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Synthesis of glycosylated-β(1-4)-amino(methoxy) and -oxyamino carbohydrate analogues

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Abstract—The synthesis of new oligosaccharides containing nitrogen or oxygen–nitrogen in interglycosidic linkage is described. Several modified β-*N*- and β-*O*-*N* linked disaccharides with glucose or galactose as reducing unit such as lactose or cellobiose analogues have been prepared stereoselectively using two different methods. All these compounds were fully characterised by one and two dimensional NMR studies, mass spectroscopy and the crystallographic structure of Gal-β-*N*-(1,4)-Gal derivative **10** was obtained. These type of structural modifications of oligosaccharides could be useful for study of various biochemical processes.

1. Introduction

Carbohydrates have subjected to an increasing interest during the last few years because of their role in various biological activities starting from fertilisation to pathological processes such as tumour growth.[1] As a result, considerable efforts have been expanded in design, synthesis and testing enzyme inhibitors or mimic of carbohydrate–protein interactions. As the conformation of an oligosaccharide depends largely on the glycosidic linkage, many structural modifications affect the interglycosidic atom. Particularly some analogues containing carbon[2] or sulphur[3] have been synthesised as useful tool for study of enzymatic process and have an attracted interest as hydrolytically stable analogues of *O*-saccharides. Only few examples of so called pseudo-sugar containing nitrogen[4] are described in literature which appear as very promising compounds yet. Generally, some carbohydrate mimics containing exocyclic nitrogen atom namely aza- or iminosugars[5] are known to be protonated in the enzyme active site and act as efficient glycosidase inhibitors because of their ability to mimic the shape or charge of the presumed transition state for enzymatic glycoside hydrolysis. Some other sugar analogue like acarbose[6] carrying nitrogen atom between sugar and pseudosugar is the highest known carbohydrate affinity for a binding protein and is currently used for the oral treatment of diabete.[7] Furthermore, unusual N–O interglycosidic linkage is rarely found in oligosaccharidic moiety of antitumour antibiotics esperamycin A_1[8] and calicheamicin γ_1[9] and has been suggested to play a critical conformational role for minor groove DNA binding. Recent investigations in this domain have provided elegant synthetic solutions for the construction of this crucial linkage. Consequently, these observations emphasise the need of synthetic oligosaccharidic models incorporating unnatural interglycosidic linkage for better understanding the structural and conformational features involved in various biochemical processes and protein or DNA recognition.

For this purpose, we report here the synthesis and structural characterisation of new modified oligosaccharides containing both N(OMe)- or N–O- in the glycosidic bond. Glycosylation is still a major problem in organic synthesis as no universal method has been devised for construction of glycosidic linkage. Among all the different coupling reactions strategies,[10] we report two different synthetic approaches to obtain stereoselectively β-N(OMe)- and β-O-N- linked disaccharides and present preliminary evaluation of these compounds in glycosidases inhibition tests.

2. Results and discussion

We have prepared 4-deoxy-4-methoxyaminoglycosyl sugars **5** or **6** (Scheme 1) following the method described by Tronchet et al.[11] related to the synthesis of hydroxyaminopyranosides. Methyl-α-D-glucopyranoside **1** was regioselectively stannylated[12] and then treated with benzoyl chloride to provide compound **2** with free OH-4. Oxidation of **2** with ruthenium tetroxide[13] afforded pure and crystalline product **3**[14] which was then transformed in oxime **4** by reaction with methoxyamine hydrochloride in ethanol/pyridine. Final reduction with sodium cyanoborohydride[15] at pH 3 gave 36% of galacto-**5** and 44% of gluco-**6** epimers (de=8%). In contrast, the use of triethylamine–borane

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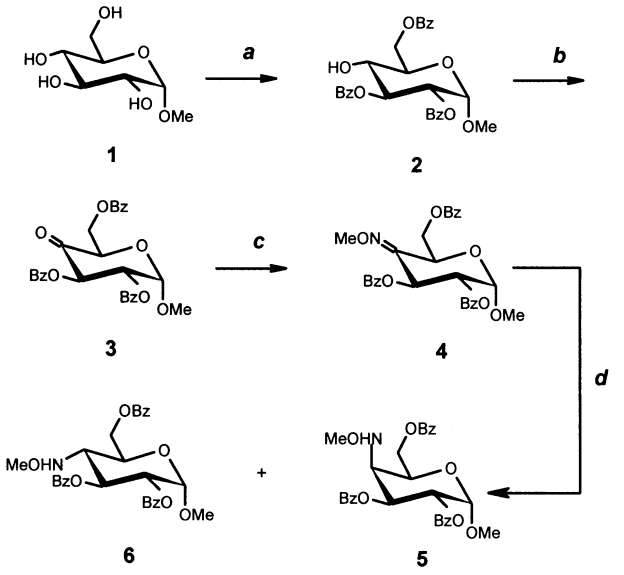


Scheme 1. *Reagents and conditions*: (a) (i) $(Bu_3Sn)_2O$, toluene, reflux; (ii) BzCl, toluene, 50°C, 85%; (b) RuO_4, CH_2Cl_2, 80%; (c) $MeONH_2{\cdot}HCl$, EtOH/pyridine, 98%; (d) $NaBH_3CN$, MeOH/HCl 6 M.

complex[16] as reducing agent was much more diastereoselective providing 90% of galacto- form **5** (de=80%).

The separation of those two diastereoisomers **5** and **6** was readily achieved by recrystallisation from CH_2Cl_2/petroleum ether and diethyl ether/petroleum ether respectively. The stereochemistry of compound **5** (Fig. 1)[17] and **6**[18] was unambiguously confirmed by X-ray studies. For compound **6**, the ring adopts a quasi-perfect $^4C_1$ chair conformation, as defined by the Cremer and Pople[19] parameters Q=0.593(3) Å, Θ=2.6(2)° and ϑ_2=195(4)°. This conformation is also adopted in solution, as outlined by the large values of the NMR coupling constants (~10 Hz). The exocyclic hydroxymethyl group adopts a staggered *gg* conformation [ω=O5–C5–C6–O6=−70.1(2)° and C4–C5–C6–O6=−52.5(2)°], which is the conformation usually observed in other structures containing gluco residues.[20]

Many procedures have been reported for the construction of glycosidic linkage but none of them involves 4-deoxy-4-methoxyaminoglycosyl derivatives as glycosidic acceptor.

Here, we demonstrated that these nucleophiles represent new building-blocks to synthesise modified disaccharides containing β-N(OMe) linkage (Scheme 2) by Koenigs–Knorr like coupling reaction.

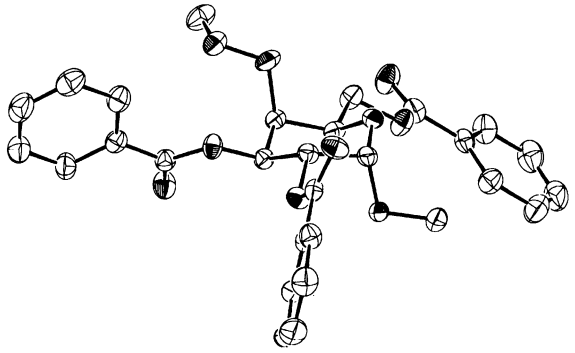


Figure 1. ORTEP drawing of compound **5**.

Furthermore, we found that this coupling reaction involving bromoglycosyl donors **7** or **8** and 4-deoxy-4-methoxy-aminoglycosyl **5** or **6** as acceptors required a very careful choice of catalyst (Table 1). Typically, glycosyl bromide donors are activated by treatment with silver or heavy metal salt. According to Lubineau et al. results,[21] we have found that disaccharides **9** and **10** were obtained the most effectively using stannous triflate as promotor in presence of collidine at room temperature (18 and 29% of yield; 46 and 70% of conversion rate, respectively).

In sharp contrast with $Sn(OTf)_2$ as catalyst, no reaction involving the 4-deoxy-4-methoxyaminoglucosyl acceptor **6** occurred. For the latter compound, the combination of silver triflate–silver carbonate[22] in nitromethane at room temperature was useful to obtain disaccharides **13** and **14** after several attempts with other catalyst. Only β-anomers were obtained as well as unreacted starting material.[23] This stereoselectivity for β glycosidic linkage results presumably from the well known anchimeric assistance of acetate group at C-2 within the glycosyl donors.

