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An easy route to seven-membered iminocyclitols from aldohexopyranosyl enamines

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Abstract—A new stereocontrolled and high yielding synthesis of biologically active polyhydroxyperhydroazepines is reported starting from easily available glycosylenamines (D-*gluco*, D-*manno*, and D-*galacto* configurations), which are transformed into 1,6-azaanhydropyranose derivatives. *O*- and *N*-Deprotection of the latter, followed by reduction with sodium cyanoborohydride, gives the target chiral iminocyclitols. The method is based on the capacity of the dialkoxycarbonylvinyl group to stabilize an amide ion, and the only limitation is the necessity for the starting glycosylenamine to have β-D-configuration. The inhibitory activity of several intermediate iminocyclitols and aldopyranosylenamines on different α- and β-glycosidases is also reported.

1. Introduction

The iminocyclitols are sugar analogues containing an imino group instead of an oxygen atom in the ring. These compounds have been discovered as natural products, and present important pharmaceutical activities due to their glycosidase- and glycosyltransferase-inhibitory properties.[1] Much effort has been devoted toward syntheses of five-[2] and six-[3] membered iminocyclitol families, as they are able to mimic the transition state of enzymatic reactions.[4] However, little attention has been directed to the synthesis of seven-membered iminocyclitols (the polyhydroxyperhydroazepines) despite data in the literature[5] indicating that many of these compounds have higher glycosidase-inhibition potencies than their five- and six-membered counterparts. This may be due to the flexibility of the perhydroazepine ring system, permitting the ring to adopt quasi-flattened conformations, which could lead to more favourable binding within the active site of the enzyme.[3a,5,6] Only a few chemical and chemoenzymatic methods for the syntheses of polyhydroxyperhydroazepines have been reported,[2g,3a,7] although interest has been growing over the last 3 years,[6,8–10] also including the preparation of related heterocycles having an additional nitrogen or sulphur atom.[11]

We have recently communicated[12] our previous results on a new method for the preparation of polyhydroxyperhydroazepines starting from *N*-diethoxycarbonylvinyl glycosylamines. Herein, we describe the preparation of glycosylenamines **1**–**16** having in many cases (**4**–**6**, **9**, **10**, **13**, and **16**) an OMs substituent on C-6, which is suitable for the formation of the 1,6-anhydroazasugars **17**–**26**. The *O*-debenzoylation of **18**, **22**, and **25**, followed by *N*-deprotection, leads to **27**–**29**, which by cleavage of the C1–O bond under reductive conditions, produces the chiral polyhydroxyperhydroazepines (azasugar analogues) **30**–**32** as their ammonium salts. From these, the known[5a] free iminocyclitols **33**–**35** were prepared. The method to form the C6–N bond is a valuable alternative to the S_N2 displacement of a sulphonyloxy or cyclic sulphate group with sodium azide, because, in our case, the seven-membered ring is formed directly, shortening the synthetic route.

2. Results and discussion

The synthetic route for the preparation of the seven-membered iminocyclitols is outlined in Scheme 1. The key step in the synthesis is the formation of a 1,6-anhydro derivative; consequently the corresponding substituents should have a *cis*-relationship, that is

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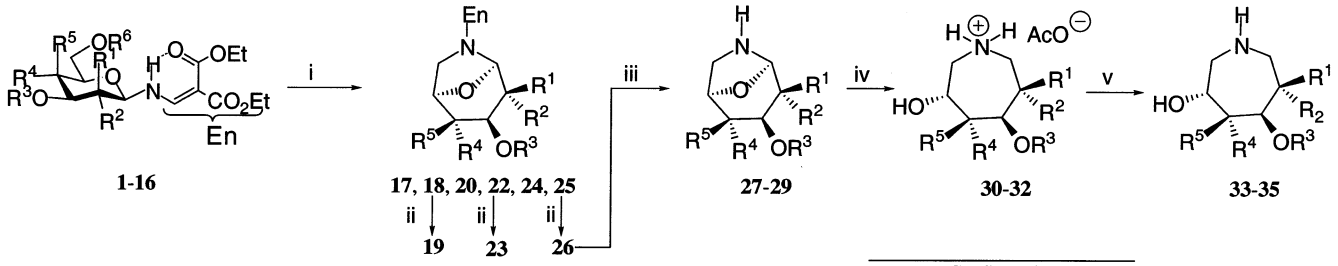


Compounds	R^1	R^2	R^3	R^4	R^5	R^6 (for **1-16**)	Configuration **1-29**	Configuration **30-35**
1[a], **19**, **27**, **30**, **33**	H	OH	H	OH	H	H	D-*gluco*	***3R,4R,5R,6S***
2[a], **23**, **28**, **31**, **34**	H	OH	H	H	OH	H	D-*galacto*	***3R,4S,5R,6S***
3[a], **26**, **29**, **32**, **35**	OH	H	H	OH	H	H	D-*manno*	***3R,4R,5R,6R***
4, **17**	H	OMs	Ms	OMs	H	Ms	D-*gluco*	-
5, **21**	H	OMs	Ms	H	OMs	Ms	D-*galacto*	-
6, **24**	OMs	H	Ms	OMs	H	Ms	D-*manno*	-
7[b], **18**	H	OBz	Bz	OBz	H	H	D-*gluco*	-
8[c]	H	OAc	Ac	OAc	H	H	D-*gluco*	-
9	H	OBz	Bz	OBz	H	Ms	D-*gluco*	-
10, **20**	H	OAc	Ac	OAc	H	Ms	D-*gluco*	-
11	H	OBz	Bz	H	OBz	Tr	D-*galacto*	-
12, **22**	H	OBz	Bz	H	OBz	H	D-*galacto*	-
13	H	OBz	Bz	H	OBz	Ms	D-*galacto*	-
14	OBz	H	Bz	OBz	H	Tr	D-*manno*	-
15, **25**	OBz	H	Bz	OBz	H	H	D-*manno*	-
16	OBz	H	Bz	OBz	H	Ms	D-*manno*	-

[a] See ref **11**

Scheme 1. *Reagents and conditions*: (i) MeONa/DMF, rt, 20 mmHg, 15 min; (ii) MeONa/MeOH, rt, 4 h; (iii) Cl_2/CH_2Cl_2, rt, 15 min; (iv) $NaCNBH_3$/AcOH, rt, 24 h; (v) Dowex-50W.NH_4^+ form. 1×20 cm.

