AgOTf)[11] seems to be the only Lewis acid salt used for thioglycoside activation under 'van Boom'-type conditions,[12] albeit Li, Na, K, Mg[13] and Bi[14] salts have been used in combination with *N*-bromosuccinimide (NBS). Pentenyl glycoside donors can too be activated by NIS/TfOH[15] and recently Fraser-Reid and co-workers have reported that $Sc(OTf)_3$ and $In(OTf)_3$ but not, for example, $Yb(OTf)_3$ act well as catalysts.[7]

GlcNAc thioglycoside donors have been used as precursors to mask the reducing sugar for later glycosyl amine synthesis[16,17] and recently with some success in glycosylation reactions.[18–20] GlcNAc-pentenyl glycoside donors have only been used to a very limited extent for the synthesis of oxazoline for enzymatic glycosylation[21] and for the chemical introduction of a 1-azido function[22] and never in combination with metal triflates. To the best of our knowledge there are no reports investigating GlcNAc-pentenyl glycoside donors as reactants in O-glycosylation reactions.

Acetyl-protected thioglycoside donor **2** was synthesised according to the literature procedures,[23,24] whereas acetylated pentenyl donor **4** was prepared by our published method[4] using 4-penten-1-ol/$Yb(OTf)_3$ from the β-acetate under microwave irradiation in excellent yield (Scheme 2). Zemplén deacetylation of both **2** and **4** followed by careful NaH/BnBr/DMF benzylation of the

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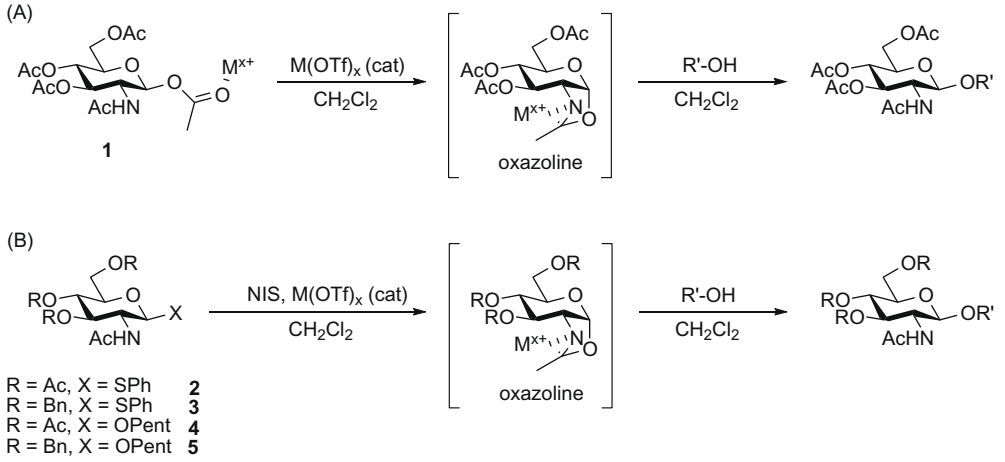
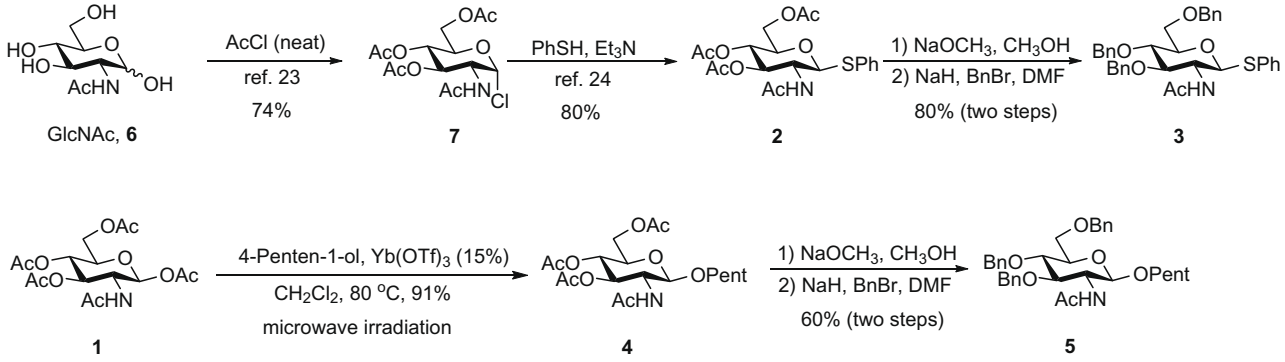


Scheme 1. Direct chemical GlcNAc-ylation; (A) acetate donor, see Ref. 4; (B) thiophenyl and pentenyl donors, present study.



Scheme 2. Preparation of thiophenyl and pentenyl donors **2**–**5**.

corresponding crude triols gave the semi-armed donors **3** and **5**, respectively. Considering the possibility of NHAc-alkylation using this benzylation procedure the overall yield for protecting group interchange was acceptable and in our hands superior to the $Ba(OH)_2$/BaO/BnBr-protocol.[25]

Glycosylation was first explored with disarmed thioglycoside donor **2** and 1-octanol as the acceptor at reflux in CH_2Cl_2 (Table 1, entries 1–6). All metal triflates tested resulted in immediate colour change of the reaction mixture and full conversion of the starting material to the expected oxazoline intermediate as indicated by thin layer chromatography (TLC) analysis. The yield of the product glycoside (**8**) was found largely to be independent of the catalyst used, with $Cu(OTf)_2$ giving slightly higher yield (76%) than the other metal triflates (Sc(III), Yb(III), Zn(II) and Mg(II)) investigated, with $Zn(OTf)_2$ giving the lowest isolated yield (52%). As previously found for the activation of the acetylated acetate donor **1**, the more Lewis acidic $Sc(OTf)_3$[26] proved to be the most active catalyst investigated with $Yb(OTf)_3$, $Cu(OTf)_2$ and $Zn(OTf)_2$ being less active. $Mg(OTf)_2$ was found to be the least active catalyst tested in the reaction with NIS/**2** only fully consuming the oxazoline intermediate by TLC analysis after 9.5 h. Interestingly, $Yb(OTf)_3$ has previously been found to be significantly less active than both $Sc(OTf)_3$ and $Cu(OTf)_2$ in the activation of **1**.[4] This order of reactivity may indicate that $Yb(OTf)_3$ is a more reactive catalyst for the activation of the intermediate oxazoline[5] than $Cu(OTf)_2$, while the opposite holds true for the activation of acetate donor **1**.[4] As indicated by TLC analysis of the two types of reactions (Scheme 1 A vs B) this originates from the resting state of the thioglycoside activation being the oxazoline, while for the acetate activation it is the acetate itself.