The structure and stereochemistry of disaccharides **9**, **10**, **13** and **14** were assigned by one and two dimensional NMR techniques (coupling constant between H-1 and H-2 of non-reducing sugar of 9.2 and 9.4 Hz for **9** and **10**, 8.4 and 8.9 Hz for **13** and **14** respectively are typical for the trans diaxial arrangement and corroborate the β stereochemistry), mass spectroscopy (ESI). Single crystal X-ray structure determination provided further confirmation of the structure of compound **10** (Fig. 2).[17]

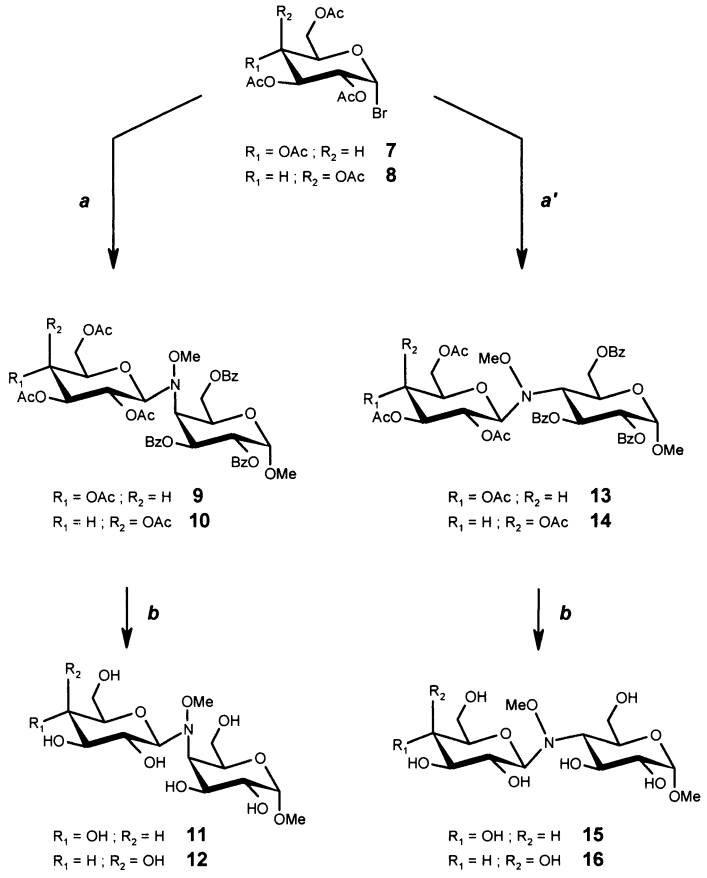
Final Zemplén de-o-acylation[24] gave pure compounds containing amino(methoxy) interglycosidic linkage **11**, **12**, **15** and **16** with quantitative yields.

To date, no route to amino-glycosylated carbohydrate have been described. Having in hands the β-N(OMe) disaccharides, we were interested to reduce the N–OMe bond to obtain the corresponding aminoglycosidic linkage and thus assess their stability. According to literature, reductive cleavage of N–O bond can be accomplished under a variety of conditions,[25] including hydrogenolysis (H_2/Pd, 1 atm, H_2, Raney nickel, 1 atm), reduction with Zn/AcOH, with $TiCl_3$, with SmI_2 or with $Mo(CO)_6$.

Unfortunately, all tried methods failed in our hands (Table 2) and no evidence for the corresponding reduced compounds was obtained.

In most cases, the starting material were recovered. In comparison, reduction of N–OMe bond of compounds **5** or **6** was achieved easily with quantitative yields. A possible explanation of this failure could be hence attributed to steric hindrance exhibited in disaccharide which prevents it to react under the numerous conditions investigated in this study.

Unusual N–O linkage is found in some few compounds



Scheme 2. *Reagents and conditions*: (a) **5**, $Sn(OTf)_2$, collidine, CH_2Cl_2, 4 Å MS, 18% (46% of conversion rate) for **9**, 29% (70% of conversion rate) for **10**; (a′) **6**, AgOTf, Ag_2CO_3, nitromethane, 4 Å MS, 10% for **13** and **14**; (b) NaOMe/MeOH, quant. yield.

such as calicheamicin γ^{I}[19] which is an extremely potent antitumour antibiotic that cleaves DNA sequence specifically. Only a few general methods of preparation of this type of linkage are described in literature.[26] For this purpose, we have adapted an efficient approach for stereoselective incorporation of this interglycosidic linkage in oligosaccharide following oxime bond formation as described by Nicolaou et al.[27] in 1990.

This method required the preparation of aminooxy glycosyl intermediate **17** and **18** that we have obtained by stereoselective phase transfer catalysed glycosylation between glycosylbromide and *N*-hydroxysuccinimide as described by Roy et al.[28] in 1995. Acetate deprotection and cleavage of the succinimide group were finally performed with hydrazine to give unprotected aminooxy derivatives **17** and **18**. The key step of the synthesis involved the selective condensation between carbonyl compound **3** and compounds **17** or **18** (Scheme 3). This reaction occurred at room temperature during 24 h in ethanol/pyridine to afford mixture of oxime bond disaccharides **19** and **20** in 52 and 35% of yield; 48% and 88% conversion rate, respectively as determined by NMR (ratio *E*/*Z* about 1/2 for **19** and 1/10 for **20**). Indeed, the coupling constant between H-3′ and H-2′ ($^3J_{2',3'}$) is more important for isomer *Z* (8.7 and 8.4 Hz for **19** and **20**) than for isomer *E* (4.8 and 5.2 Hz for **19** and **20**) due to the presence allylic $A^{1,3}$ strain involving H-3′ or H-5′ within the pyranose cycle.[29] Moreover, these coupling constant values measured are in very good agreement with previous *E*/*Z* attribution.[11] Subsequent reduction using borane–triethylamine complex[16] in dry diethyl ether saturated with HCl provided the diastereoisomer mixture of glucose and

Table 1. Yields and conditions for coupling reaction between aminooxy glycosyl acceptors and glycosyl donors

Glycosyl acceptor	Glycosyl donor	Promotor	Disaccharide	Yield (after purification) (%)
5	**7**	$Sn(OTf)_2$, collidine	**9**	18
5	**7**	AgOTf, collidine	**9**	21
5	**7**	BF_3/Et_2O, triethylamine	No reaction	–
5	**8**	$Sn(OTf)_2$, collidine	**10**	29
5	**8**	$AgOTf/Ag_2CO_3$	**10**	17
5	**8**	AgOTf, collidine	No reaction	–
6	**7**	$AgOTf/Ag_2CO_3$	**13**	10
6	**7**	$Sn(OTf)_2$, collidine	No reaction	–
6	**8**	AgOTf, collidine	No reaction	–
6	**8**	$AgOTf/Ag_2CO_3$	**14**	10

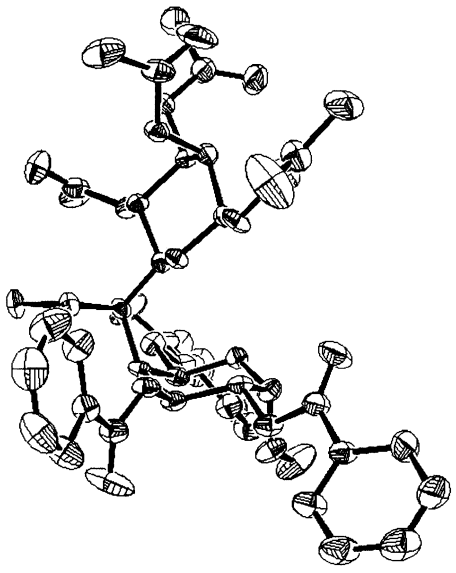


Figure 2. ORTEP drawing of compound **10**

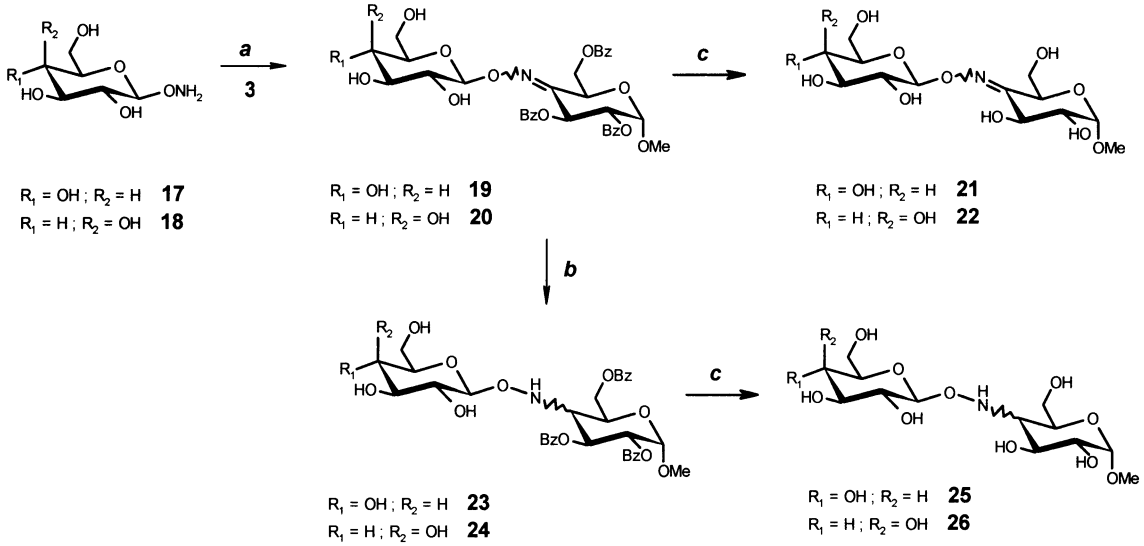
Table 2. Reaction condition for N–O reductive cleavage

Compound	Method	Result
9	H_2 1 atm, Pd/C or PdH_2O_2, MeOH	No reaction
9	H_2 1 atm, PtO_2, MeOH	No reaction
9	Zn/AcOH or AcOH/H_2O, 60°C	No reaction
9	SmI_2, THF	No reaction
9	$Mo(CO)_6$, CH_3CN, H_2O	No reaction
9	Al/Ni, KOH, MeOH	No reaction
9	$TiCl_3$, HCl	Degradation
11	H_2 1 atm, Pd/C, MeOH	No reaction
11	Zn/AcOH	No reaction
11	Al/Ni, KOH, MeOH	No reaction
10	H_2 1 atm, Pd/C, MeOH	No reaction
10	Zn/AcOH	No reaction
13	H_2 1 atm, Pd/C, MeOH	No reaction
13	Zn/AcOH	No reaction
14	H_2 1 atm, Pd/C, MeOH	No reaction
14	Zn/AcOH	No reaction

galactose derivatives **23** and **24** in very good yield (91–97%) while no reaction were performed using classical sodium cyanoborohydride method.[15] This reduction reaction favoured the galacto stereochemistry at C-4′ (de≈33%). Indeed according to NMR data, the major H-3′ signal provided coupling constant values, $^3J_{3'Gal,4'Gal}$, of 4.3 Hz for **23** as well as $^3J_{3'Gal,4'Gal}$=4.7 Hz for **24** while the minor signal exhibited much larger values ($^3J_{3'Glc,4'Glc}$=10.0 Hz for **23**; $^3J_{3'Glc,4'Glc}$=10.0 Hz for **24**). These values are typically encountered in $^4C_1$ pyranoside system with axial–equatorial or axial–axial between H-4 and H-3 proton arrangements thus inferring that here the galacto-form was obtained as the major isomer.