monosaccharide enamines with β-D-configuration are the most suitable and available starting materials. Additionally, the configuration of C2, C3, C4 and C5 in the sugar moiety is retained in the final iminocyclitols. Thus, the β-D-aldopyranosylenamines **1**–**3** with D-*gluco*, D-*galacto*, and D-*manno* configurations[13] were chosen as starting materials. The partially *O*-acylated β-D-glucosylenamines **7** and **8**, prepared[14] from **1**, have also been used. With the aim of forming products useful for enzymatic studies and, simultaneously, for further transformation, the 6-*O*-mesyl derivatives **4**–**6**, **9**, **10**, **13**, and **16** were prepared (Scheme 1) from the corresponding *N*-diethoxycarbonylvinyl-β-D-glycopyranosyl amines by per-*O*-mesylation with mesyl chloride (→**4**–**6**), 6-*O*-mesylation (→**9**, **10**) or through conventional strategies of one-pot 6-*O*-tritylation and benzoylation (→**11**, **14**), de-*O*-tritylation (→**12**, **15**), and *O*-mesylation (→**13**, **16**). The presence of the trityl group in **11** and **14** was evident from NMR (^1H and ^{13}C signals for the phenyl rings, the resonances of H6a and H6b at 3.25–3.50 ppm and the resonance of C6 at ≈61 ppm, see Table 1) and MS analyses (peak for Ph_3C^+ at *m*/*e* 243).[14,15] The NMR data of the 6-hydroxy derivatives **12** and **15** were very close to those for **11** and **14**, except for a downfield shift of ≈0.4 ppm in the signals for H6a and H6b.[15] The chemical shifts for the resonances of H6a, H6b and C6 for the 6-*O*-mesyl derivatives **4**–**6**, **9**, **10**, **13**, and **16** also showed strong deshielding (≈0.6 and ≈6 ppm, respectively) compared to the values for the corresponding hydroxy derivatives, as corresponds to the formation of the sulphonyloxy compound.

Treatment of the 6-*O*-mesylated *N*-diethoxycarbonylvinyl-D-glucopyranosyl amines **4**–**6**, **9**, **10**, **13**, and **16** with one equiv. of sodium methoxide in DMF, in a similar way to that we have described[16] for 4-*O*-mesyl derivatives, gave the 1,6-anhydroazapyranoses **17**, **18**, **20**–**22**, **24**, and **25** in high yields. The ^1H NMR spectra of these compounds (Table 1) contained no NH proton signals and showed a singlet for the HC= of the enamino moiety (=$CHNR_2$) instead of the doublet (=CHNHR) of the spectra of the parent compounds. The signals for H1 were shifted downfield (≈0.8 ppm), whereas the resonances for H6a and H6b were shifted upfield as corresponds to the substitution of the sulphonyloxy group by an enamino group. These changes are analogous, but quantitatively smaller (except in the case of δ C6), to those described for 1,4-anhydroaza compounds,[16] where a five-membered ring is formed and a $^{1,4}B$ conformation of the sugar ring is a requirement. Other differences observed in the NMR spectra were shielding in the chemical shifts for HC=, very marked changes in all coupling constants of the sugar ring (which were in accord with a conformational change due to the formation of the bicyclic system, see below), small shifts in the chemical shift of C1, a strong (18–20 ppm) upfield shift in the resonance of C6, and significant changes in the chemical shifts for the resonances of the carbons of the enamino moiety.

The formation of **17**, **18**, **20**–**22**, **24**, and **25** can be explained by the presence of an intermediate amide ion (stabilized by the dialkoxycarbonylvinyl group[2e]),

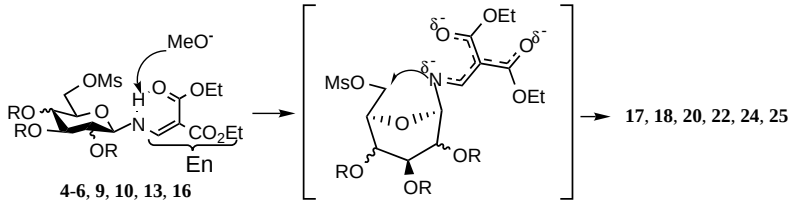
Table 1. Relevant NMR data (δ, ppm; J, Hz) for compounds **4–6** and **9–26**

	Sugar ring									Enamino moiety				
	$\delta_{H\text{-}1}$	$J_{1,2}$	$\delta_{H\text{-}6a}$	$\delta_{H\text{-}6b}$	$J_{6a,6b}$	$J_{5,6a}$	$J_{5,6b}$	$\delta_{C\text{-}1}$	$\delta_{C\text{-}6}$	δ_{NH}	$J_{1,NH}$	$\delta_{=CH}$	$\delta_{=CH}$	$\delta_{=C}$
4	4.70t	9.2	4.64dd	4.45dd	11.6	2.1	4.3	86.5	66.6	9.32dd	9.2	7.96d	156.8	96.1
5	4.74t	9.0	4.37m	4.32m	[a]	[a]	[a]	86.8	65.9	9.39dd	9.0	7.98d	157.1	95.9
6	5.03dd	0.8	4.61dd	4.40dd	11.7	2.2	5.0	84.0	67.0	9.49dd	9.2	8.01d	156.7	95.2
9	4.87t	9.8	4.46–4.42m	4.33–4.15m	[a]	[a]	[a]	87.3	66.8	9.40dd	9.8	7.98d	156.9	95.5
10	4.57t	8.9	3.76m	3.61m	[a]	[a]	[a]	87.0	66.0	9.20dd	8.9	7.93d	157.2	94.8
11	4.75t	8.7	3.47dd	3.26t	9.0	5.4	9.0	87.1	60.5	9.39dd	8.7	7.99d	157.4	94.6
12	4.85t	8.9	3.84dd	3.65dd	11.9	6.6	6.7	87.8	60.4	9.50dd	8.9	8.02d	157.5	94.6
13	4.86t	8.9	←4.42–4.32m→		[a]	[a]	[a]	87.9	66.0	9.51dd	8.9	8.01d	157.2	95.2
14	5.11dd	1.1	3.54dd	3.26dd	10.7	2.2	3.5	84.4	61.8	9.56dd	8.0	8.24d	156.6	93.9
15	4.13dd	1.1	←3.92–3.78m→		[a]	[a]	[a]	85.0	61.3	9.48dd	8.9	8.11d	156.7	94.5
16	4.16dd	1.1	←4.48–4.47m→		[a]	[a]	[a]	84.8	67.5	9.51dd	8.8	8.10d	156.6	94.9
17	5.55bs	1.4	3.71d	3.48d	10.7	[a]	[a]	88.6	48.4	–	–	7.59s	144.9	98.7
18	5.65s	0.0	3.82d	3.70dd	10.9	–	6.4	89.4	48.1	–	–	7.84s	144.6	97.8
19	5.32bs	1.4	3.54m	3.40m	[a]	[a]	[a]	93.2	49.0	–	–	7.74s	147.5	95.8
20	5.38bs	[a]	3.61d	3.40dd	10.7	–	6.7	89.0	47.7	–	–	7.62s	144.0	97.7
21	5.49bs	1.3	3.89d	3.41m	10.5	–	[a]	87.9	47.5	–	–	7.56s	145.0	98.5
22	5.59s	–	3.00d	3.63dd	10.5	–	6.4	89.3	47.3	–	–	7.84s	144.7	97.6
23	5.24bs	[a]	3.70m	3.33m	[a]	[a]	[a]	92.6	48.5	–	–	7.72s	147.6	95.3
24	5.43bs	0.9	3.74d	3.36dd	11.1	–	6.5	89.5	47.1	–	–	7.64s	144.4	98.2
25	5.50bs	[a]	3.87d	3.82dd	10.9	–	6.5	89.5	47.6	–	–	7.84s	144.8	97.0
26	5.13bs	[a]	3.62d	3.26dd	10.5	–	7.1	93.7	48.5	–	–	7.80s	148.1	95.0

[a] Not measured.

which is formed by attack of methoxide ion on the NH group (Scheme 2). Intramolecular nucleophilic displacement of the 6-OMs group gives the 1,6-anhydro-azasugar derivative. Stereochemically, this reaction is limited to sugar derivatives with β-D configuration. Debenzoylation of **18**, **22**, and **25** with sodium methoxide afforded **19**, **23**, and **26**, respectively, in high yields, the ^{1}H NMR spectra of which showed the expected upfield shifts in the signals for H2, H3, and H4 (see Section 4).