As a more challenging acceptor, the secondary alcohol (−)-menthol was chosen for direct GlcNAc-ylation with acetylated thioglycoside **2** promoted by NIS in combination with $Sc(OTf)_3$, $Cu(OTf)_2$, or $Yb(OTf)_3$ resulting in a noteworthy drop in both yield and reaction time. The reaction conditions, however, still successfully produced the expected glycoside product in acceptable yields around 50% (Table 1, entries 7–9).

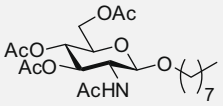
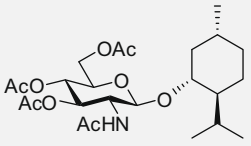
To investigate the effect of *O*-protecting groups on reactivity and glycosylation yield a similar series of reactions was carried out with the benzylated thioglycoside donor **3** (Scheme 1B). Full activation was found to proceed smoothly at ambient temperature indicating an increased reactivity of ether protected over ester-protected glycosyl donors in accordance with the armed/disarmed principle[27] and relative reactivity values.[28]

As the expected intermediate oxazoline (Scheme 1B) did not appear to be stable to TLC analysis hampering reaction monitoring, the acceptor (1-octanol) was chosen to be the limiting reagent (Table 2, entries 1–5). Only moderate yields (39–54%) being largely independent of the catalyst could be isolated under these conditions. Upon $Cu(OTf)_2$-promoted reaction with secondary acceptor (−)-menthol, a further drop in yield to 28% was observed (Table 2, entry 8).

However, changing the reaction stoichiometry by making the thioglycoside (**3**) donor the limiting reagent a significant yield improvement in both reactions with 1-octanol (Table 2, entry 6) and (−)-menthol (Table 2, entry 9) was observed. Conducting the reaction at reflux in CH_2Cl_2 had an insignificant effect on octyl glycoside formation (Table 2, entry 7).

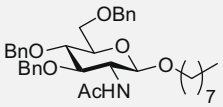
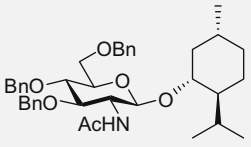
We next undertook a study of GlcNAc pentenyl donors **4** and **5** in combination with NIS/metal triflate promoters under similar

Table 1
Glycosylation results obtained in CH_2Cl_2, $M(OTf)_x$ 15 mol % with respect to thioglycoside donor **2**

Entry	Donor	Acceptor	Product	D/A[a]	Activation	Temp	Time (h)	Yield[b] (%)
1	**2**	1-Octanol	 **8**	1:3	$Sc(OTf)_3$ NIS	Reflux	2	67
2	**2**	1-Octanol	**8**	1:3	$Yb(OTf)_3$ NIS	Reflux	3	65
3	**2**	1-Octanol	**8**	1:3	$Cu(OTf)_2$ NIS	Reflux	4.5	76
4	**2**	1-Octanol	**8**	1:3	$Zn(OTf)_2$ NIS	Reflux	4.5	52
5	**2**	1-Octanol	**8**	1:3	$Mg(OTf)_2$ NIS	Reflux	9.5	67
6	**2**	1-Octanol	**8**	1:3	$Sc(OTf)_3$ NIS	Reflux	16	69
7	**2**	(−)-Menthol	 **9**	1:2	$Yb(OTf)_3$ NIS	Reflux	23	54
8	**2**	(−)-Menthol	**9**	1:2	$Sc(OTf)_3$ NIS	Reflux	23	46
9	**2**	(−)-Menthol	**9**	1:2	$Cu(OTf)_2$ NIS	Reflux	23	50

[a] Donor/acceptor ratio.
[b] Isolated yield.

Table 2
Glycosylation results obtained in CH_2Cl_2, $M(OTf)_x$ 15 mol % with respect to thioglycoside donor 3

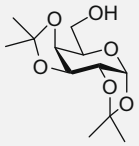
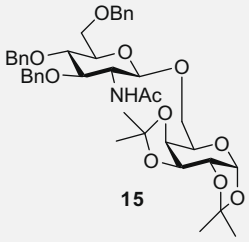
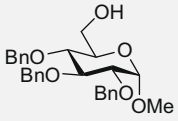
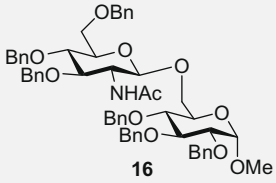
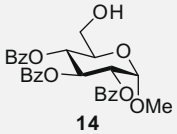
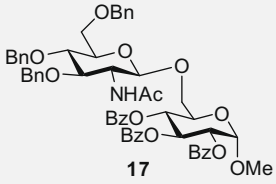
Entry	Donor	Acceptor	Product	D/A[a]	Activation	Temp	Time (h)	Yield[b] (%)
1	**3**	1-Octanol	 **10**	2:1	$Sc(OTf)_3$ NIS	rt	16	39
2	**3**	1-Octanol	**10**	2:1	$Yb(OTf)_3$ NIS	rt	16	49
3	**3**	1-Octanol	**10**	2:1	$Cu(OTf)_2$ NIS	rt	16	50
4	**3**	1-Octanol	**10**	2:1	$Zn(OTf)_2$ NIS	rt	16	43
5	**3**	1-Octanol	**10**	2:1	$Mg(OTf)_2$ NIS	rt	16	54
6	**3**	1-Octanol	**10**	1:3	$Cu(OTf)_2$ NIS	rt	16	71
7	**3**	1-Octanol	**10**	1:3	$Cu(OTf)_2$ NIS	Reflux	16	70
8	**3**	(−)-Menthol	 **11**	2:1	$Cu(OTf)_2$ NIS	rt	16	28
9	**3**	(−)-Menthol	**11**	1:2	$Cu(OTf)_2$ NIS	rt	16	67

[a] Donor/acceptor ratio.
[b] Isolated yield.

conditions as described for the corresponding thioglycoside donors (vide supra). Jayaprakash and Fraser-Reid have described the successful use of $Sc(OTf)_3$ in the activation of armed and disarmed *n*-pentenyl glucoside and mannoside donors, but have also noted that milder metal triflates like $Yb(OTf)_3$ do not promote glycosylation in combination with NIS.[7]

We first investigated the activation of disarmed pentenyl donor **4** with NIS/$Sc(OTf)_3$ in the presence of 1-octanol (Table 3, entry 1). This successfully produced the octyl glycoside product although in a disappointing yield of 50%. We next turned to the more reactive, semi-armed donor **5** where GlcNAc-ylation was carried out according to the standard *modus operandi* for pentenyl

Table 3
Glycosylation results obtained in CH_2Cl_2, $M(OTf)_x$ 15 mol % with respect to pentenyl donors 4 and 5