Further Zemplén de-o-acylation of oxime-linked disaccharides **19** and **20** as well as diastereoisomer mixtures **23** and **24** leads to pure and stable compounds **21**, **22**, **25** and **26** with quantitative yields.

Finally, the six unprotected compounds **11**, **12**, **21**, **22**, **25** and **26** have been tested for their inhibitory activities toward the following enzymes under pH and standard conditions:[30] α-L-fucosidase from bovine epididymis, α-galactosidase from coffee beans, from *Aspergillus niger* and from *Escherichia coli*, β-galactosidase from *E. coli*, from bovine liver, from *A. niger*, from *Aspergilus orizae* and from jack beans, α-glucosidase (maltase) from yeast and from rice, α-glucosidase (isomaltase) from baker yeasts, amyloglucosidase from *A. niger* and from *Rhizopus* mold, β-glucosidase from almonds and from *Caldocellum saccharolyticum*, α-mannosidase from jack beans and from almonds, β-mannosidase from *Helix pomentia*, β-xylosidase from *A. niger*, α-*N*-acetylgalactosaminidase from chiken liver and β-*N*-acetylglucosaminidase from jack bean, from bovine epididymis A and from bovine epididymis B. At 1 mM concentration (solution buffered just before use) of **11**, **12** and **25**, β-galactosidase from bovine liver was selectively inhibited by 42, 52 and 29%, respectively. **21** inhibited α-L-fucosidase from bovine epididymis by 25%. **22** and **26** were not found to have any inhibiton activity.



Scheme 3. *Reagents and conditions*: (a) EtOH/pyridine, 52% (48% of conversion rate) for **19**, 35% (88% of conversion rate) for **20**; (b) BH_3/triethylamine, Et_2O/HCl, 97–91%; (c) NaOMe/MeOH, quant. yield.

3. Conclusion

We have described here the stereoselective preparation of new type of interglycosidic linkage. For this purpose, we have prepared several original modified disaccharides **11**, **12**, **15**, **16**, **21**, **22**, **25** and **26** containing either β-1→4-*N*- or β-1→4-*O*-*N* linkage using methoxyaminoglycosyl derivatives **5** and **6** as glycosidic acceptor in Koenigs–Knorr like coupling reaction on the one hand. The stereochemistry of the β-1→4-*N*- interglycosidic linkage was confirmed by one and two dimensional NMR studies as well as by the X-ray analysis of compound **10**. On the other hand, we have developed a method of condensation between aminoxyglycosyl derivatives **17** or **18** and ketone-glycosyl **3** followed by reduction of oxime-linked disaccharides. Preliminary glycosidases inhibition assays were also initiated to evaluate enzymatic activity of such compounds. Further biological screening with these compounds are currently under investigated.

4. Experimental

4.1. Generality

All chemical reagents were purchased from Sigma Alrdich, Flucka or Acros and were used without further purification. Analytical TLC were performed on 0.2 mm silica 60 coated aluminium foils with F-254 indicator (Merck). Prep. column chromatographies were done using silica gel (Merck 60, 200–63 μm). Melting points were measured on an Electrothermal Serie IA9100 apparatus. NMR spectra were recorded on Bruker Avance spectrometers. Spectra were referenced to the residual proton solvent peaks. The exact mass spectra were recorded on a Finnigan MAT95XL spectrometer (LSIMS) using a glycerol matrix in positive mode. ES-MS analyses were performed on a VG Platform II (Micromass) in the positive ion mode.

4.1.1. Methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-4-methoxyimino-α-D-xylo-hexopyranoside (4). To a stirring solution of **3** (2.01 g, 4.0 mmol) in ethanol (40 mL) and pyridine (5 mL) was added methoxylamine hydrochloride salt (1.33 g, 16 mmol). After 4 h at 20°C, the solvent was removed in vacuo and the residue diluted with ethyl acetate, then washed with 5% solution of $NaHCO_3$ and finally with water. The organic layer was dried with sodium sulfate and evaporated to afford pure product **4** (1/4 *Z*/*E* mixture) as a colourless oil (98% yield). ^{1}H NMR (200 MHz, $CDCl_3$): δ=8.16–7.30 (m, Har.$_{Z,E}$), 6.53 (d, $^3J_{2Z,3Z}$=7.5 Hz, H-3$_Z$), 6.12 (d, $^3J_{2E,3E}$=4.8 Hz, H-3$_E$), 5.56 (dd, $^3J_{1Z,2Z}$=3.1 Hz, H-2$_Z$), 5.49 (dd, $^3J_{1E,2E}$=3.6 Hz, H-2$_E$), 5.27–5.23 (m, H-1$_E$, H-5$_{Z,E}$), 5.19 (d, H-1$_Z$), 4.95–4.61 (m, H-6$_{Z,E}$), 3.92 (s, C=NOCH$_{3E}$), 3.73 (s, C=NOCH$_{3Z}$), 3.46 (s, OCH$_{3Z}$), 3.44 (s, OCH$_{3E}$).

4.1.2. Methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-4-methoxyamino-α-D-galactopyranoside (5) and methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-4-methoxyamino-α-D-glucopyranoside (6). To a stirring solution of **4** (1.16 g, 2.2 mmol) in methanol (20 mL) was added sodium cyanoborohydride (2.74 g, 44 mmol) followed by a mixture of 6 M HCl/methanol dropwise to keep the reaction at pH 3. After 3 h the mixture was concentrated and taken up in ethyl acetate. The organic layer was washed with aqueous $NaHCO_3$ solution, dried over sodium sulfate and evaporated. Separation of each epimers was accomplished by column chromatography (CH_2Cl_2/ethyl acetate, 20/1) then recrystallisation to give **5** (0.42 g, 36% yield) from CH_2Cl_2/petroleum ether and **6** (0.51 g, 44% yield) from diethyl ether/petroleum ether. **5**: mp: 133°C; ^{1}H NMR (300 MHz, $CDCl_3$): δ=8.09–7.34 (m, 15H, Har.), 6.05 (d, 1H, $^3J_{4,NH}$=4.6 Hz, NH), 5.80 (dd, 1H, $^3J_{3,4}$=4.6 Hz, $^3J_{2,3}$=11.0 Hz, H-3), 5.50 (dd, 1H, $^3J_{1,2}$=3.8 Hz, H-2), 5.19 (d, 1H, H-1), 4.67–4.61 (m, 2H, H-6a, H-6b), 4.45 (m, 1H, H-5), 3.83 (td, 1H, $^3J_{4,5}$=1.5 Hz, H-4), 3.52 (s, 3H, HNOCH$_3$), 3.42 (s, 3H, OCH$_3$); ^{13}C NMR (75 MHz, $CDCl_3$): δ=166.4 (C=O), 166.1 (C=O), 165.8 (C=O), 133.5 (Car.), 133.4 (Car.), 133.2 (Car.), 130.0 (Car.), 129.9 (Car.), 129.8 (Car.), 128.6 (Car.), 128.5 (Car.), 97.5 (C-1), 69.6 (C-3), 69.4 (C-2), 67.9 (C-5), 65.1 (C-6), 62.0 (HNOCH$_3$), 60.2 (C-4), 55.7 (OCH$_3$); MS (ESI): *m*/*z*=536.1 (M+H)$^+$. **6**: mp: 123°C; ^{1}H NMR (300 MHz, $CDCl_3$): δ=8.12–7.34 (m, 15H, Har.), 6.17 (t, 1H, $^3J_{2,3}$=$^3J_{3,4}$=10.0 Hz, H-3), 5.91 (d, 1H, $^3J_{4,NH}$=2.1 Hz, NH), 5.20 (dd, 1H, $^3J_{1,2}$=3.6 Hz, H-2), 5.16 (d, 1H, H-1), 4.76–4.72 (m, 2H, H-6a, H-6b), 4.42 (td, 1H, $^3J_{5,6}$=3.6 Hz, $^3J_{4,5}$=10.3 Hz, H-5), 3.51 (s, 3H, OCH$_3$), 3.44 (s, 3H, HNOCH$_3$) 3.19 (bt, 1H, H-4); ^{13}C NMR (75 MHz, $CDCl_3$): δ=166.7 (C=O), 166.2 (C=O), 166.0 (C=O), 133.4 (Car.), 133.3 (Car.), 130.1 (Car.), 129.9 (Car.), 129.7 (Car.), 129.3 (Car.), 128.6 (Car.), 128.5 (Car.), 97.2 (C-1), 73.3 (C-2), 67.8 (C-3), 67.3 (C-5), 64.3 (C-6), 62.9 (HNOCH$_3$), 61.4 (C-4), 55.6 (OCH$_3$); MS (ESI): *m*/*z*=536.1 (M+H)$^+$.