The bibliographic data on conformational analysis of 1,6-anhydrosugars[16] indicate that the $^1C_4$(D) form is the major conformation, although the $B_{3,0}$ conformation has also been postulated. Both conformations present 1,3-diaxial interactions and/or eclipsing of electron pairs. The only precedent[17] for 1,6-anhydro-azasugars refers to *N*-triphenylphosphonio derivatives, also proposing the $^1C_4$(D) conformation. The ^{1}H NMR data of compounds **17–26** were indicative of the $^1C_4$(D)



Scheme 2.

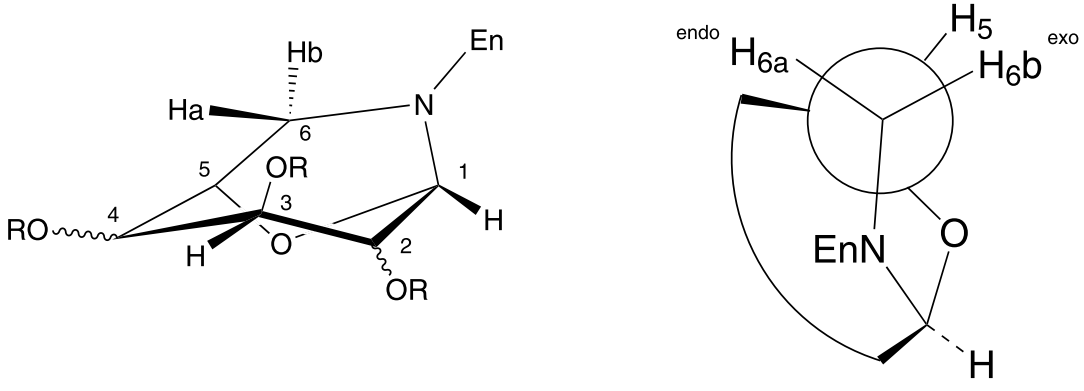


Figure 1. Preferred conformations of **17–26** in $CDCl_3$ solutions.

conformation distorted in the region C2, C3, C4 (Fig. 1a). The $J_{2,3}$ value ≈ 0 Hz in D-*gluco* (**17**–**20**) and D-*galacto* (**21**–**23**) compounds indicates a dihedral angle of 90°; the $J_{3,4}$ value, also ≈ 0 Hz, in D-*gluco* and D-*manno* derivatives (**24**–**26**) supports the same angle between H3 and H4. In the D-*manno* derivatives the $J_{2,3}$ values (5.1–5.3 Hz) indicate an angle close to 38°. The $J_{3,4}$ values (≈ 5.0 Hz) for the D-*galacto* compounds also support the indicated conformation. For compounds **17**, **19** (D-*gluco*), **21** (D-*galacto*), and **24** (D-*manno*) an H1–H3 coupling constant of 0.9–1.0 Hz, indicative of a W arrangement between the corresponding protons, was measured, which also ruled out the $B_{3,0}$ conformation.

In all cases, H6a resonated as a doublet ($J_{6a,6b} = 11.1$, $J_{5,6a} \approx 0$ Hz), which permitted the identification of H6a, and H6b as the *endo* and *exo* protons, respectively (Fig. 1b), which also supports the assigned conformation.

N-Deprotection of **19**, **23**, and **26** with chlorine in chloroform[18] gave the corresponding 1,6-anhydro-aza-sugar derivative **27**–**29** in virtually quantitative yield. Compounds **27**–**29** were characterized by their FABMS spectra, and used directly in the next step of the sequence.

The iminocyclitol ammonium acetates **30**–**32** were obtained by reaction of **27**–**29** with sodium cyanoborohydride in acetic acid. The H7a, H7b[19] resonances appeared at 3.16–3.36 ppm, whereas the signal for the corresponding proton (H1) in the parent compounds (**19**, **23**, **26**) appeared at 5.13–5.32 ppm. Similar differences were observed in the resonances of C7 (≈ 47.6 ppm) in **30**–**32** and C1 (92.6–93.7 ppm) in compounds **19**, **23**, and **26**.

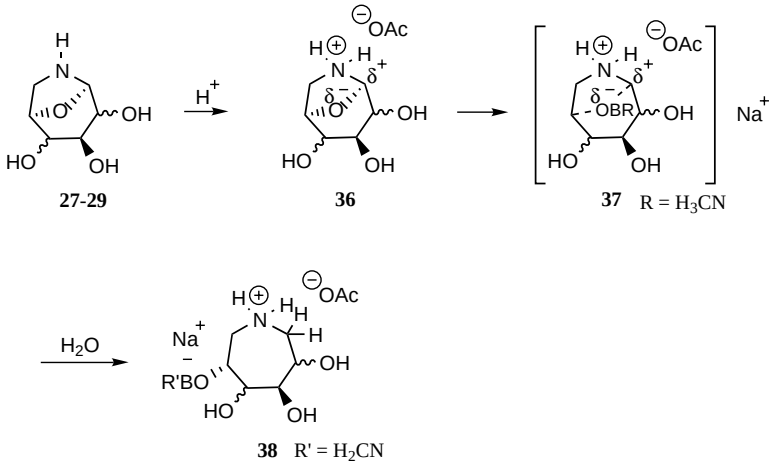
A possible mechanism for the formation of **30**–**32** is depicted in Scheme 3. The starting compound is protonated at the nitrogen atom (**36**), which produces an increase in the positive character of C1 of the sugar ring (C7 of the azepine ring). Transfer of hydride from the boron atom to C1 then takes place (**37**) with simultaneous bonding of the boron atom and the endocyclic oxygen to give **38**. The process is repeated with three molecules of **27**–**29**. Final hydrolysis produces **30**–**32**. Attempts to carry out the reduction on the enamino derivatives **19**, **23**, and **26** were unsuccessful. Probably, the enamino nitrogen atom, less basic than the amino group of **27**–**29**, is not protonated under the reaction conditions, and as a result attack of hydride ion on C1 is not favoured. Thus, this observation supports the proposed mechanism.