Entry	Donor	Acceptor	Product	D/A[a]	Activation	Temp	Time	Yield[b]
1	**4**	1-Octanol	**8**	1:3	$Sc(OTf)_3$ NIS	Reflux	3 h	50
2	**5**	1-Octanol	**10**	2:1	$Sc(OTf)_3$ NIS	rt	16 h	88
3	**5**	1-Octanol	**10**	2:1	$Yb(OTf)_3$ NIS	rt	16 h	81
4	**5**	1-Octanol	**10**	2:1	$Cu(OTf)_2$ NIS	rt	16 h	84
5	**5**	1-Octanol	**10**	2:1	$Zn(OTf)_2$ NIS	rt	16 h	88
6	**5**	1-Octanol	**10**	2:1	$Mg(OTf)_2$ NIS	rt	16 h	85
7	**5**	(−)-Menthol	**11**	2:1	$Yb(OTf)_3$ NIS	rt	24 h	53
8	**5**	(−)-Menthol	**11**	2:1	$Sc(OTf)_3$ NIS	rt	25 h	65
9	**5**	(−)-Menthol	**11**	2:1	$Cu(OTf)_2$ NIS	rt	25 h	76
10	**5**	(−)-Menthol	**11**	2:1	$Mg(OTf)_2$ NIS	rt	24 h	42
11	**5**	(−)-Menthol	**11**	2:1	$Zn(OTf)_2$ NIS	rt	26 h	73
12	**5**	(−)-Menthol	**11**	2:1	TfOH NIS	rt	26 h	67
13	**5**	 **12**	 **15**	3:1	$Cu(OTf)_2$ NIS	rt	5 days	37
14	**5**	 **13**	 **16**	3:1	$Cu(OTf)_2$ NIS	rt	2 days	50
15	**5**	 **14**	 **17**	3:1	$Cu(OTf)_2$ NIS	rt	2 days	17

[a] Donor/acceptor ratio.
[b] Isolated yield.

donor glycosylation with excess donor and NIS.[7,29] As in the case of the analogous thioglycoside donor (**3**) all metal triflates were found to catalyse donor activation, which is in contrast to other pentenyl donors not being activated by $Yb(OTf)_3$ (vide supra).[7] Although the reactions were carried out at room temperature, full activation was found to occur within minutes even at 0 °C. In GlcNAc-ylation of 1-octanol, the yields were significantly higher (81–88%) compared to those of the thioglycoside examples (39-54%) but also largely independent of the metal triflate used (Table 3, entries 2–6). The pentenyl glycoside donor (**5**) was also superior in terms of yield to the analogous thioglycoside (**3**) in GlcNAc-ylation of secondary alcohol (−)-menthol where yields ranged between 42% and 76% (Table 3, entries 7–11), with $Cu(OTf)_2$ giving the best result. Traditional NIS-activation with trifluoromethanesulfonic acid (TfOH)[15] (entry 12) was also found to efficiently give the (−)-menthyl glycoside (**11**) in acceptable yield (67%).

NIS/$Cu(OTf)_2$-mediated direct GlcNAc-ylation of carbohydrate-based acceptors (**12**–**14**)[30] was next investigated with the superior pentenyl donor system (Table 3, entries 13–15) and indeed found to be possible. However, a significant drop in the yield and extension of the reaction time was observed for all three acceptors (**12**–**14**) despite them being primary alcohols. Diacetone galactose (**12**) could be GlcNAc-ylated in only 37% yield, whereas benzylated glucoside **13** gave a moderate glycosylation yield of 50%. The more electron poor primary alcohol of benzoylated glucoside **14** gave a disappointing yield of 17%.

Pentenyl glycosides and especially thioglycosides are widely used efficient donors in glycosylation reactions but this study has shown a noteworthy difference between the two types with respect to direct GlcNAc-ylation in terms of reaction yield with the former being superior. This could be a result of the pentenyl donor by-products being more benign than those arising from thioglycoside activation.

The present method of pentenyl glycoside-mediated GlcNAc-ylation appears to be equally efficient to our previously published method involving acetate donors (Scheme 1A)[4] in reaction with simple primary and secondary alcohols. In the reaction with more demanding carbohydrate-based acceptors, however, the yields seem to be somewhat diminished. We believe this to be the result of the unfavourable resting state of the pentenyl glycoside method, which according to TLC analysis is the oxazoline intermediate. This, contrary to the slowly converting acetate donor **1**, produces a high concentration of the oxazoline in solution, which in the presence of less reactive alcohols is capable of reacting as an acceptor causing unproductive dimerisation.

The results presented here clearly demonstrate that it is possible to perform direct GlcNAc-ylation with traditionally used pentenyl and thioglycoside donors and exclusively obtain the biologically important β-anomers. The glycosylation reaction was found to be largely independent of the choice of the metal triflate tested. The yields were found to be good in the case of simple acceptors such as 1-octanol and (−)-menthol, but moderate to poor in the case of carbohydrate-based acceptors. It, however, has to be kept in mind that several protecting group manipulation is avoided when performing direct GlcNAc-ylation, and we believe that this in certain cases can be a viable alternative to known glycosylation methods employing traditional *N*-protecting groups such as phthalimido and trichloroethylcarbamate.

3. Experimental section

All reagents except otherwise stated were used as purchased from Sigma–Aldrich without further purification. Oven-dried glassware (ca. 120 °C) was used for the reactions carried out under nitrogen or argon atmosphere. The solvents were dried according to the standard procedures prior to use.[32] Dichloromethane was dried by distillation over CaH_2. THF was dried over sodium and distilled from benzophenone. Flash chromatography was performed with Merck silica 60 (230–400 mesh) as stationary phase and TLC was performed on silica-coated aluminium plates (Merck 60 F_{254}). TLC plates were first observed in UV-light and then visualised with ceric sulphate/ammonium molybdate in 10% H_2SO_4 stain or $KMnO_4$-stain. ^{1}H NMR (400 MHz) and ^{13}C NMR (100 MHz) were recorded at a Varian Mercury 400 spectrometer. $CDCl_3$ (δ 7.26 ppm ($CHCl_3$) for proton and δ 77.16 ppm for carbon resonances) and D_2O (δ 4.79 ppm for proton) were used as internal references. Spectra were assigned based on *g*COSY, *g*HMQC and DEPT-135 experiments. MS spectra were recorded at a Micromass LC-TOF instrument by using electrospray ionisation (ESI). High resolution spectra were recorded with either of the following compounds as internal standard: (Boc-L-alanine: $C_8H_{15}NO_4Na$: 212.0899; BzGly-PheOMe: $C_{19}H_{20}N_2O_4Na$: 363.1321; BocSer(OBn)SerLeuOMe: $C_{25}H_{39}N_3O_8Na$: 532.2635; erythromycin: $C_{37}H_{67}NO_{13}Na$: 756.4510). Masses of standards and analytes are calculated and reported in Daltons for uncharged species. Melting points were measured on a Büchi B-540 instrument and are uncorrected. Optical rotation was measured on a PE-241 polarimeter and reported in units of deg·cm^2/g. Concentrations are reported in g/100 mL. Microwave experiments were carried out on a Biotage Initiator (Biotage, Sweden). Reaction times listed refer to´hold timé at the specified temperature.