4.1.3. Methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-4-methoxyamino-4-*N*-(2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl)-α-D-galactopyranoside (9). Under inert gas, a solution of **5** (0.73 g, 1.4 mmol) and collidine (0.36 mL, 2.8 mmol) in anhydrous CH_2Cl_2 (5 mL) was added to a stirring solution of **7** (1.12 g, 2.8 mmol), stannous triflate (0.85 g, 2.1 mmol) and 4 Å molecular sieves in anhydrous CH_2Cl_2 (5 mL). After one night at room temperature, the solution was filtrated, concentrated in vacuo and taken up in ethyl acetate. The organic layer was washed with aqueous $NaHCO_3$ solution and water, dried over sodium sulfate and evaporated. Column chromatography (CH_2Cl_2/ethyl acetate, 15/1) of the resulting oil gave starting material **5** (0.36 g) and coupling product **9** (0.28 g, 18% yield, 46% conversion rate) after precipitation from CH_2Cl_2/pentane. Mp: 112–114°C; ^{1}H NMR (300 MHz, $CDCl_3$): δ=8.11–7.39 (m, 15H, H′ar.), 5.80 (dd, 1H, $^3J_{3',4'}$=4.6 Hz, $^3J_{2',3'}$=10.9 Hz, H-3′), 5.08 (dd, 1H, $^3J_{1',2'}$=3.9 Hz, H-2′), 5.37 (t, 1H, $^3J_{1,2}$=$^3J_{2,3}$=9.2 Hz, H-2), 5.24 (d, 1H, H-1′), 5.22–5.18 (m, 2H, H-3, H-4), 4.76 (d, 1H, H-1), 4.67–4.48 (m, 4H, H-5′, H-6a′, H-6b′, H-6a), 4.33 (dd, 1H, $^3J_{4',5'}$=2.5 Hz, H-4′), 4.08 (dd, 1H, $^3J_{5,6b}$=2.1 Hz, $^2J_{6a,6b}$=12.5 Hz, H-6b), 3.80 (bs, 1H, H-5), 3.42 (s, 3H, OCH$_3$), 3.34 (s, 3H, NOCH$_3$), 2.17, 2.01, 2.00, 1.96 (4 s, 12H, 4OCOCH$_3$); ^{13}C NMR (75 MHz, $CDCl_3$): δ=171.1 (C=O), 170.7 (C=O), 170.3 (C=O), 169.8 (C=O), 167.1 (C=O), 166.7 (C=O), 166.6 (C=O), 133.4 (Car′.), 133.2 (Car′.), 133.1 (Car′.), 129.9 (Car′.), 129.8 (Car′.), 129.7 (Car′.), 129.5 (Car′.), 129.3 (Car′.), 128.6 (Car′.), 128.5 (Car′.), 128.3 (Car′.), 124.6 (Car′.), 97.2 (C-1′), 90.1 (C-1), 74.6 (C-3), 73.6 (C-4), 69.4 (C-3′), 69.3 (C-2′),

68.9 (C-2), 67.8 (C-5, C-5′), 65.3 (C-6′), 62.2 (C-6), 61.3 ($NOCH_3$), 58.5 (C-4′), 55.4 (OCH_3), 20.9 ($OCOCH_3$), 20.8 ($OCOCH_3$), 20.7 ($OCOCH_3$), 20.6 ($OCOCH_3$); MS (ESI): m/z=866.4 $(M+H)^+$, 888.4 $(M+Na)^+$; MS (FAB (+), NBA+NaCl): m/z=806 $(M-OAc)^+$, 866 $(M+H)^+$, 888 $(M+Na)^+$.

4.1.4. Methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-4-methoxy amino-4-*N*-(2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranosyl)-α-D-galactopyranoside (10). Compound **10** was prepared following the procedure described for **9**. 29% yield (70% conversion rate); mp: 96–98°C; ^{1}H NMR (300 MHz, $CDCl_3$): δ=8.06–7.34 (m, 15H, H′ar.), 5.78 (dd, 1H, $^3J_{3',4'}$=3.5 Hz, $^3J_{2',3'}$=10.9 Hz, H-3′), 5.73 (dd, 1H, $^3J_{1',2'}$=3.2 Hz, H-2′), 5.48 (t, 1H, $^3J_{1,2}$=9.4 Hz, H-2), 5.39 (bd, 1H, $^3J_{3,4}$=3.5 Hz, H-4), 5.23 (d, 1H, H-1′), 5.04 (dd, 1H, $^3J_{2,3}$=10.1 Hz, H-3), 5.06–4.54 (m, 4H, H-1, H-5′, H-6′), 4.32 (bt, 1H, H-4′), 4.26–4.15 (m, 2H, H-6), 3.96 (bt, 1H, $^3J_{5,6}$=6.4 Hz, H-5), 3.45 (s, 3H, $NOCH_3$), 3.43 (s, 3H, OCH_3), 2.18, 2.17, 1.99, 1.94 (4 s, 12H, 4$OCOCH_3$); ^{13}C NMR (75 MHz, $CDCl_3$): δ=170.8 (C=O), 170.7 (C=O), 170.5 (C=O), 170.2 (C=O), 166.7 (C=O), 166.6 (C=O), 166.5 (C=O), 133.7 (Car′.), 133.6 (Car′.), 130.6 (Car′.), 130.3 (Car′.), 129.9 (Car′.), 129.7 (Car′.), 128.9 (Car′.), 128.8 (Car′.), 128.7 (Car′.), 97.7 (C-1′), 91.4 (C-1), 72.9 (C-3), 72.7 (C-5), 70.1 (C-3′), 69.6 (C-2′), 68.6 (C-5′), 67.5 (C-4), 66.9 (C-2), 66.0 (C-6′), 62.0 ($NOCH_3$), 61.4 (C-6), 59.4 (C-4′), 55.7 (OCH_3), 21.3 ($OCOCH_3$), 21.2 ($OCOCH_3$), 20.9 ($OCOCH_3$); MS (ESI): m/z=806.3 $(M-OAc)^+$, 865.9 $(M)^+$, 866.2 $(M+H)^+$, 867.5 $(M+2H)^+$, 887.8 $(M+Na)^+$, 889.4 $(M+H+Na)^+$.

4.1.5. Methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-4-methoxy-amino-4-*N*-(2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl)-α-D-glucopyranoside (13). In the dark at room temperature, a suspension of silver carbonate (0.18 g, 0.66 mmol), silver triflate (0.02 g, 0.07 mmol) and 4 Å molecular sieve in nitromethane (5 mL) was stirred for 1 h. Bromide compound **7** (0.41 g, 0.99 mmol) was then added to the catalyst suspension at room temperature. After 15 min, solid compound **6** (0.19 g, 0.37 mmol) was added and stirred at room temperature for 3 h. The reaction mixture was then filtered through celite, the filtrate evaporated in vacuo, taken up in ethyl acetate and washed with water and dried over sodium sulfate. The yellow oil residue remaining after evaporation was chromatographed on silica gel with CH_2Cl_2/ethyl acetate (10/1) to give **13** as a white powder (0.02 g, 10% yield) after precipitation from ether/pentane. Mp: 104–106°C; ^{1}H NMR (300 MHz, $CDCl_3$): δ=8.09–7.33 (m, 15H, Har.), 5.87 (dd, 1H, $^3J_{2',3'}$=9.6 Hz, $^3J_{3',4'}$=10.9 Hz, H-3′), 5.30 (t, 1H, H-2′), 5.29–5.21 (m, 2H, H-2, H-3), 5.17 (d, 1H, $^3J_{1',2'}$=3.8 Hz, H-1′), 5.01 (t, 1H, $^3J_{3,4}$=$^3J_{4,5}$=10.0 Hz, H-4), 4.86 (dd, 1H, $^3J_{5',6a'}$=1.8 Hz, $^2J_{6a',6b'}$=12.1 Hz, H-6a′), 4.68 (dd, 1H, $^3J_{5',6b'}$=5.4 Hz, H-6b′), 4.65 (d, 1H, $^3J_{1,2}$=8.4 Hz, H-1), 4.49–4.42 (m, 1H, H-5′), 4.20 (dd, 1H, $^3J_{5,6a}$=2.3 Hz, $^2J_{6a,6b}$=12.6 Hz, H-6a), 4.09 (dd, 1H, $^3J_{5,6b}$=5.4 Hz, H-6b), 3.84 (t, 1H, H-4′), 3.80–3.73 (m, 1H, H-5), 3.38 (s, 3H, OCH_3), 3.29 (s, 3H, $NOCH_3$), 2.10, 1.93, 1.85, 1.22 (4 s, 12H, 4$OCOCH_3$); NMR (75 MHz, $CDCl_3$): δ=170.4 (C=O), 170.2 (C=O), 169.6 (C=O), 169.4 (C=O), 166.1 (C=O), 165.8 (C=O), 165.3 (C=O), 133.3 (Car′.), 132.9 (Car′.), 130.2 (Car′.), 129.9 (Car′.), 129.6 (Car′.), 129.5 (Car′.), 129.4 (Car′.), 129.0 (Car′.), 128.5 (Car′.), 128.4 (Car′.), 96.7 (C-1′), 86.6 (C-1), 74.5, 73.4, 73.3 (C-2, C-3, C-5), 68.6 (C-5′), 68.2 (C-4), 67.9 (C-2′), 66.9 (C-3′), 65.5 (C-6′), 62.5 (C-6), 61.6 (C-4′), 60.7 ($NOCH_3$), 55.6 (OCH_3), 20.6 ($OCOCH_3$), 20.5 ($OCOCH_3$), 19.7 ($OCOCH_3$); MS (ESI): m/z=866.1 $(M+H)^+$, 867.1 $(M+2H)^+$, 883.1 $(M+H_2O)^+$.