Treatment of **30**–**32** with Dowex–50W resin produced the target polyhydroxyperhydroazepines **33**–**35**, whose physical data were coincident with the data reported in the literature.[5]

Attempts to carry out similar sequences starting from the tri-*O*-acetyl derivative **8**, and from the per-*O*-mesyl compounds **17**, **21**, and **24** were either low-yielding or unsuccessful. In the case of **8**, acetyl migrations to the primary hydroxyl group were the main reactions, and for the per-*O*-mesyl derivatives (**17**, **21**, and **24**) elimination reactions were predominant.

The inhibitory potential of several iminocyclitols and aldohexopyranosyl enamines was determined on various glycosidases (α-glucosidase, β-galactosidase and β-glucosidase). The compounds were selected according to their hydrosolubilities (**1**–**4**, **17**, **19**, **23** and **26**), and the results are listed in Table 2.

All of the compounds assayed were weak inhibitors or did not inhibit the glycosidases, even at the millimolar range. As expected, no activity of **1**–**4** was found on α-glucosidase, due to the β-configuration. The poor inhibition by **17**, **19**, **23** and **26** on the three enzymes could be explained if they were forced to adopt a different conformation to the substrate. For β-galactosidase, the most active inhibitors were **23**, **3**, **19** and **26**, whereas for β-glucosidase, the most active inhibitors were **17**, **2**, **4**, and **26**.



Scheme 3.

Table 2. Comparison of the inhibition on various glycosidases of several iminocyclitols and aldohexopyranosyl enamines

Enzyme	α-Glucosidase baker's yeast			β-Glucosidase almonds			β-Galactosidase bovine liver		
Compound	% Inh[a]	*K*i[b]	IC_{50}[b]	% Inh	*K*i	IC_{50}	% Inh	*K*i	IC_{50}
1	N.I.	N.I.	N.I.	28	7.7	4.4	4	8.6	4.8
2	N.I.	N.I.	N.I.	27	2.1	1.5	N.I.	N.I.	N.I.
3	N.I.	N.I.	N.I.	27	6.6	3.8	N.I.	N.I.	N.I.
4	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.
17	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.	N.I.
19	N.I.	N.I.	N.I.	31	*	*	8	2.4	1.7
23	N.I.	N.I.	N.I.	25	4.2	2.7	21	1.5	1.2
26	N.I.	N.I.	N.I.	25	4.1	2.6	5	3.8	2.4

[a] % Inhibition determined at 1 mM concentration of inhibitor; N.I.: no inhibition.
[b] Values are given in mM.
* No non-competitive inhibitor.

3. Conclusions

In conclusion, the use of glycosylenamines in a new, short, experimentally easy and high-yielding synthetic route to polyhydroxyperhydroazepines is reported. The dialkoxycarbonylvinyl group is used to protect the amino function and to stabilize the intermediate amide ion. The configuration of the final product is defined by the starting glycosylenamine. The only limitation of the method is the need for the starting amino sugar to have the β-D-configuration.

4. Experimental

4.1. General methods

Melting points were determined with a Gallenkamp apparatus and are uncorrected. A Perkin–Elmer Model 141 MC polarimeter, 1 or 10 cm tubes, and solutions in CH_2Cl_2, were used for the measurement of specific rotations. IR spectra were recorded for KBr discs on a Bomen Michelson MB-120 FTIR spectrophotometer. ^1H (and ^{13}C NMR) spectra were recorded at 500 (125.7) or 300 (75.5) MHz with, respectively, Brüker 500 AMX, Brüker 300 AMX instruments. Chemical shifts are given in ppm and tetramethylsilane was the internal standard. Assignments were confirmed by homonuclear 2D COSY correlated experiments. Heteronuclear 2D correlated spectra were obtained in order to assist in carbon resonance assignments. Mass spectra (EI, CI and FAB) were recorded with a Kratos MS-80RFA or a Micromass AutoSpecQ instrument with a resolution of 1000 or 10000 (10% valley definition). For the FAB spectra, ions were produced by a beam of xenon atoms (6–7 KeV), using 3-nitrobenzyl alcohol and thioglycerol as matrix and NaI as salt. TLC was performed on Silica Gel HF_{254}, with detection by UV light or charring with H_2SO_4. Silica Gel 60 (Merck, 70–230 and 230–400 mesh) was used for preparative chromatography. The term 'conventional acetylation' means treatment with Ac_2O–pyridine (1:1 v/v, 10 mL for 1 g of sample) overnight. The reaction mixture was then poured into ice-water and extracted with CH_2Cl_2 and the organic layer was washed with 2N H_2SO_4 and saturated aqueous $NaHCO_3$, dried over $MgSO_4$, filtered, and concentrated.

The inhibition tests were performed[20] on α-D-glucosidase from baker's yeast, β-D-glucosidase from almonds and β-D-galactosidase from bovine liver, which were purchased from Sigma Chemical Co.

The inhibition constants (*K*i) and the nature of the inhibition were determined from Lineweaver–Burk plots. A typical enzymatic assay (final volume 160 μL) contains 0.01–0.5 units/mL of the enzyme and an aqueous solution of the appropriate *p*-nitrophenyl glycoside substrates at various final concentrations ranging from 3.0×10^{-5} to 6.2×10^{-3} mM buffered to the optimum pH of the enzyme.

Enzyme and inhibitor were incubated in a 96-well polystyrene microplate for 15 min at 37°C and the reaction was started by addition of the substrate. After 15 min of incubation at 37°C, the reaction was stopped by addition of 0.1 mL of 0.5 M sodium hydroxide.

The *p*-nitrophenolate formed was quantified by measuring the absorption at 414 nm on a microplate reader (Labsystem Multiskan RC). Under the conditions of the assay, the released *p*-nitrophenolate led to optical densities linear with both time of the reaction and concentration of the substrate.

4.2. Preparation of compounds 4–6, 9, 10, 13, 16

To a cooled (0°C) stirred solution of the corresponding *N*-(2,2-diethoxycarbonylvinyl)-β-D-glycopyranosylamine **1**, **2**, **3**, **7**, **8**, **12** and **15** (*m* g) in pyridine (*y* mL) under argon, a solution of mesyl chloride (*x* mL) was dropped. The mixture was stirred at rt for *t* min, the solution was poured into ice-water and extracted with CH_2Cl_2, the organic layer was separated, washed with 1 M sulphuric acid, saturated aqueous sodium hydrogencarbonate, and water, dried ($MgSO_4$), filtered and evaporated to dryness. The residue was purified by column chromatography.