3.1. Phenyl 2-acetamido-3,4,6-tri-*O*-acetyl-2-deoxy-1-thio-β-D-glucopyranoside (2)

Thiophenol (1.80 mL, 17.6 mmol) and triethylamine (4.20 mL, 30.1 mmol) were added to 2-acetamido-3,4,6-tri-*O*-acetyl-2-deoxy-α-D-glucopyranosyl chloride (**7**)[23] (5.483 g, 15.0 mmol) in dry MeCN (60 mL). The reaction mixture was stirred at room temperature under an atmosphere of nitrogen. After 2 h, TLC analysis showed full conversion of the starting material. The mixture was diluted with CH_2Cl_2, washed with aq HCl (0.5 M), water, brine, dried ($MgSO_4$), filtered and concentrated. Column chromatography (CH_2Cl_2/EtOAc 1:1→1:2→1:4→EtOAc) gave the phenyl thioglycoside **3** as a white solid (5.197 g, 80%). R_f (EtOAc/CH_2Cl_2 1:3) 0.46. Mp 205–206 °C. ^{1}H NMR ($CDCl_3$): δ 7.51–7.48 (m, 2H, Ar), 7.30–7.29 (m, 3H, Ar), 5.58 (d, 1H, $J_{NH,2}$ 9.6 Hz, NH), 5.22 (t, 1H, *J* 9.6 Hz, H-3), 5.05 (t, 1H, H-4), 4.85 (d, 1H, $J_{1,2}$ 9.6 Hz, H-1), 4.21 (dd, 1H, $J_{5,6a}$ 5.4 Hz, $J_{6a,6b}$ 12.2 Hz, H-6a), 4.16 (dd, 1H, $J_{5,6b}$ 2.6 Hz, H-6b), 4.02 (q, 1H, *J* 9.6 Hz, H-2), 3.72 (ddd, 1H, $J_{5,6b}$ 2.6 Hz, $J_{5,6a}$ 5.4 Hz, $J_{4,5}$ 9.6 Hz, H-5), 2.07, 2.02, 2.01, 1.98 (s, 12H, COC*H*$_3$). ^{13}C NMR ($CDCl_3$): δ 171.2, 170.8, 170.2, 169.5 (*C*OCH$_3$), 132.7, 129.1, 128.3, (Ar), 86.9 (C-1), 76.0 (C-5), 73.9 (C-3), 68.6 (C-4), 62.6 (C-6), 53.6 (C-2), 23.6, 21.0, 20.9, 20.8 (CO*C*H$_3$). LRMS(ES+): calcd for $C_{20}H_{25}O_8NSNa$: 462.1; found: 462.1. The spectral data were in accordance with the previously published values, see Ref. 24.

3.2. Phenyl 2-acetamido-3,4,6-tri-*O*-benzyl-2-deoxy-1-thio-β-D-glucopyranoside (3)

Sodium methoxide (0.5 M in MeOH) (2.0 mL, 1.00 mmol) was added to a suspension of acetyl-protected thiophenyl glycoside **2** (3.629 g, 8.26 mmol) in dry MeOH (50 mL). The reaction mixture was stirred at room temperature under an atmosphere of nitrogen. After 10 min, an aliquot of the precipitated product was analysed by NMR, which showed the reaction completion. The mixture was concentrated and co-evaporated several times with toluene to give the deprotected thioglycoside as a white solid (2.816 g crude). This was pure enough for further reaction. R_f (MeOH/EtOAc 1:2) 0.57. ^{1}H NMR (D_2O): δ 7.50–7.48 (m, 2H, Ar), 7.31–7.23 (m, 3H, Ar), 4.78 (d, 1H, $J_{1,2}$ 10.4 Hz, H-1), 3.87 (dd, 1H, $J_{5,6a}$ 2.4 Hz, $J_{6a,6b}$ 12.4 Hz, H-6a), 3.76 (dd, 1H, $J_{2,3}$ 9.6 Hz, $J_{1,2}$ 10.4 Hz, H-2), 3.68 (dd, $J_{5,6b}$ 5.6 Hz, H-6b), 3.49–3.32 (m, 3H, H-3, H-4, H-5), 1.99 (s, 3H, COC*H*$_3$). The deprotected thioglycoside (2.816 g crude) was dissolved in dry DMF (35 mL) and cooled to 0 °C before sodium hydride (60% in mineral oil) (1.00 g, 25.0 mmol) and benzyl bromide (3.90 mL, 32.8 mmol) were added. The reaction mixture was stirred under an atmosphere of nitrogen and allowed to warm to room temperature. TLC analysis after 22 h indicated incomplete reaction. Additional sodium hydride (60% in mineral oil) (329 mg, 8.22 mmol) was added. After five days, the reaction mixture was diluted with water and then EtOAc causing precipitation. The aqueous phase was removed and the organic phase was filtered. The precipitated product was washed repeatedly with water and then co-evaporated several times with toluene. The organic filtrate was washed alternately with water and brine, dried ($MgSO_4$), filtered and concentrated. The combined crude mixture was purified by column chromatography (EtOAc/CH_2Cl_2 5:95→8:92) to give the benzylated thioglycoside **3** as a white solid (3.854 g, 80% over two steps). R_f (EtOAc/pentane 1:1.5) 0.31. Mp 177–181 °C. $[\alpha]_D^{23}$ 14.5 (*c* 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 7.52–7.49 (m, 2H, Ar), 7.34–7.21 (m, 18H, Ar), 5.35 (d, 1H, $J_{NH,2}$ 8.4 Hz, NH), 5.05 (d, 1H, $J_{1,2}$ 10.0 Hz, H-1), 4.83 (d, 1H, ^2J 12.0 Hz, OC*H*$_2$Ph), 4.80 (d, 1H, ^2J 12.0 Hz, OC*H*$_2$Ph), 4.64 (d, 1H, ^2J 12.0 Hz, OC*H*$_2$Ph), 4.61 (d, 1H, ^2J 12.0 Hz, OC*H*$_2$Ph), 4.60 (d, 1H, ^2J 12.0 Hz, OC*H*$_2$Ph), 4.53 (d, 1H, ^2J 12.0 Hz, OC*H*$_2$Ph), 3.99 (t, 1H, *J* 9.2 Hz, H-3), 3.79 (dd, 1H, $J_{5,6a}$ 2.0 Hz, $J_{6a,6b}$ 11.2 Hz, H-6a), 3.74 (dd, 1H, $J_{5,6b}$ 4.4 Hz, H-6b), 3.66–3.58 (m, 3H, H-2, H-4, H-5), 1.87 (s, 3H, COC*H*$_3$). ^{13}C NMR ($CDCl_3$): δ 170.5 (*C*OCH$_3$), 138.5, 138.3, 133.6, 132.2, 129.1–127.7 (Ar), 85.9 (C-1), 82.5 (C-3), 79.4, 78.8 (C-3, C-4), 75.1, 75.0, 73.7 (OC*H*$_2$Ph), 69.3 (C-6), 55.6 (C-2), 23.8 (CO*C*H$_3$). HRMS(ES+): calcd for $C_{35}H_{37}O_5NSNa$: 606.2290; found: 606.2301.