4.1.6. Methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-4-methoxy-amino-4-*N*-(2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranosyl)-α-D-glucopyranoside (14). Compound **14** was prepared following the procedure described for **13**. 10% yield; mp: 106–108°C; ^{1}H NMR (300 MHz, $CDCl_3$): δ=8.26–7.32 (m, 15H, Har.), 5.86 (dd, 1H, $^3J_{2',3'}$=9.5 Hz, $^3J_{3',4'}$=11.0 Hz, H-3′), 5.37 (t, 1H, $^3J_{1,2}$=8.9 Hz, H-2), 5.33 (bd, 1H, $^3J_{3,4}$=3.6 Hz, H-4), 5.16 (dd, 1H, $^3J_{1',2'}$=3.8 Hz, H-2′), 5.09 (d, 1H, H-1′), 4.96 (dd, 1H, H-3), 4.81 (dd, 1H, $^3J_{5',6a'}$=1.8 Hz, $^2J_{6a',6b'}$=11.8 Hz, H-6a′), 4.66 (dd, 1H, $^3J_{5',6b'}$=5.1 Hz, H-6b′), 4.52 (d, 1H, H-1), 4.41–4.34 (m, 1H, H-5′), 4.12–3.98 (m, 2H, H-6), 3.91 (t, 1H, $^3J_{5,6}$=6.1 Hz, H-5), 3.79 (t, 1H, H-4′), 3.38 (s, 3H, OCH_3), 3.29 (s, 3H, $NOCH_3$), 2.10, 1.93, 1.85, 1.22 (4 s, 12H, 4$OCOCH_3$); NMR (75 MHz, $CDCl_3$): δ=170.5 (C=O), 170.2 (C=O), 169.9 (C=O), 169.6 (C=O), 166.2 (C=O), 165.8 (C=O), 165.3 (C=O), 133.4 (Car′.), 133.3 (Car′.), 132.9 (Car′.), 130.3 (Car′.), 129.9 (Car′.), 129.6 (Car′.), 129.5 (Car′.), 129.4 (Car′.), 129.1 (Car′.), 128.4 (Car′.), 128.3 (Car′.), 96.7 (C-1′), 86.9 (C-1), 73.3 (C-2′), 72.6 (C-3), 72.4 (C-5), 68.6 (C-5′), 67.3 (C-4), 66.9 (C-3′), 65.5 (C-6′), 65.2 (C-2), 62.1 (C-6), 61.7 (C-4′), 60.6 ($NOCH_3$), 55.6 (OCH_3), 20.8 ($OCOCH_3$), 20.6 ($OCOCH_3$), 20.5 ($OCOCH_3$), 19.8 ($OCOCH_3$); MS (ESI): m/z=866.1 $(M+H)^+$, 867.1 $(M+2H)^+$, 867.9 $(M+3H)^+$.

4.1.7. Methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-(*O*-β-D-glucopyranosylhydroxyimino)-α-D-xylo-hexopyranoside (19). To a stirring solution of **3** (0.24 g, 0.5 mmol) in ethanol (10 mL) and pyridine (1 mL) was added compound **17** (0.09 g, 0.5 mmol). The solution was ajusted to pH 3 with few drops of hydrochloric acid. After 12 h at 20°C, the solvent was removed in vacuo and the residue diluted with ethyl acetate, then wached with 5% solution of $NaHCO_3$ and finally with water. The organic layer was dried with anhydrous sodium sulfate and evaporated. Column chromatography (ethyl acetate) afford product **19** (*Z*/*E*, 1/2 mixture) after precipitation from CH_2Cl_2/pentane (52% yield, 48% conversion rate). ^{1}H NMR (300 MHz, $CDCl_3$): δ=8.19–7.21 (m, Har.$_{Z,E}$), 6.61 (d, $^3J_{2'Z,3'Z}$=8.7 Hz, H-3′$_Z$), 6.11 (d, $^3J_{2'E,3'E}$=4.8 Hz, H-3′$_E$), 5.56 (dd, $^3J_{1'Z,2'Z}$=3.0 Hz, H-2′$_Z$), 5.52 (t, $^3J_{1'E,2'E}$=4.4 Hz, H-2′$_E$), 5.21 (d, H-1′$_Z$), 5.16 (dd, $^3J_{5'E,6a'E}$=2.3 Hz, $^3J_{5'E,6b'E}$=5.6 Hz, H-5′$_E$), 5.27 (d, H-1′$_E$), 5.03 (d, $^3J_{1E,2E}$=7.5 Hz, H-1$_E$), 4.97–4.85 (m, H-6′$_E$, H-5′$_Z$, H-6a′$_Z$), 4.78 (d, $^3J_{1Z,2Z}$=8.3 Hz, H-1$_Z$), 4.69 (dd, $^3J_{5'Z,6b'Z}$=2.6 Hz, $^2J_{6a'Z,6b'Z}$=11.3 Hz, H-6b′$_Z$), 3.92 (dd, $^3J_{5E,6aE}$=3.4 Hz, $^2J_{6aE,6bE}$=12.0 Hz, H-6a$_E$), 3.80 (dd, $^3J_{5E,6bE}$=3.4 Hz, H-6b$_E$), 3.72 (dd, $^3J_{5Z,6aZ}$=3.0 Hz, $^2J_{6aZ,6bZ}$=12.0 Hz, H-6a$_Z$), 3.66–3.61 (m, H-2$_E$, H-4$_E$, H-4$_Z$), 3.54–3.41 (m, H-3$_{E,Z}$, H-5$_{E,Z}$, H-6b$_Z$), 3.50 (s, OCH_{3Z}), 3.44 (s, OCH_{3E}), 2.93 (t, $^3J_{2Z,3Z}$=8.3 Hz, H-2$_Z$); ^{13}C NMR (75 MHz, $CDCl_3$): δ=168.1 (C=O), 167.3 (C=O), 166.7 (C=O), 166.5 (C=O), 166.2 (C=O), 165.9 (C=O), 165.4 (C=O), 154.0 (C-4′$_Z$), 153.8 (C-4′$_E$), 133.9 (Car′.), 133.8 (Car′.), 132.7 (Car′.), 131.3 (Car′.), 130.4

(Car′.), 130.3 (Car′.), 130.2 (Car′.), 130.0 (Car′.), 129.7 (Car′.), 129.4 (Car′.), 129.3 (Car′.), 129.2 (Car′.), 129.0 (Car′.), 128.9 (Car′.), 128.8 (Car′.), 128.7 (Car′.), 104.8 (C-1_E), 103.4 (C-1_Z), 96.9 (C-$1'_Z$), 96.0 (C-$1'_E$), 75.6, 75.5 (C-3_E, C-5_E), 72.2 (C-2_Z), 72.1 (C-2_E), 71.9 (C-$2'_E$), 69.9 (C-4_E), 69.0 (C-$3'_E$), 68.0 (C-$5'_E$), 65.8 (C-$3'_Z$), 64.1 (C-$6'_E$), 62.1 (C-6_E), 56.7 (OCH_{3E}), 56.4 (OCH_{3Z}); MS (ESI): *m*/*z*=682.6 $(M+H)^+$, 704.5 $(M+Na)^+$.