4.2.1. *N*-(2,2-Diethoxycarbonylvinyl)-2,3,4-6-tetra-*O*-mesyl-β-D-glucopyranosylamine, 4. $m=1.00$ g (2.86 mmol); $x=1.56$ mL (17.2 mmol); $y=40$ mL; $t=3.0$ h. Column chromatography (EtOAc/hexane, 1:1) gave **4** as an amorphous solid. Yield 98%; $[\alpha]_D^{22}$ −30 (*c* 1.0, CH_2Cl_2); FABMS *m/z* 684 [(M+Na)$^+$]; IR 3036, 2945, 1707, 1615, 1354, 1244, 1179, 959, 812 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.32 (dd, 1H, $J_{NH,1}=9.2$, $J_{NH,HC=}=12.8$, NH), 7.96 (d, 1H, HC=), 5.01 (t, 1H, $J_{2,3}=J_{3,4}=9.2$, H-3), 4.87 (t, 1H, $J_{4,5}=9.2$, H-4), 4.80 (t, 1H, $J_{1,2}=9.2$, H-2), 4.70 (t, 1H, H-1), 4.64 (dd, 1H, $J_{5,6a}=2.1$, $J_{6a,6b}=11.6$, H-6a), 4.45 (dd, 1H, $J_{5,6b}=4.3$, H-6b), 4.30–4.18 (m, 4H, 2 CH_2CH$_3$), 3.96 (ddd, 1H, H-5), 3.29, 3.08 (each s, each 6H, 4 Ms), 1.33, 1.31 (each t, each 3H, $J_{H,H}=7.0$, 2 CH$_2$CH_3); ^{13}C NMR (125.7 MHz, $CDCl_3$) δ 167.6 (CO chelated), 165.0 (CO free), 156.8 (HC=), 96.1 (=C), 86.5 (C-1), 76.8 (C-3), 76.0 (C-2), 73.1 (C-5), 71.9 (C-4), 66.6 (C-6), 60.6, 60.3 (2 *C*H$_2$CH$_3$), 39.3, 39.2, 38.9, 37.6 (4 Ms), 14.1, 14.0 (2 CH$_2$*C*H$_3$). Anal calcd for $C_{18}H_{31}NO_{17}S_4$: C, 32.67; H, 4.72; N, 2.12. Found: C, 32.79; H, 4.72; N, 2.23%.

4.2.2. *N*-(2,2-Diethoxycarbonylvinyl)-2,3,4-6-tetra-*O*-mesyl-β-D-galactopyranosylamine, 5. $m=1.00$ g (2.86 mmol); $x=1.56$ mL (17.2 mmol); $y=40$ mL; $t=3.0$ h. Column chromatography (EtOAc/hexane, 1:1) gave **5** as an amorphous solid. Yield 97%. $[\alpha]_D^{26}$ +4 (*c* 1.0, CH_2Cl_2); FABMS *m/z* 684 [(M+Na)$^+$]; IR 3285, 3032, 2944, 1699, 1616, 1371, 1179, 1071, 970, 831 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.39 (dd, 1H, $J_{NH,1}=9.0$, $J_{NH,HC=}=12.8$, NH), 7.98 (d, 1H, HC=), 5.33 (d, 1H, $J_{3,4}=3.2$, H-4), 5.02 (dd, 1H, $J_{2,3}=9.9$, H-3), 4.88 (m, 1H, H-2), 4.74 (t, 1H, $J_{1,2}=9.0$, H-1), 4.37 (m, 1H, H-6a), 4.32 (m, 1H, H-6b), 4.30–4.19 (m, 5H, H-5, 2 CH_2CH$_3$), 3.29, 3.24, 3.08, 3.07 (each, s, 3H, 4 Ms), 1.33, 1.30 (each t, 3H, $J_{H,H}=7.1$, 2 CH$_2$CH_3); ^{13}C NMR (500 MHz, $CDCl_3$, δ ppm, *J* Hz) δ 168.0 (CO chelated), 165.2 (CO free), 157.1 (HC=), 95.9 (=C), 86.8 (C-1), 75.5 (C-5), 75.3 (C-3), 74.8 (C-2), 72.2 (C-4), 65.9 (C-6), 60.6, 60.4 (2 *C*H$_2$CH$_3$), 39.4, 39.1, 39.0, 37.6 (4 Ms), 14.2, 14.1 (2 CH$_2$*C*H$_3$). Anal. calcd for $C_{18}H_{31}NO_{17}S_4$: C, 32.67; H, 4.72; N, 2.12. Found: C, 32.89; H, 4.69; N, 2.12%.

4.2.3. *N*-(2,2-Diethoxycarbonylvinyl)-2,3,4-6-tetra-*O*-mesyl-β-D-manopyranosylamine, 6. $m=1.00$ g (2.86 mmol); $x=1.56$ mL (17.2 mmol); $y=40$ mL; $t=3.0$ h. Column chromatography (EtOAc/hexane, 2:1) gave **6** as an amorphous solid. Yield 95%. $[\alpha]_D^{26}$ −9 (*c* 1.0, CH_2Cl_2); FABMS *m/z* 684 [(M+Na)$^+$]; IR 3358, 3287, 3032, 2944, 1717, 1651, 1456, 1373, 1260, 1179, 1086, 1024, 801, 754 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.49 (dd, 1H, $J_{NH,1}=9.2$, $J_{NH,HC=}=13.0$, NH), 8.01 (d, 1H, HC=), 5.33 (dd, 1H, $J_{1,2}=0.8$, $J_{2,3}=3.1$, H-2), 5.08 (dd, 1H, $J_{3,4}=9.7$, H-3), 5.03 (dd, 1H, H-1), 4.86 (t, 1H, $J_{4,5}=9.7$, H-4), 4.61 (dd, 1H, $J_{5,6a}=2.2$, $J_{6a,6b}=11.7$, H-6a), 4.40 (dd, 1H, $J_{5,6b}=5.0$, H-6b), 4.23, 4.19 (each, q, 2H, $J_{H,H}=7.1$, 2 CH_2CH$_3$), 3.99 (ddd, 1H, H-5), 3.35, 3.26, 3.21, 3.08 (each, s, 3H, 4 Ms), 1.31, 1.29 (each, t, 3H, 2 CH$_2$CH_3); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 168.0, 165.3 (2 CO), 156.7 (HC=), 95.2 (=C), 84.0 (C-1), 76.6 (C-2), 73.9 (C-3), 73.4 (C-5), 70.6 (C-4), 67.0 (C-6), 60.4, 60.3 (2 *C*H$_2$CH$_3$), 39.1 (Ms), 39.0 (2 C, 2 Ms), 37.6 (Ms), 14.2, 14.1 (2 CH$_2$*C*H$_3$). Anal. calcd for $C_{18}H_{31}NO_{17}S_4$: C, 32.67; H, 4.72; N, 2.12; S, 19.38. Found: C, 32.92; H, 4.72; N, 2.16; S, 18.93%.