3.3. 4-Pentenyl 2-acetamido-3,4,6-tri-*O*-acetyl-2-deoxy-β-D-glucopyranoside (4)

Peracetylated β-GlcNAc **1** (3.00 g, 7.7 mmol), 4-penten-1-ol (1.6 mL, 15.4 mmol) and $Yb(OTf)_3$ (720 mg, 1.16 mmol) were dissolved in dry CH_2Cl_2 (7.5 mL) in a microwave vial under nitrogen atmosphere and heated at 80 °C under microwave irradiation for 1 h. The reaction mixture was diluted with CH_2Cl_2 and washed with saturated $NaHCO_3$, dried over $MgSO_4$ and filtered. The residue was purified by column chromatography (pentane/EtOAc 2:1→EtOAc) to give the pentenyl glycoside (2.90 g, 91%) as a white solid. R_f (EtOAc) 0.43. Mp 127–129 °C, ^{1}H NMR ($CDCl_3$): δ 5.77 (m, 1H, C*H*=CH_2), 5.60 (d, 1H, $J_{NH,2}$ 8.4 Hz, N*H*), 5.29 (t, 1H, *J* 10.0 Hz, H-3), 5.00 (m, 3H, H-4, CH=CH_2), 4.66 (d, 1H, $J_{1,2}$ 8.0 Hz, H-1), 4.25 (dd, 1H, $J_{6a,5}$ 4.4 Hz, $J_{6a,6b}$ 12.0 Hz, H-6a), 4.12 (dd, 1H, $J_{6b,5}$ 2.0 Hz, H-6b), 3.84 (m, 2H, OC*H*H, H-2) 3.69 (ddd, 1H, $J_{5,6b}$ 2.4 Hz, $J_{4,5}$ 10.0 Hz, H-5) 3.48 (m, 1H, OCH*H*), 2.02 (m, 14H, –CH_2–, COCH_3), 1.66 (m, 2H, –CH_2–). ^{13}C NMR ($CDCl_3$): δ 171.0, 171.0, 170.6, 169.6 (*C*OCH$_3$), 138.1 (CH_2=*C*H$_2$), 115.2 (CH_2=*C*H$_2$), 100.9 (C-1), 72.7, 71.8, 69.3, 69.1, 62.5, 54.9 (C-2, C-3, C-4, C-5, C-6, OCH_2), 30.1, 28.8 (*C*H$_2$) 23.4, 21.0, 20.9, 20.8 (CO*C*H$_3$). LRMS(ES+) calcd for $C_{19}H_{29}NO_9Na$: 438.2; found 438.1. The spectral data were in accordance with the previously published values, see Ref. 31.

3.4. 4-Pentenyl 2-acetamido-3,4,6-*O*-tri-benzyl-2-deoxy-β-D-glucopyranoside (5)

A catalytic amount of a freshly prepared solution of $NaOCH_3$ in MeOH (1 M, 5 mL, 5 mmol) was added to acetylated pentenyl glycoside **4** (2.80 g, 7.17 mmol) in dry MeOH (20 mL) under nitrogen atmosphere. After 45 min TLC analysis indicated full consumption of the starting material and the reaction mixture was then concentrated under reduced pressure. The resulting solid was dissolved in dry DMF (25 mL) and cooled to 0 °C before NaH (60% in mineral oil) (1.13 g, 28.3 mmol) and BnBr (4.5 mL, 37.7 mmol) were added. Additional NaH (377 mg, 9.4 mmol) was added after 20 h and 92 h. The reaction mixture was then poured into water and the formed precipitate was filtered off and recrystallised from cyclohexane/EtOAc to give the benzylated glycoside (3.09 g, 60%) as a white solid. R_f (pentane/EtOAc 1:1) 0.45. Mp 129–131 °C. $[\alpha]_D^{23}$ −10.4 (*c* 1, $CHCl_3$). ^{1}H NMR ($CDCl_3$) δ 7.37–7.18 (m, 15 H, Ar*H*), 5.80 (ddt, 1H, *J* 6.8 Hz *J* 10.2 Hz *J* 17.0 Hz –C*H*=CH$_2$), 5.54 (d, 1H, $J_{NH,2}$ 8.0 Hz, N*H*), 5.00 (dd, 1H, *J* 1.4 Hz, *J* 17.0 Hz, H-5′), 4.95 (dd, 1H, *J* 1.4 Hz, *J* 10.2 Hz, H-5′), 4.83–4.77 (m, 2H, PhC*H*, H-1), 4.67–4.50 (m, 5H, PhC*H*), 4.10 (dd, 1H, *J* 1.6 Hz, *J* 8.0 Hz, H-3), 3.86 (dt, 1H, ^3J 6.4 Hz, ^2J 10.0 Hz, OCH_2(CH$_2$)$_2$), 3.77 (dd, 1H, $J_{5,6a}$ 2.2 Hz, $J_{6a,6b}$ 10.6 Hz, H-6a) 3.71 (dd, 1H, $J_{5,6b}$ 4.4 Hz, H-6b), 3.63 (t, 1H, *J* 9.0 Hz, H-4), 3.58 (ddd, 1H, $J_{4,5}$ 9.0 Hz, H-5), 3.47 (dt, 1H, ^3J 6.4 Hz, ^2J 13.6 Hz, OCH_2(CH$_2$)$_2$), 3.42–3.35 (m, 1H, H-2), 2.09 (m, 2H, CH_2), 1.85 (s, 3H, HNCOCH_3), 1.65 (m, 2H, CH_2). ^{13}C NMR ($CDCl_3$) δ 170.5 (*C*OCH$_3$), 138.7, 138.4, 138.3, 138.3 (*ipso*-C, *C*H=CH$_2$), 128.7, 128.6, 128.6, 128.2, 128.1, 128.0, 127.8 (Ar), 115.2 (CH=*C*H$_2$), 100.1 (C-1), 80.5, 79.8, 75.0, 74.8, 73.7, 69.3, 69.1 (C-2, C-3, C-4, C-5, C-6, PhCH_2), 57.1, 30.3, 29.0 (*C*H$_2$), 23.8 (CO*C*H$_3$). HRMS(ES+) calcd for $C_{34}H_{41}O_6Na$: 582.2828; found 582.2825.