4.1.8. Methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-(*O*-β-D-galactopyranosylhydroxyimino)-α-D-xylo-hexopyranoside (20). Compound **20** was prepared following the procedure described for **19**. 35% yield, 88% conversion rate (*Z*/*E*, 1/10); ^{1}H NMR (300 MHz, $CDCl_3$): δ=8.09–7.26 (m, 15H, Har.$_{Z,E}$), 6.63 (d, $^3J_{2'Z,3'Z}$=8.4 Hz, H-$3'_Z$), 6.17 (d, $^3J_{2'E,3'E}$=5.2 Hz, H-$3'_E$), 5.54 (dd, $^3J_{1'E,2'E}$=4.1 Hz, H-$2'_E$), 5.23–5.20 (m, H-$5'_E$), 5.22 (d, H-$1'_E$), 5.06 (dd, $^3J_{5'E,6a'E}$=5.9 Hz, $^2J_{6a'E,6b'E}$=11.5 Hz, H-$6a'_E$), 4.97 (d,,$^3J_{1E,2E}$=8.2 Hz, H-1_E), 4.80 (bd, H-$6b'_E$), 4.07–3.82 (m, H-4_E, H-5_E), 3.97 (bt, H-2_E), 3.69–3.58 (m, H-3_E, H-6_E), 3.48 (s, OCH_{3Z}), 3.42 (s, OCH_{3E}); ^{13}C NMR (75 MHz, $CDCl_3$): δ=167.4 (C═O), 165.9 (C═O), 165.3 (C═O), 153.7 (C-4′), 133.9 (Car′.), 133.7 (Car′.), 130.4 (Car′.), 130.2 (Car′.), 129.6 (Car′.), 129.4 (Car′.), 128.9 (Car′.), 128.8 (Car′.), 128.7 (Car′.), 105.8 (C-1), 96.5 (C-1′), 74.9 (C-6), 73.9 (C-3), 72.2 (C-2′), 70.3 (C-2), 69.4 (C-4), 69.2 (C-3′), 68.4 (C-5′), 64.5 (C-6′), 62.3 (C-5), 57.0 (OCH_3); MS (ESI): *m*/*z*=682.4 $(M+H)^+$, 699.3 $(M+H_2O)^+$.

4.1.9. Methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-(*O*-β-D-glucopyranosylhydroxyamino)-α-D-gluco, galactopyranoside (23). Oxime **19** (0.11 g, 0.2 mmol) was dissolved in diethyl ether (50 mL) saturated with dry HCl and BH_3/Et_3N complex (0.23 mL, 2 mmol) was added. This solution was stirred at room temperature for 2 h and was taken up in diethyl ether. The organic layer was washed with aqueous $NaHCO_3$ solution, dried with sodium sulfate and evaporated. The resulting white powder was chromatographied on silica gel column (solvent gradient of CH_2Cl_2 through pure ethyl acetate) to give gluco- and galacto- mixture **23** (87% yield, 1/3:2/3) as white solid after precipitation from CH_2Cl_2/pentane. ^{1}H NMR (300 MHz, $CDCl_3$): δ=8.06–7.27 (m, Har.$_{Gal,Glc}$), 6.29 (t, $^3J_{2'Glc,3'Glc}$=$^3J_{3'Glc,4'Glc}$=10.0 Hz, H-$3'_{Glc}$), 5.75 (dd, $^3J_{3'Gal,4'Gal}$=4.3 Hz, $^3J_{2'Gal,3'Gal}$=11.1 Hz, H-$3'_{Gal}$), 5.43 (dd, $^3J_{1'Gal,2'Gal}$=3.7 Hz, H-$2'_{Gal}$), 5.18 (dd, $^3J_{1'Glc,2'Glc}$=3.4 Hz, H-$2'_{Glc}$), 5.13 (m, H-$1'_{Gal,Glc}$), 4.81–4.50 (m, H-$6'_{Gal}$), 4.62 (d, $^3J_{1Gal,2Gal}$=7.4 Hz, H-1_{Gal}), 4.54 (d, $^3J_{1Glc,2Glc}$=7.4 Hz, H-1_{Glc}), 4.35 (m, H-$5'_{Gal}$), 4.02 (d, H-$4'_{Gal}$), 3.65–3.55 (m, H-5_{Gal}), 3.54–3.31 (m, H-2_{Glc}, H-3_{Gal}), 3.31–3.18 (m, H-2_{Gal}, H-$4'_{Glc}$), 3.36 (s, OCH_3), 3.09 (bd, $^3J_{3Gal,4Gal}$=8.7 Hz, H-4_{Gal}); ^{13}C NMR (75 MHz, $CDCl_3$): δ=166.8 (C═O), 166.0 (C═O), 165.9 (C═O), 133.5 (Car′.), 133.2 (Car′.), 133.1 (Car′.), 129.8 (Car′.), 129.7 (Car′.), 129.6 (Car′.), 129.2 (Car′.), 129.1 (Car′.), 128.9 (Car′.), 128.5 (Car′.), 128.4 (Car′.), 128.3 (Car′.), 105.3 (C-$1'_{Gal}$), 105.2 (C-$1'_{Glc}$), 97.1 (C-1_{Gal}), 97.0 (C-1_{Glc}), 77.2, 76.2, 75.6, 75.5, 73.1, 71.9, 71.8, 69.3, 69.2, 69.1, 67.8, 66.6, 65.5 (C-$6'_{Gal}$), 64.2, 61.1 (C-6_{Gal}), 60.9, 60.3, 55.4 (OCH_{3Glc}), 55.1 (OCH_{3Gal}); MS (ESI): *m*/*z*=684.6 $(M+H)^+$, 706.5 $(M+Na)^+$.

4.1.10. Methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-(*O*-β-D-galactopyranosylhydroxyamino)-α-D-gluco, galactopyranoside (24). Compound **24** was prepared following the procedure described for **23**. 91% yield, Glc 1/4, Gal 3/4); ^{1}H NMR (300 MHz, $CDCl_3$): δ=8.09–7.28 (m, Har.$_{Gal,Glc}$), 6.33 (t, $^3J_{2'Glc,3'Glc}$=$^3J_{3'Glc,4'Glc}$=10.0 Hz, H-$3'_{Glc}$), 5.77 (dd, $^3J_{3'Gal,4'Gal}$=4.7 Hz, $^3J_{2'Gal,3'Gal}$=11.0 Hz, H-$3'_{Gal}$), 5.49 (dd, $^3J_{1'Gal,2'Gal}$=3.6 Hz, H-$2'_{Gal}$), 5.18 (dd, $^3J_{1'Glc,2'Glc}$=3.6 Hz, H-$2'_{Glc}$), 5.15 (d, H-$1'_{Gal}$), 5.12 (d, H-$1'_{Glc}$), 4.84–4.61 (m, H-$6'_{Gal,Glc}$, H-$5'_{Glc}$), 4.58 (d, $^3J_{1Gal,2Gal}$=7.9 Hz, H-1_{Gal}), 4.50 (d, $^3J_{1Glc,2Glc}$=7.9 Hz, H-1_{Glc}), 4.43 (m, $^3J_{5'Gal,6'Gal}$=6.4 Hz, H-$5'_{Gal}$), 4.03 (bd, H-$4'_{Gal}$), 3.90 (bs, H-3_{Gal}), 3.80 (bd, $^3J_{3Gal,4Gal}$=6.1 Hz, H-4_{Gal}), 3.75–3.36 (m, H-$2_{Gal,Glc}$, H-5_{Gal}, H-6_{Gal}, H-3_{Glc}), 3.42 (s, OCH_{3Gal}), 3.41 (s, OCH_{3Glc}), 3.27 (t, H-$4'_{Glc}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 167.3 (C═O), 166.9 (C═O), 166.4 (C═O), 166.4 (C═O), 133.9 (Car′.), 133.7 (Car′.), 133.6 (Car′.), 130.6 (Car′.), 130.3 (Car′.), 130.2 (Car′.), 130.1 (Car′.), 130.0 (Car′.), 129.6 (Car′.), 129.5 (Car′.), 129.4 (Car′.), 128.8 (Car′.), 128.7 (Car′.), 128.2 (Car′.), 105.7 (C-$1'_{Gal}$), 105.4 (C-$1'_{Glc}$), 97.5 (C-1_{Gal}), 97.4 (C-1_{Glc}), 77.8, 77.4, 76.6, 76.0, 75.9, 73.5, 72.5, 72.2, 69.9, 69.7, 69.6, 69.4, 68.1, 67.0, 65.9 (C-$6'_{Gal}$), 64.6, 61.5 (C-6_{Gal}), 60.7, 55.8 (OCH_{3Glc}), 55.6 (OCH_{3Gal}); MS (ESI): *m*/*z*=684.4 $(M+H)^+$, 706.4 $(M+Na)^+$.

4.1.11. Methyl 4-deoxy-4-methoxyamino-4-*N*-(β-D-glucopyranosyl)-α-D-galactopyranoside (11). Compound **9** (0.11 g, 0.1 mmol) in methanol (2 mL) was treated with few drops (pH 9–10) of sodium methanoate (30% in methanol). After 2 h at room temperature, the solution was neutralised with cation exchange resin Amberlite IR-120 (H^+), filtrated and concentrated in vacuo. The residue was then taken up in water and extracted three times with CH_2Cl_2. The aqueous phase was lyophilised to give **11** with quantitative yield. ^{1}H NMR (300 MHz, D_2O): δ=4.91 (d, 1H, $^3J_{1',2'}$=4.2 Hz, H-1′), 4.38 (d, 1H, $^3J_{1,2}$=8.7 Hz, H-1), 4.09 (m, 1H, H-5′), 4.04 (dd, 1H, $^3J_{2',3'}$=10.2 Hz, H-2′), 3.95–3.81 (m, 5H, H-3′, H-4′, H-6′, H-6a), 3.79–3.70 (m, 1H, H-5), 3.74 (dd, 1H, $^3J_{5',6b'}$=5.5 Hz, $^2J_{6a',6b'}$=12.2 Hz, H-6b), 3.58 (s, 3H, OCH_3), 3.55–3.42 (m, 3H, H-2, H-3, H-4), 3.41 (s, 3H, $NOCH_3$); ^{13}C NMR (75 MHz, D_2O): δ=99.5 (C-1′), 93.0 (C-1), 77.7, 77.2 (C-2, C-3 or C-4), 71.1 (C-5′), 70.3, 70.0, 69.5, 69.4 (C-2′, C-3′, C-4′, C-2, C-3 or C-4), 62.5 (C-6′), 61.5 (C-3′ or C-4′), 61.4 ($NOCH_3$), 61.1 (C-6), 55.4 (OCH_3); $[\alpha]_{589}^{20}$=+26.9°, $[\alpha]_{546}^{20}$=+39.2° (*c*=0.36, methanol); MS (ESI): *m*/*z*=386.2 $(M+H)^+$, 408.1 $(M+Na)^+$, 793.7 $(2M+Na)^{+;}$ HRMS (FAB): calcd for $C_{14}H_{28}NO_{11:}$ 386.1662, found 386.1656.