4.2.4. 2,3,4-Tri-*O*-benzoyl-*N*-(2,2-diethoxycarbonylvinyl)-6-*O*-mesyl-β-D-glucopyranosylamine, 9. $m=2.00$ g (3.02 mmol); $x=0.66$ mL (7.26 mmol); $y=90$ mL; $t=24$ h. Column chromatography (toluene/methanol, 9:1) gave **9** as a solid. Yield 73%; mp 150–152 (ether); $[\alpha]_D^{28}$ −33 (*c* 1.1, CH_2Cl_2); FABMS *m/z* 762 [(M+Na)$^+$]; IR 2980, 1732, 1615, 1454, 1362, 1262, 1177, 1092, 1026, 970, 802, 710 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.40 (dd, 1H, $J_{NH,1}=9.8$, $J_{NH,HC=}=12.9$, NH), 8.17–7.16 (m, 15H, 3 Ph), 7.98 (d, 1H, HC=), 5.99 (t, 1H, $J_{2,3}=J_{3,4}=9.8$, H-3), 5.57 (t, 1H, $J_{4,5}=9.8$, H-4), 5.55 (t, 1H, $J_{1,2}=9.8$, H-2), 4.87 (t, 1H, H-1), 4.46–4.42 (m, 1H, H-6a), 4.41 (m, 1H, H-5), 4.33–4.14 (m, 5H, H-6b, 2 CH_2CH$_3$), 3.04 (s, 3H, Ms), 1.33, 1.27 (each t, each 3H, $J_{H,H}=7.1$, 2 CH$_2$CH_3); ^{13}C NMR (125.7 MHz, $CDCl_3$) δ 167.3, 165.5, 165.3, 165.2, 165.1 (5 CO), 156.9 (HC=), 133.7–125.2 (18 C, 3 Ph), 95.5 (=C), 87.3 (C-1), 73.9 (C-3), 72.3 (C-2), 70.9 (C-5), 68.5 (C-4), 66.8 (C-6), 60.3, 60.1 (2 *C*H$_2$CH$_3$), 37.6 (Ms), 14.2, 14.1 (2 CH$_2$*C*H$_3$). Anal. calcd for $C_{36}H_{37}NO_{14}S$: C, 58.45; H, 5.04; N, 1.89. Found: C, 58.41; H, 5.05; N, 1.93%.

4.2.5. 2,3,4-Tri-*O*-acetyl-*N*-(2,2-diethoxycarbonylvinyl)-6-*O*-mesyl-β-D-glucopyranosylamine, 10. $m=0.22$ g (0.46 mmol); $x=0.1$ mL (1.10 mmol); $y=6.5$ mL; $t=12.0$ h. Column chromatography (ether/hexane, 12:1) gave **10** as an amorphous solid. Yield 72%; $[\alpha]_D^{28}$ −4 (*c* 1.0, CH_2Cl_2); FABMS *m/z* 576 [(M+Na)$^+$]; IR 2980, 1753, 1697, 1655, 1613, 1373, 1223, 1038, 907, 802 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.20 (dd, 1H, $J_{NH,1}=8.9$, $J_{NH,HC=}=13.1$, NH), 7.93 (d, 1H, HC=), 5.33 (t, 1H, $J_{2,3}=J_{3,4}=9.6$, H-3), 5.18–5.02 (m, 2H, H-2, H-4), 4.57 (t, 1H, $J_{1,2}=8.9$, H-1), 4.33–4.16 (m, 5H, H-5, 2 CH_2CH$_3$), 3.76 (m, 1H, H-6a), 3.61 (m, 1H, H-6b), 3.04 (s, 3H, Ms), 2.07, 2.03, 2.02 (each s, each 3H, 3 Ac), 1.32, 1.29 (each t, each 3H, $J_{H,H}=7.1$, 2 CH$_2$CH_3); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 170.0 (2 C, 2 CO), 169.5, 167.5, 165.5 (3 CO), 157.2 (HC=), 94.8 (=C), 87.0 (C-1), 73.4 (C-3), 72.2 (C-2), 70.2 (C-5), 67.7 (C-4), 66.0 (C-6), 60.3, 60.1 (2 *C*H$_2$CH$_3$), 37.6 (Ms), 20.5 (2 C, 2 Ac), 20.4 (Ac), 14.2, 14.1 (2 CH$_2$*C*H$_3$). Anal. calcd for $C_{21}H_{31}NO_{14}S$: C, 45.56; H, 5.64; N, 2.53. Found: C, 45.83; H, 5.65; N, 2.54%.

4.2.6. 2,3,4-Tri-*O*-benzoyl-*N*-(2,2-diethoxycarbonylvinyl)-6-*O*-mesyl-β-D-galactopyranosylamine, 13. $m=$ 1.18 g (1.78 mmol); $x=0.41$ mL (4.40 mmol); $y=53.10$ mL; $t=24$ h. Column chromatography (toluene/methanol, 9:1) gave **13** as an amorphous solid. Yield 92%; $[\alpha]_D^{28}$ +7 (*c* 1.0, CH_2Cl_2); FABMS *m/z* 762 [(M+Na)$^+$]; IR 3289, 2980, 1736, 1657, 1613, 1452, 1366, 1283, 1069, 1026, 801, 708 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.51 (dd, 1H, $J_{NH,1}=8.9$, $J_{NH,HC=}=13.0$, NH), 8.09–7.23 (m, 15H, 3 Ph), 8.01 (d, 1H, HC=), 5.97 (d, 1H, $J_{3,4}=3.3$, H-4), 5.81 (dd, 1H, $J_{1,2}=8.9$, $J_{2,3}=$ 10.1, H-2), 5.72 (dd, 1H, H-3), 4.86 (t, 1H, H-1), 4.42–4.32 (m, 3H, H-5, H-6a, H-6b) 4.33–4.30, 4.17 (each q, each 2H, $J_{H,H}=7.1$, 2 CH_2CH$_3$), 3.01 (s, 3H,

Ms), 1.34, 1.23 (each t, each 3H, 2 CH_2CH_3); ^{13}C NMR (125.7 MHz, $CDCl_3$) δ 167.7, 165.5, 165.4, 165.3, 165.2 (5 CO), 157.2 (HC=), 133.7–125.2 (18 C, 3 Ph), 95.2 (=C), 87.9 (C-1), 73.3 (C-5), 71.2 (C-3), 68.9 (C-2), 67.7 (C-4), 66.0 (C-6), 60.3, 60.1 (2 CH_2CH_3), 37.6 (Ms), 14.3, 14.2 (2 CH_2CH_3). Anal. calcd for $C_{36}H_{37}NO_{14}S$: C, 58.45; H, 5.04; N, 1.89. Found: C, 58.05; H, 5.07; N, 2.18%.