3.5. General procedure for the coupling of glycosyl donors to various acceptors

Donor **2**, **3**, **4** or **5** (100 or 200 mg, 1 equiv), *N*-iodosuccinimide[32] (2.5 equiv), acceptor and $M(OTf)_x$ (0.15 equiv) were dissolved in dry CH_2Cl_2 (2.0 mL) and heated to reflux (in the case of **2** and **4**) or stirred at ambient temperature (in the case of **3** and **5**) under an atmosphere of nitrogen. When no further reaction development was observed by TLC analysis, the mixture was diluted with CH_2Cl_2, washed with aq $Na_2S_2O_3$/$NaHCO_3$, brine, dried ($MgSO_4$), filtered and concentrated. the products were purified by column chromatography on silica.

3.6. *n*-Octyl 2-acetamido-3,4,6-tri-*O*-acetyl-2-deoxy-β-D-glucopyranoside (8)

White solid. R_f (pentane/EtOAc 1:2) 0.27. Mp 124–126 °C. ^{1}H NMR ($CDCl_3$): δ 5.97 (d, 1H, $J_{NH,2}$ 8.8 Hz, NH), 5.27 (dd, 1H, $J_{2,3}$ 9.2 Hz, $J_{3,4}$ 10.2 Hz, H-3), 5.01 (t, 1H, *J* 10.2 Hz, H-4), 4.66 (d, 1H, $J_{1,2}$ 8.0 Hz, H-1), 4.22 (dd, 1H, $J_{5,6a}$ 4.8 Hz, $J_{6a,6b}$ 12.2 Hz, H-6a), 4.08 (dd, 1H, $J_{5,6b}$ 2.4 Hz, H-6b), 3.82–3.76 (m, 2H, H-2, OCH_2), 3.68 (ddd, 1H, H-5), 3.43 (dt, 1H, ^2J 9.6 Hz, ^3J 6.8 Hz, OCH_2), 2.03, 1.98, 1.97, 1.89 (s, 12H, COCH_3), 1.51 (br s, 2H, OCH$_2$CH_2), 1.20 (br s, 10 H, OCH$_2$CH$_2$(CH_2)$_5$CH$_3$), 0.82 (t, 3H, *J* 7.0 Hz, O(CH$_2$)$_7$CH_3). ^{13}C NMR ($CDCl_3$): δ 171.0, 170.9, 170.5, 169.6 (*C*OCH$_3$), 100.9 (C-1), 72.7 (C-3), 71.9 (C-5), 70.1 (OCH_2), 69.1 (C-4), 62.5 (C-6), 54.9 (C-2), 32.0, 29.6, 29.5, 29.4, 26.0 (*C*H$_2$), 23.4 (COCH$_3$) 22.8 (*C*H$_2$), 20.9, 20.9, 20.8 (COCH_3), 14.3 (O(CH$_2$)$_7$CH_3). LRMS (ES+): calcd for $C_{22}H_{37}O_9NNa$: 482.2; found: 482.2. The spectral data were in accordance with the previously published values, see Ref. 33.

3.7. (−)-Menthyl 2-acetamido-3,4,6-tri-*O*-acetyl-2-deoxy-β-D-glucopyranoside (9)

White solid. R_f (pentane/EtOAc 1:2) 0.30. Mp 201–204 °C. ^{1}H NMR ($CDCl_3$): δ 5.53 (d, 1H, $J_{NH,2}$ 8.8 Hz, NH), 5.40 (dd, 1H, $J_{3,4}$ 9.6 Hz, $J_{2,3}$ 10.8 Hz, H-3), 5.01 (t, 1H, *J* 9.6 Hz, H-4), 4.79 (d, 1H, $J_{1,2}$ 8.4 Hz, H-1), 4.17 (dd, 1H, $J_{5,6a}$ 5.6 Hz, $J_{6a,6b}$ 11.8 Hz, H-6a), 4.10 (dd, 1H, $J_{5,6b}$ 2.8 Hz, H-6b), 3.71–3.62 (m, 2H, H-2, H-5), 3.39 (dt, 1H, *J* 4.4 Hz, *J* 10.8 Hz, C*H*OGlcNAc), 2.22 (d septet, 1H, *J* 2.4 Hz, *J* 6.8 Hz, C*H*(CH$_3$)$_2$), 2.04, 2.01, 2.01, 1.93 (s, 12H, COCH_3), 1.89 (m, 1H, H-6′eq), 1.64–1.60 (m, 2H), 1.33 (m, 1H), 1.18 (m, 1H), 0.96–0.75 (m, 3H), 0.89 (d, 3H, *J* 6.8 Hz, CH$_3$CHCH_3), 0.85 (d, 3H, *J* 7.2 Hz, CH_3CHCH$_3$), 0.72 (d, 3H, *J* 7.2 Hz, CH_3). ^{13}C NMR ($CDCl_3$): δ 170.9, 170.8, 170.3, 169.7 (*C*OCH$_3$), 98.3 (C-1), 78.7 (*C*HOGlcNAc), 72.5 (C-3), 71.5 (C-5), 69.4 (C-4), 62.8 (C-6), 55.6 (C-2), 47.7, 40.9, 34.4, 31.6, 25.1, 23.5 (COCH$_3$), 23.1, 22.4, 21.1, 20.9, 20.8, 20.8 (COCH$_3$), 15.5. HRMS(ES+): calcd for $C_{24}H_{39}O_9NNa$: 508.2523; found: 508.2517. The spectral data were in accordance with the previously published values, see Ref. 34.

3.8. *n*-Octyl 2-acetamido-3,4,6-tri-*O*-benzyl-2-deoxy-β-D-glucopyranoside (10)