4.1.12. Methyl 4-deoxy-4-methoxyamino-4-*N*-(β-D-galactopyranosyl)-α-D-galactopyranoside (12). Compound **12** was prepared following the procedure described for **11**. Quantitative yield; ^{1}H NMR (300 MHz, D_2O): δ=4.95 (d, 1H, $^3J_{1',2'}$=4.2 Hz, H-1′), 4.39 (d, 1H, $^3J_{1,2}$=8.3 Hz, H-1), 4.34 (dd, 1H, $^3J_{5',6a'}$=2.3 Hz, $^3J_{5',6b'}$=8.3 Hz, H-5), 4.20–4.08 (m, 1H, H-4), 4.03 (dd, 1H, $^3J_{2',3'}$=9.9 Hz H-2′), 4.05–3.88 (m, 3H, H-3, H-6a, H-5′), 3.82 (m, 1H, H-4′), 3.78–3.69 (m, 4H, H-2, H-6b, H-6′), 3.64 (s, 3H, $NOCH_3$), 3.63 (m, 1H, H-3′), 3.46 (s, 3H, OCH_3); ^{13}C NMR (75 MHz, D_2O): δ=99.6 (C-1′), 93.6 (C-1), 77.0 (C-4′), 74.2 (C-2), 70.8 (C-2′), 70.5, 70.0, 69.6, 69.1, (C-3, C-5, C-3′, C-5′), 68.0 (C-4), 63.6 (C-6′), 62.4 (C-6), 61.2 ($NOCH_3$), 55.4 (OCH_3); $[\alpha]_{589}^{20}$=+109.9°, $[\alpha]_{546}^{20}$=+145.4° (*c*=0.24, methanol); MS (ESI): *m*/*z*=387.0 $(M+H)^+$, 408.9

$(M+Na)^+$, 793.5 $(2M+Na)^+$; HRMS (FAB): calcd for $C_{14}H_{28}NO_{11}$: 386.1662, found 386.1662.

4.1.13. Methyl 4-deoxy-4-methoxyamino-4-*N*-(β-D-glucopyranosyl)-α-D-glucopyranoside (15). Compound **15** was prepared following the procedure described for **11**. Quantitative yield; ^{1}H NMR (300 MHz, D_2O): δ=4.84 (d, 1H, $^3J_{1',2'}$=3.8 Hz, H-1′), 4.25 (d, 1H, $^3J_{1,2}$=8.6 Hz, H-1), 4.10 (dd, 1H, $^3J_{5',6a'}$=2.3 Hz, $^2J_{6a',6b'}$=12.5 Hz, H-6a′), 4.04–3.90 (m, 3H, H-5′, H-6a, H-3′), 3.83 (dd, 1H, $^3J_{5',6b'}$=5.5 Hz, H-6b′), 3.76–3.62 (m, 3H, H-2′, H-6b, H-2), 3.68 (s, 3H, $NOCH_3$), 3.58–3.50 (m, 2H, H-3, H-5), 3.46 (s, 3H, OCH_3), 3.41 (t, 1H, $^3J_{3,4}$=$^3J_{4,5}$=9.3 Hz, H-4), 3.10 (t, 1H, $^3J_{3',4'}$=$^3J_{4',5'}$=10.2 Hz, H-4′); ^{13}C NMR (75 MHz, D_2O): δ=98.1 (C-1′), 90.7 (C-1), 77.0, 76.1 (C-3, C-5), 71.1 (C-2 or C-2′), 69.8 (C-3′ or C-5′), 69.1 (C-2 or C-2′), 68.6 (C-4), 66.4 (C-3′ or C-5′), 65.1 (C-4′), 62.5 ($NOCH_3$), 61.5 (C-6′), 60.1 (C-6), 54.4 (OCH_3); $[\alpha]_{589}^{20}$=+11.4°, $[\alpha]_{546}^{20}$=+26.3° (*c*=0.23, methanol); HRMS (FAB): calcd for $C_{14}H_{28}NO_{11}$: 386.1662, found 386.1664.

4.1.14. Methyl 4-deoxy-4-methoxyamino-4-*N*-(β-D-galactopyranosyl)-α-D-glucopyranoside (16). Compound **16** was prepared following the procedure described for **11**. Quantitative yield; ^{1}H NMR (300 MHz, D_2O): δ=4.84 (d, 1H, $^3J_{1',2'}$=3.7 Hz, H-1′), 4.19 (d, 1H, $^3J_{1,2}$=9.0 Hz, H-1), 4.16 (dd, 1H, $^3J_{5',6b'}$=2.2 Hz, $^2J_{6a',6b'}$=11.9 Hz, H-6a′), 4.07–3.92 (m, 3H, H-3′, H-5′, H-4), 3.90 (t, 1H, H-2), 3.84 (dd, 1H, $^3J_{5',6a'}$=5.4 Hz, H-6b′), 3.80–3.66 (m, 5H, H-2′, H-3, H-5, H-6), 3.70 (s, 3H, $NOCH_3$), 3.47 (s, 3H, OCH_3), 3.10 (t, 1H, $^3J_{3',4'}$=$^3J_{4',5'}$=10.2 Hz, H-4′); ^{13}C NMR (75 MHz, D_2O): δ=97.0 (C-1′), 91.2 (C-1), 75.3, 72.0, 70.1 (C-2′, C-3, C-5), 68.7, 66.9, 65.7 (C-3′, C-5′, C-4), 65.3 (C-2), 64.1 (C-4′), 61.5 ($NOCH_3$), 60.4 (C-6′), 59.3 (C-6), 53.3 (OCH_3); $[\alpha]_{589}^{20}$=+69.0°, $[\alpha]_{546}^{20}$=+112.0° (*c*=0.11, methanol); HRMS (FAB): calcd for $C_{14}H_{28}NO_{11}$: 386.1662, found 386.1656.

4.1.15. Methyl 4-deoxy-(*O*-β-D-glucopyranosylhydroxyimino)-α-D-xylo-hexopyranoside (21). Compound **21** was prepared following the procedure described for **11**. Quantitative yield; ^{1}H NMR (300 MHz, D_2O): δ=5.11 (d, $^3J_{1E,2E}$=7.9 Hz, H-1$_E$), 5.07 (d, $^3J_{1'E,2'E}$=3.0 Hz, H-1′$_E$, H-1$_Z$), 5.04 (dd, $^3J_{5'E,6a'E}$=3.0 Hz, $^3J_{5'E,6b'E}$=7.5 Hz, H-5′$_E$), 5.00 (d, $^3J_{1'Z,2'Z}$=2.6 Hz, H-1′$_Z$), 4.92 (d, $^3J_{5'Z,6'Z}$=6.4 Hz, H-5′$_Z$), 4.53 (dd, $^3J_{5Z,6aZ}$=4.1 Hz, $^3J_{5Z,6bZ}$=5.7 Hz, H-5$_Z$), 4.35 (d, $^3J_{2'E,3'E}$=4.5 Hz, H-3′$_E$), 4.02-3.90 (m, H-2′$_{Z,Z}$, H-6a′$_E$, H-6′$_Z$), 3.89–3.74 (m, H-6b′$_E$, H-5$_E$, H-6$_E$, H-6$_Z$), 3.73–3.60 (m, H-4$_E$), 3.54–3.32, (m, H-2$_{Z,Z}$, H-3$_E$), 3.53 (s, OCH_{3E}), 3.50 (s, OCH_{3Z}); ^{13}C NMR (75 MHz, D_2O): δ=158.9 (C-4′$_Z$), 158.5 (C-4′$_E$), 104.5 (C-1$_Z$), 104.0 (C-1$_E$), 98.6 (C-1′$_Z$), 97.4 (C-1′$_E$), 77.0, 76.9, 76.4, 76.3, 72.5 (C-5$_Z$), 72.0, 71.9, 71.7, 71.1, 70.9 (C-5′$_E$), 70.6, 69.9, 69.8, 65.6 (C-5′$_Z$), 63.3 (C-6$_E$), 61.2 (C-6′$_E$), 61.0 (C-6$_Z$), 56.9 (OCH_{3E}), 56.5 (OCH_{3Z}); $[\alpha]_{589}^{20}$=+33.6°, $[\alpha]_{546}^{20}$=+71.8° (*c*=0.11, methanol); MS (ESI): *m*/*z*=370.4 $(M+H)^+$, 387.4 $(M+H_2O)^+$, 392.3 $(M+Na)^+$, 761.8 $(2M+Na)^+$; HRMS (FAB): calcd for $C_{13}H_{23}NO_{11}Na$: 392.1168, found 392.1161.