4.2.7. 2,3,4-Tri-*O*-benzoyl-*N*-(2,2-diethoxycarbonylvinyl)-6-*O*-mesyl-β-D-manopyranosylamine, 16. $m=1.30$ g (1.97 mmol); $x=0.43$ mL (4.73 mmol); $y=59.1$ mL; $t=24$ h. Column chromatography (toluene/methanol, 9:1) gave **16** as an amorphous solid. Yield 89%; $[\alpha]_D^{28}$ −39 (c 1.0, CH_2Cl_2); FABMS m/z 762 [(M+Na)$^+$]; IR 3067, 2980, 2932, 1728, 1620, 1452, 1381, 1287, 1061, 1021, 801, 702 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 9.51 (dd, 1H, $J_{NH,1}=8.8$, $J_{NH,HC=}=13.0$, NH), 8.10 (d, 1H, HC=), 8.08–7.26 (m, 15H, 3 Ph), 5.98 (dd, 1H, $J_{1,2}=1.1$, H-2), 5.79 (t, 1H, $J_{3,4}=J_{4,5}=10.0$, H-4), 5.68 (dd, $J_{2,3}=3.1$, 1H, H-3), 5.16 (dd, 1H, H-1), 4.48–4.47 (m, 2H, H-6a, H-6b), 4.20 (m, 1H, H-5), 4.19, 4.10 (each m, each 2H, 2 CH_2CH_3), 3.05 (s, 3H, Ms), 1.29, 1.19 (each t, each 3H, $J_{H,H}=7.0$, 2 CH_2CH_3); ^{13}C NMR (125.7 MHz, $CDCl_3$) δ 167.6, 165.5, 165.3 (2 C), 165.2 (5 CO), 156.6 (HC=), 133.9–128.4 (18 C, 3 Ph), 94.9 (=C), 84.8 (C-1), 74.1 (C-5), 71.7 (C-3), 69.8 (C-2), 67.5 (C-6), 65.8 (C-4), 60.2, 60.1 (2 CH_2CH_3), 37.7 (Ms), 14.3, 14.1 (2 CH_2CH_3). Anal. calcd for $C_{36}H_{37}NO_{14}S$: C, 58.45; H, 5.04; N, 1.89. Found: C, 58.11; H, 5.02; N, 1.82%.

4.3. Preparation of compounds 11 and 14

To a stirred solution of the corresponding *N*-(2,2-diethoxycarbonylvinyl)-β-D-glycopyranosylamine **2** and **3** (3.10 g, 8.88 mmol) in dry pyridine (16 mL), trityl chloride (2.7 mL, 9.69 mmol) was added. The mixture was heated for 24 h at 50°C, then cooled to 0°C and benzoyl chloride (2.40 g, 20.64 mmol) was added dropwise. The solution was stirred at rt for 24 h, then poured into ice-water and extracted with CH_2Cl_2. The combined extracts were washed with 1 M H_2SO_4, satd aq. $NaHCO_3$, and water, dried ($MgSO_4$) and evaporated to dryness. Column chromatography (EtOAc/hexane, 1:2) gave **11** and **14**, respectively, as amorphous solids.

4.3.1. 2,3,4-Tri-*O*-benzoyl-*N*-(2,2-diethoxycarbonylvinyl)-6-*O*-trityl-β-D-galactopyranosylamine, 11. Yield 91%; $[\alpha]_D^{20}$ +20 (c 0.8, CH_2Cl_2); FABMS m/z 926 [(M+Na)$^+$]; IR 3298, 3032, 2980, 2938, 1732, 1719, 1705, 1616, 1451, 1282, 1279, 1096, 1071, 706 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 9.39 (dd, $J_{1,NH}=8.7$, $J_{NH,=CH}=$ 13.3, 1H, NH), 7.99 (d, 1H, HC=), 7.93–7.12 (m, 30H, 6 Ph), 6.13 (dd, $J_{3,4}=3.3$, $J_{4,5}=1.1$, 1H, H-4), 5.75 (dd, $J_{2,3}=10.3$, 1H, H-3), 5.66 (dd, $J_{1,2}=8.7$, 1H, H-2), 4.75 (t, 1H, H-1), 4.26 (q, $J_{H,H}=7.1$, 2H, CH_2CH_3), 4.18–4.09 (m, 3H, H-5, CH_2CH_3), 3.47 (dd, $J_{5,6a}=5.4$, $J_{6a,6b}=9.0$, 1H, H-6a), 3.26 (t, $J_{5,6b}=9.0$, 1H, H-6b), 1.26, 1.24 (each t, each 3H, 2 CH_2CH_3); ^{13}C NMR (125.7 MHz, $CDCl_3$) δ 167.5, 165.4, 165.5, 165.1 (5 CO), 157.4 (HC=), 143.1–127.0 (6 Ph), 94.6 (=C), 87.8 ($C(Ph)_3$), 87.1 (C-1), 74.4 (C-5), 71.5 (C-3), 69.3 (C-2), 67.8 (C-4), 60.5 (C-6), 60.2, 60.0 (2 CH_2CH_3), 14.3, 14.2 (2 CH_2CH_3). Anal. calcd for $C_{54}H_{49}NO_{12}$: C, 71.75; H, 5.46; N, 1.55. Found: C, 71.50; H, 5.50; N, 1.81%.

4.3.2. 2,3,4-Tri-*O*-benzoyl-*N*-(2,2-diethoxycarbonylvinyl)-6-*O*-trityl-β-D-mannopyranosylamine, 14. Yield 90%; $[\alpha]_D^{20}$ −41 (c 1.1, CH_2Cl_2); FABMS m/z 926 [(M+Na)$^+$]; IR 3288, 3061, 2982, 2934, 1774, 1699, 1651, 1616, 1454, 1271, 1103, 1067, 1026, 706 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 9.56 (dd, $J_{1,NH}=8.0$, $J_{NH,=CH}=$ 13.3, 1H, NH), 8.24 (d, 1H, HC=), 8.17–7.10 (m, 30H, 6 Ph), 6.17 (t, $J_{3,4}=J_{4,5}=10.2$, 1H, H-4), 5.98 (dd, $J_{1,2}=1.1$, $J_{2,3}=3.1$, 1H, H-2), 5.55 (dd, 1H, H-3), 5.11 (dd, 1H, H-1), 4.17–4.08 (m, 4H, 2 CH_2CH_3), 3.90 (ddd, $J_{5,6a}=2.2$, $J_{5,6b}=3.5$, 1H, H-5), 3.54 (dd, $J_{6a,6b}=$ 10.7, 1H, H-6a), 3.26 (dd, 1H, H-6b), 1.22, 1.18 (each t, each 3H, $J_{H,H}=7.1$, 2 CH_2CH_3); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 167.7, 165.5 (2 C), 165.3, 164.7 (5 CO), 156.6 (HC=), 143.4–126.8 (6 Ph), 93.9 (=C), 86.6 ($C(Ph)_3$), 84.4 (C-1), 75.9 (C-5), 72.4 (C-3), 70.2 (C-2), 65.6 (C-4), 61.8 (C-6), 60.0, 59.8 (2 CH_2CH_3), 14.2, 14.1 (2 CH_2CH_3). Anal. calcd for $C_{54}H_{49}NO_{12}$: C, 71.75; H, 5.46; N, 1.55. Found: C, 72.03; H, 5.54; N, 1.57%.