White solid. R_f (pentane/EtOAc 1:1) 0.55. Mp 115–118 °C. $[\alpha]_D^{23}$ 14.2 (*c* 1.0, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 7.35–7.19 (m, 15H, Ar), 5.56 (d, 1H, $J_{NH,2}$ 8.0 Hz, NH), 4.82 (d, 1H, ^2J 11.4 Hz, OCH_2Ph), 4.82 (d, 1H, $J_{1,2}$ 8.0 Hz, H-1), 4.78 (d, 1H, ^2J 11.4 Hz, OCH_2Ph), 4.67 (d, 1H, ^2J 11.4 Hz, OCH_2Ph), 4.62 (d, 1H, ^2J 12.2 Hz, OCH_2Ph), 4.58 (d, 1H, ^2J 11.4 Hz, OCH_2Ph), 4.55 (d, 1H, ^2J 12.2 Hz, OCH_2Ph), 4.13 (dd, 1H, $J_{2,3}$ 8.0 Hz, $J_{3,4}$ 9.6 Hz, H-3), 3.85 (dt, 1H, ^3J 6.8 Hz, ^2J 9.6 Hz, OCH_2(CH$_2$)$_6$CH$_3$), 3.77 (dd, 1H, $J_{5,6a}$ 2.4 Hz, $J_{6a,6b}$ 11.0 Hz, H-6a), 3.72 (dd, 1H, $J_{5,6b}$ 4.4 Hz, H-6b), 3.65-3.58 (m, 2H, H-4, H-5), 3.45 (dt, 1H, ^3J 6.8 Hz, ^2J 9.6 Hz, OCH_2(CH$_2$)$_6$CH$_3$), 3.38 (q, 1H, *J* 8.0 Hz, H-2), 1.85 (s, 3H, COCH_3), 1.56 (br s, 2H, OCH$_2$CH_2(CH$_2$)$_5$CH$_3$), 1.26 (br s, 10H, OCH$_2$CH$_2$(CH_2)$_5$CH$_3$), 0.88 (t, 3H, *J* 6.4 Hz, O(CH$_2$)$_7$CH_3). ^{13}C NMR ($CDCl_3$): δ 170.5, (*C*OCH$_3$), 138.8, 138.5, 138.3, 128.7–127.8, 100.0 (C-1), 80.6 (C-3), 79.0, 75.0 (C-4, C-5), 74.8, 74.8, 73.7 (OCH_2Ph), 69.9 (OCH_2(CH$_2$)$_6$CH$_3$), 69.3 (C-6), 57.4 (C-2), 32.1, 29.8, 29.6, 29.5, 26.2 (*C*H$_2$), 23.8 (COCH$_3$) 22.9 (1 *C*H$_2$), 14.3 (O(CH$_2$)$_7$CH$_3$). HRMS(ES+): calcd for $C_{37}H_{49}O_6NNa$: 626.3458; found: 626.3453.

3.9. (−)-Menthyl 2-acetamido-3,4,6-tri-*O*-benzyl-2-deoxy-β-D-glucopyranoside (11)

Colourless oil. R_f (pentane/EtOAc 1:2) 0.29. $[\alpha]_D^{23}$ −5.6 (*c* 1.0, $CHCl_3$). ^1H NMR ($CDCl_3$): δ 7.19–7.11 (m, 15H, Ar), 5.53 (d, 1H, $J_{NH,2}$ 7.2 Hz, NH), 4.95 (d, 1H, $J_{1,2}$ 8.4 Hz, H-1), 4.85 (d, 1H, ^2J 12.0 Hz, OCH_2Ph), 4.81 (d, 1H, ^2J 11.2 Hz, OCH_2Ph), 4.67 (d, 1H, ^2J 12.0 Hz, OCH_2Ph), 4.64 (d, 1H, ^2J 11.2 Hz, OCH_2Ph), 4.62 (d, 1H, ^2J 12.2 Hz, OCH_2Ph), 4.54 (d, 1H, ^2J 12.2 Hz, OCH_2Ph), 4.33 (dd, 1H, $J_{2,3}$ 8.8 Hz, $J_{3,4}$ 9.6 Hz, H-3), 3.75 (dd, 1H, $J_{5,6a}$ 4.2 Hz, $J_{6a,6b}$ 11.0 Hz, H-6a), 3.69 (dd, 1H, $J_{5,6b}$ 1.8 Hz, H-6b), 3.62 (t, 1H, *J* 9.6 Hz, H-4), 3.51 (ddd, 1H, H-5), 3.42 (dt, 1H, *J* 4.4 Hz, *J* 10.8 Hz, C*H*OGlcNAc), 3.13 (m, 1H, H-2), 2.31 (d septet, 1H, *J* 2.8 Hz, *J* 7.2 Hz, C*H*$(CH_3)_2$), 1.93 (m, 1H), 1.84 (s, 3H, COCH_3), 1.64–1.61 (m, 2H), 1.32 (m, 1H), 1.18 (m, 1H), 0.97–0.74 (m, 3H), 0.89 (d, 3H, *J* 6.0 Hz, CH_3CHCH_3), 0.88 (d, 3H, *J* 7.2 Hz, CH_3CHCH_3), 0.79 (d, 3H, *J* 6.8 Hz, CH_3). ^{13}C NMR ($CDCl_3$): δ 170.6 (*C*OCH$_3$), 139.0, 138.6, 138.5, 128.6–127.7 (Ar), 97.5 (C-1), 80.7 (C-3), 79.4 (C-4), 78.3, 75.0 (C-5, OCH_2Ph), 73.9 (OCH_2Ph), 69.5 (C-6), 58.8 (C-2), 48.1, 41.1, 34.6, 31.6, 25.3, 23.8 (COCH_3), 23.3, 22.5 (CH_3), 21.3 (CH_3), 16.0 (CH_3). HRMS(ES+): calcd for $C_{39}H_{51}O_6NNa$: 652.3614; found: 652.3611.

3.10. 6-*O*-(2-Acetamido-3,4,6-tri-*O*-benzyl-2-deoxy-β-D-glucopyranosyl)-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (15)

Colourless syrup. Purified by column chromatography (pentane/EtOAc 3:1→1:1). R_f 0.25 (pentane/EtOAc 2:1). ^1H NMR ($CDCl_3$) δ 7.34–7.17 (m, 15H, Ar*H*), 5.55 (d, 1H, $J_{NH,2}$ 8.0 Hz, N*H*), 5.50 (d, 1H, $J_{1,2}$ 5.2 Hz, H-1), 4.80 (d, 1H, ^2J 11.2 Hz, PhC*H*) 4.76 (d, 1H, ^2J 11.2 Hz, PhC*H*), 4.70 (d, 1H, *J* 7.6 Hz, H-1′), 4.68 (d, 1H, ^2J 11.6 Hz, PhC*H*), 4.62 (d, 1H, ^2J 12.0 Hz, PhC*H*), 4.57–4.51 (m, 3H, PhC*H*, H-3), 4.28 (dd, 1H, H-2), 4.16 (dd, 1H, *J* 1.6 Hz, *J* 6.4 Hz, H-6′a), 4.00 (dd, 1H, *J* 3.6 Hz, *J* 7.2 Hz, H-6a), 3.96–3.88 (m, 2H, H-4, H-2′), 3.76–3.64 (m, 4H, H-3′, H-4′, H-5, H-6′b), 3.57–3.53 (m, 1H, H-5), 1.89 (s, 3H, COCH_3), 1.50, 1.41, 1.30, 1.29 (s, 12H, CH_3). ^{13}C NMR ($CDCl_3$) δ 170.8 (*C*OCH$_3$), 138.7, 138.5, 138.4 (*ipso-C*) 128.6, 128.6, 128.3, 128.1, 128.0, 128.0, 127.9, 127.8 (Ar), 109.6, 108.9 ((CH$_3$)$_2$CO$_2$), 101.4 (C-1′), 96.5 (C-1), 81.5, 78.6, 75.2 (PhCH), 74.9, 74.7, 73.7, 71.4, 70.9, 70.7, 69.2, 69.0, 68.1 (C-2, C-3, C-3′, C-4, C-4′, C-5, C-5′, C-6, C-6′), 56.4 (C-2′), 26.3, 26.2, 25.3, 24.6, 23.8 ((CH_3)$_2$CO$_2$, COCH_3). LRMS(ES+) calcd for $C_{41}H_{51}NO_{11}Na$: 756.34; found 756.3. The spectral data were in accordance with the previously published values, see Ref. 35.