4.1.16. Methyl 4-deoxy-(*O*-β-D-galactopyranosylhydroxyimino)-α-D-xylo-hexopyranoside (22). Compound **22** was prepared following the procedure described for **11**. Quantitative yield; ^{1}H NMR (300 MHz, D_2O): δ=5.08 (d, $^3J_{1'E,2'E}$=3.0 Hz, H-1′$_E$), 5.05–5.03 (m, H-1$_E$, H-5′$_E$, H-1$_Z$), 4.99 (d, $^3J_{1',2'Z}$=3.0 Hz, H-1′$_Z$), 4.93 (d, $^3J_{5'Z,6'Z}$=6.4 Hz, H-5′$_Z$), 4.36 (d, $^3J_{2'E,3'E}$=5.3 Hz, H-3′$_E$), 4.53 (dd, $^3J_{5Z,6aZ}$=4.1 Hz, $^3J_{5Z,6bZ}$=5.7 Hz, H-5$_Z$), 4.08 (dd, $^3J_{5'E,6a'E}$=7.2 Hz, $^2J_{6a'E,6b'E}$=12.1 Hz, H-6a′$_E$), 4.01 (m, H-2′$_E$, H-3$_E$, H-6′$_Z$), 3.90 (dd, $^3J_{5'E,6b'E}$=7.2 Hz, H-6b′$_E$), 3.87–3.75 (m, H-2$_E$, H-4$_E$, H-5$_E$, H-4$_Z$, H-6$_{Z,E}$, H-2′$_Z$), 3.53 (s, OCH_{3E}), 3.50 (s, OCH_{3Z}); ^{13}C NMR (75 MHz, D_2O): δ=158.3 (C-4$_Z$), 157.8 (C-4$_E$), 105.0 (C-1$_Z$), 104.1 (C-1$_E$), 98,2 (C-1′$_Z$), 96.9 (C-1′$_E$), 75.8, 72.9 (C-4$_E$, C-5$_E$), 72.0 (C-5$_Z$), 71.2 (C-2′$_E$ or C-3$_E$), 70.5 (C-5′$_E$), 70.0 (C-3′$_E$), 69.1 (C-2$_E$), 68.6 (C-2′$_E$ or C-3$_E$), 65.2 (C-5′$_Z$), 61.0 (C-6$_E$), 60.7 (C-6′$_E$), 56.4 (OCH_3); $[\alpha]_{589}^{20}$=+70.0°, $[\alpha]_{546}^{20}$=+91.9° (*c*=0.38, methanol); MS (ESI): *m*/*z*=370.4 $(M+H)^+$, 387.4 $(M+H_2O)^+$, 392.3 $(M+Na)^+$, 756.3 $(2M+H_2O)^+$, 760.8 $(2M+Na)^+$; HRMS (FAB): calcd for $C_{13}H_{24}NO_{11}$: 370.1349, found 370.1345.

4.1.17. Methyl 4-deoxy-(*O*-β-D-glucopyranosylhydroxyamino)-α-D-gluco, galactopyranoside (25). Compound **25** was prepared following the procedure described for **11**. Quantitative yield; ^{1}H NMR (300 MHz, D_2O): δ=4.86 (d, $^3J_{1'Glc,2'Glc}$=3.6 Hz, H-1′$_{Glc}$), 4.85 (d, $^3J_{1'Gal,2'Gal}$=3.6 Hz, H-1′$_{Gal}$), 4.71 (d, $^3J_{1Gal,2Glal}$=8.3 Hz, H-1$_{Gal}$), 4.61 (d, $^3J_{1Glc,2Glc}$=8.4 Hz, H-1$_{Glc}$), 4.13 (t, $^3J_{2'Glc,3'Glc}$=$^3J_{3'Glc,4'Glc}$=9.9 Hz, H-3′$_{Glc}$), 4.08 (dd, $^3J_{2'Gal,3'Gal}$=4.8 Hz, $^3J_{3'Gal,4'Gal}$=10.5 Hz, H-3′$_{Gal}$), 4.11–4.05 (m, H-4$_{Glc}$), 4.04–3.89 (m, H-5$_{Gal}$, H-6$_{Gal}$, H-4$_{Glc}$, H-3$_{Glc}$, H-6′$_{Glc}$), 3.88–3.72 (m, H-4$_{Gal}$, H-6$_{Glc}$), 3.65 (dd, $^3J_{2'Gal,3'Gal}$=8.0 Hz, H-2′$_{Gal}$), 3.62 (dd, H-2′$_{Glc}$), 3.57–3.46 (m, H-3$_{Gal}$, H-4′$_{Gal}$, H-6′$_{Gal}$), 3.45 (s, OCH_{3Gal}), 3.45–3.38 (m, H-5′$_{Gal}$), 3.34 (t, $^3J_{2Glc,3Glc}$=8.3 Hz, H-2$_{Glc}$), 3.31 (t, $^3J_{4'Glc,5'Glc}$=9.9 Hz, H-4′$_{Glc}$); ^{13}C NMR (75 MHz, D_2O): δ=105.0 (C-1$_{Glc}$), 104.3 (C-1$_{Gal}$), 99.8 (C-1′$_{Glc}$), 99.5 (C-1′$_{Gal}$), 76.1 (C-3$_{Gal}$ or C-4′$_{Gal}$), 76.0, 72.4, 72.2 (C-2$_{Glc}$), 72.1 (C-2$_{Gal}$), 70.7, 69.9 (C-5′$_{Gal}$), 69.1 (C-2′$_{Glc}$), 68.9 (C-2′$_{Gal}$), 68.2 (C-3′$_{Gal}$), 67.1 (C-3′$_{Glc}$), 62.7 (C-6$_{Gal}$), 62.2 (C-4′$_{Glc}$), 62.1 (C-6′$_{Glc}$), 61.6 (C-6$_{Glc}$), 61.0 (C-6$_{Gal}$), 55.4 (OCH_{3Gal}), 55.3 (OCH_{3Glc}); $[\alpha]_{589}^{20}$=+55.0°, $[\alpha]_{546}^{20}$=+81.5° (*c*=0.20, methanol); MS (ESI): *m*/*z*=372.3 $(M+H)^+$, 394.4 $(M+Na)^+$, 765.3 $(2M+Na)^+$; HRMS (FAB): calcd for $C_{13}H_{26}NO_{11}$: 370.1505, found 370.150.

4.1.18. Methyl 4-deoxy-(*O*-β-D-galactopyranosylhydroxyamino)-α-D-gluco, galactopyranoside (26). Compound **26** was prepared following the procedure described for **11**. Quantitative yield; ^{1}H NMR (300 MHz, D_2O): δ=4.87–4.83 (m, $^3J_{1'Gal,2'Gal}$=3.8 Hz, H-1′$_{Gal}$, H-1′$_{Glc}$), 4.65 (d, $^3J_{1Gal,2Gal}$=8.3 Hz, H-1$_{Gal}$), 4.55 (d, $^3J_{1Glc,2Glc}$=8.3 Hz, H-1$_{Glc}$), 4.15 (t, $^3J_{2'Glc,3'Glc}$=$^3J_{3'Glc,4'Glc}$=9.8 Hz, H-3′$_{Glc}$), 4.07 (dd, $^3J_{3'Gal,4'Gal}$=4.9 Hz, $^3J_{2'Gal,3'Gal}$=10.6 Hz, H-3′$_{Gal}$), 4.12–4.07 (m, H-5′$_{Glc}$), 4.03–3.94 (m, H-4$_{Gal}$, H-5′$_{Gal}$), 3.90–3.62 (m, H-3$_{Gal}$, H-6$_{Gal}$, H-3$_{Glc}$, H-2′$_{Gal}$, H-6′$_{Gal}$), 3.55 (t, H-2$_{Glc}$), 3.55–3.48 (m, H-2$_{Gal}$, H-4′$_{Gal}$), 3.44 (s, OCH_{3Gal}), 2.79 (t, H-4′$_{Glc}$); ^{13}C NMR (75 MHz, D_2O): δ=105.5 (C-1$_{Glc}$), 104.7 (C-1$_{Gal}$), 99.7 (C-1′$_{Glc}$), 99.5 (C-1′$_{Gal}$), 75.3, 73.0, 72.3, 70.7, 69.9, 69.7, 69.1, 68.9 (C-4$_{Gal}$ or C-5′$_{Gal}$), 68.2, 67.0, 62.7 (C-4′$_{Glc}$), 62.0 (C-6′$_{Gal}$ or C-6$_{Gal}$), 61.6, 61.4, 61.3 (C-6′$_{Gal}$ or C-6$_{Gal}$), 57.8 (OCH_{3Glc}), 55.4 (OCH_{3Gal}); $[\alpha]_{589}^{20}$=+87.5°, $[\alpha]_{546}^{20}$+157.5° (*c*=0.28, methanol); MS (ESI): *m*/*z*=372.3 $(M+H)^+$, 394.4 $(M+Na)^+$, 743.3 $(2M)^+$, 765.3 $(2M+Na)^+$.

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