3.11. Methyl O-(2-*N*-acetamido-2-deoxy-3,4,6-tri-*O*-benzyl-β-D-glucopyranosyl)-(1→6)-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside (16)

Colourless syrup. Purified by column chromatography (CH_2Cl_2/EtOAc, 5:1). R_f 0.19 (CH_2Cl_2/EtOAc 5:1). ^1H NMR ($CDCl_3$) δ 7.36–7.20 (m, 30H, Ar*H*), 5.45 (d, 1H, $J_{NH,2}$ 7.8 Hz, N*H*), 4.98 (d, 1H, ^2J 11.2 Hz, PhC*H*), 4.85 (d, 1H, $J_{1,2}$ 7.8 Hz, H-1′), 4.83 (d, 1H, ^2J 10.8 Hz, PhC*H*), 4.82 (d, 1H, ^2J 10.8 Hz, PhC*H*), 4.81 (d, 1H, ^2J 11.6 Hz PhC*H*), 4.78 (d, 1H, ^2J 12.0 Hz, PhC*H*), 4.65 (d, 1H, ^2J 12.4 Hz, PhC*H*), 4.64 (d, 1H, ^2J 11.6 Hz, PhC*H*), 4.60 (d, 1H, ^2J 11.2 Hz, PhC*H*), 4.59 (d, 1H, ^2J 10.8 Hz, PhC*H*), 4.58 (d, 1H, ^2J 10.8 Hz, PhC*H*), 4.55–4.50 (m, 2H, PhC*H*, H-1), 4.10 (dd, 1H, *J* 1.6 Hz, *J* 10.4 Hz, H-6a), 3.99 (t, 1H, *J* 9.2 Hz, H-3′), 3.79–3.66 (m, 4H, H-2′, H-3, H-4′, H-6′b), 3.61–3.60 (m, 2H, H-5′, H-6′a), 3.45 (q, 1H, *J* 7.8 Hz, H-2′), 3.56–3.50 (m, 2H, H5, H6b), 3.36 (s, 3H, OCH_3), 1.72 (s, 3H, COCH_3). ^{13}C NMR ($CDCl_3$) δ 170.4 (*C*OCH$_3$), 139.1, 138.7, 138.6, 138.5, 138.4, 138.3 (*ipso*-Ar*C*), 128.7, 128.7, 128.6, 128.6, 128.4, 128.2, 128.2, 128.1, 128.1, 128.1, 128.0, 128.0, 127.9, 127.8, 127.8, 127.7 (Ar) 100.1 (C-1′), 98.3 (C-1) 82.3, 80.4, 80.0, 79.0, 77.9, 76.0, 75.2, 75.0, 74.8, 74.8, 73.6, 69.8, 69.4, 67.7 (PhCH, C-3, C-3′, C-4, C-4′, C-5, C-5′, C-6, C-6′, OCH$_3$) 57.0, 55.3 (C-2, C-2′) 23.8 (COCH$_3$). LRMS(ES+) calcd for $C_{57}H_{63}NO_{11}Na$: 960.43; found 960.4. The spectral data were in accordance with the previously published values, see Ref. 36.

3.12. Methyl *O*-(2-*N*-acetamido-2-deoxy-3,4,6-tri-*O*-benzyl-β-D-glucopyranosyl)-(1→6)-2,3,4-tri-*O*-benzoyl-α-D-glucopyranoside (17)

Colourless syrup. Purified by column chromatography (CH_2Cl_2/EtOAc 8:1). R_f 0.23 (CH_2Cl_2/EtOAc 8:1). ^1H NMR ($CDCl_3$) δ 7.89 (d, 2H, *J* 7.6 Hz, Ar*H*), 7.85 (d, 2H, *J* 7.6 Hz, Ar*H*), 7.75 (d, 2H, *J* 7.6 Hz, Ar*H*), 7.47–7.10 (m, 24H, Ar*H*), 6.06 (t, 1H, $J_{3,4}$ 9.6 Hz, H-3 or H-4), 5.89 (d, 1H, $J_{NH,2}$ 8.0 Hz, N*H*), 5.54 (t, 1H, $J_{3,4}$ 9.6 Hz, H-3 or H-4), 5.18–5.14 (m, 2H, H1, H2) 4.72 (t, 2H, ^2J 10.8 Hz, PhC*H*), 4.64 (d, 1H, ^2J 11.6 Hz, PhC*H*), 4.48 (d, 1H, ^2J 12.4 Hz, PhC*H*), 4.48 (d, 1H, ^2J 12.4 Hz, PhC*H*), 4.40–4.41 (m, 2H, PhC*H*, H-1′), 4.13–4.05 (m, 2H, H-2′, H-4′), 3.83–3.78 (m, 1H, H-6a), 3.71 (q, 1H, *J* 8.0 Hz, H-3′), 3.63 (dd, 1H, $J_{6a,5}$ 2.4 Hz $J_{6a,6b}$ 10.8 Hz, H-6′a), 3.60–3.53 (m, 2H, H6′b, H6b), 3.48 (dd, *J* 4.0 Hz, *J* 11.2 Hz, H-5), 3.42 (ddd, 1H, *J* 5.2 Hz, *J* 10.8 Hz, H-5′), 3.37 (s, 3H, OCH_3), 1.87 (s, 3H, COCH_3). ^{13}C NMR ($CDCl_3$) δ 170.7 (*C*OCH$_3$), 165.9 (PhCO), 138.7, 138.4, 138.3, 133.9, 133.5, 133.3 (*ipso-C*), 130.1, 130.1, 129.8, 129.5, 129.4, 129.0, 128.8, 128.6, 128.6, 128.5, 128.3, 128.1, 128.0, 127.9, 127.8 (Ar), 101.5 (C-1′), 97.2 (C-1), 81.9, 78.6, 75.4, 74.9, 73.6, 72.2, 71.0, 69.4, 69.2, 68.6, 68.0, 56.4 (C-3, C-3′, C-4, C-4′, C-5, C-5′, C-6, C-6′, PhCH, OCH$_3$), 55.8, 53.7 (C-2, C-2′), 23.7 (COCH$_3$). HRMS(ES+): calcd for $C_{57}H_{57}NO_{14}Na$: 1002.3677; found 1002.3655.

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