4.4. Procedure for the preparation of compounds 12, 15

A cooled (0°C) solution of the corresponding trityl derivatives **11**, **14** (2.76 g, 3.06 mmol) in F_3CCOOH/H_2O (3:1) (44 mL) was stirred for 5 min and then neutralized with sodium hydrogen carbonate and extracted with CH_2Cl_2. The organic layer was separated, washed with water, dried ($MgSO_4$), filtered, and evaporated to dryness. The residue was purified by column chromatography (toluene/methanol, 9:1).

4.4.1. 2,3,4-Tri-*O*-benzoyl-*N*-(2,2-diethoxycarbonylvinyl)-β-D-galactopyranosylamine, 12. Amorphous solid; yield 83%; $[\alpha]_D^{20}$ +5 (c 1.1, CH_2Cl_2); EIMS m/z 662 (M$^+$); IR 3482, 3065, 2980, 2938, 1736, 1613, 1452, 1260, 1101, 801, 710 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 9.50 (dd, $J_{1,NH}=8.9$ $J_{NH,=CH}=13.2$, 1H, NH), 8.13–7.22 (m, 15H, 3 Ph), 8.02 (d, 1H, HC=), 5.88 (d, $J_{3,4}=3.3$, 1H, H-4), 5.86 (dd, $J_{1,2}=8.9$, $J_{2,3}=10.3$, 1H, H-2), 5.73 (dd, 1H, H-3), 4.85 (t, 1H, H-1), 4.26, 4.15 (each q, each 2H, $J_{H,H}=7.1$, CH_2CH_3), 4.19–4.04 (m, 1H, H-5), 3.84 (dd, $J_{5,6a}=6.6$, $J_{6a,6b}=11.9$, 1H, H-6a), 3.65 (dd, $J_{5,6b}=6.7$, 1H, H-6b), 1.33, 1.25 (each t, each 3H, 2 CH_2CH_3); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 167.6, 166.4, 165.5, 165.3, 165.2 (5 CO), 157.5 (HC=), 133.8–128.2 (3 Ph), 94.6 (=C), 87.8 (C-1), 75.8 (C-5), 71.4 (C-3), 69.3 (C-2), 68.6 (C-4), 60.4 (C-6), 60.2, 60.0 (2 CH_2CH_3), 14.2, 14.1 (2 CH_2CH_3). Anal. calcd for $C_{35}H_{35}NO_{12}$: C, 63.53; H, 5.33; N, 2.12. Found: C, 63.20; H, 5.42; N, 2.20%.

4.4.2. 2,3,4-Tri-*O*-benzoyl-*N*-(2,2-diethoxycarbonylvinyl)-β-D-mannopyranosylamine, 15. Amorphous solid; yield 98%; $[\alpha]_D^{20}$ −44 (c 1.1, CH_2Cl_2); FABMS m/z 684 (M+Na)$^+$; IR 3281, 3065, 2980, 2876, 1732, 1678, 1609, 1452, 1258, 1069, 1028, 710 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 9.48 (dd, $J_{1,NH}=8.9$ $J_{NH,=CH}=13.2$, 1H, NH), 8.11 (d, 1H, HC=), 8.10–7.29 (m, 15H, 3 Ph),

5.97 (dd, $J_{1,2}=1.1$, $J_{2,3}=3.0$, 1H, H-2), 5.78 (t, $J_{3,4}=J_{4,5}=10.1$, 1H, H-4), 5.72 (dd, 1H, H-3), 4.13 (dd, 1H, H-1), 4.23–4.04 (m, 4H, 2 CH_2CH$_3$), 3.92–3.78 (m, 3H, H-5, H-6a, H-6b), 1.28, 1.17 (each t, each 3H, $J_{H,H}=$ 7.1, 2 CH$_2$CH_3); ^{13}C NMR (75.5 MHz, CDCl$_3$) δ 167.4, 166.0, 165.5, 165.4 (2 C) (5 CO), 156.7 (HC=), 133.7–128.2 (3 Ph), 94.5 (=C), 85.0 (C-1), 76.6 (C-5), 71.6 (C-3), 69.9 (C-2), 66.1 (C-4), 61.3 (C-6), 60.1, 60.0 (2 CH$_2$CH$_3$), 14.2, 14.0 (2 CH$_2$$CH_3$). Anal. calcd for $C_{35}H_{35}NO_{12}$: C, 63.53; H, 5.33; N, 2.12. Found: C, 63.52; H, 5.29; N, 2.10%.

4.5. General procedure for the preparation of compounds 17, 18, 20, 21, 22, 24, and 25

To a stirred solution of the corresponding 6-*O*-mesylated *N*-diethoxycarbonylvinyl-D-glycopyranosylamines **4**, **5**, **6**, **9**, **10**, **13**, and **16** (273 g, 0.37 mmol) in DMF (4.8 mL) at 40°C, 20 mmHg of sodium methoxide (21 mg, 0.37 mmol) was added. The reaction was stirred for 15 min and controlled by TLC (CH$_2$Cl$_2$/MeOH, 70:1). The mixture was added to ice-water and extracted with CH$_2$Cl$_2$. The organic layer was separated, washed with 1 M sulphuric acid, saturated aqueous sodium hydrogencarbonate, and water, dried (MgSO$_4$), filtered, and evaporated to dryness. The residue was purified by column chromatography.

4.5.1. 1,6-Anhydro-*N*-(2,2-diethoxycarbonylvinyl)-2,3,4-tri-*O*-mesyl-β-D-glucopyranosylamine, 17. Column chromatography (toluene/EtOAc, 2:1) gave **17** as an amorphous solid. Yield 70%; $[\alpha]_D^{22}$ −33 (*c* 1.0, CH$_2$Cl$_2$); FABMS *m*/*z* 588 [(M+Na)$^+$]; IR 3027, 2942, 1707, 1607, 1366, 1179, 959, 816 cm^{-1}; ^{1}H NMR δ (500 MHz, CDCl$_3$) 7.59 (s, 1H, HC=), 5.55 (bs, 1H, H-1), 5.00 (m, 1H, H-3), 4.92 (d, 1H, $J_{5,6b}=6.5$, H-5), 4.76 (m, 2H, H-2, H-4), 4.31–4.18 (m, 4H, 2 CH_2CH$_3$), 3.71 (d, 1H, $J_{6a,6b}=10.7$, H-6a), 3.48 (m, 1H, H-6b), 3.23, 3.22, 3.20 (each s, each 3H, 3 Ac), 1.32, 1.28 (each t, each 3H, $J_{H,H}=7.1$, 2 CH$_2$CH_3); ^{13}C NMR (75.5 MHz, CDCl$_3$) δ 166.5, 166.1 (2 CO), 144.9 (HC=), 98.7 (=C), 88.6 (C-1), 75.6 (C-5), 73.6 (C-4), 72.6 (C-3), 72.0 (C-2), 61.1, 60.6 (2 CH$_2$CH$_3$), 48.4 (C-6), 38.6, 38.5, 38.4 (3 Ms), 14.2, 14.0 (2 CH$_2$$CH_3$). Anal. calcd for $C_{17}H_{27}NO_{14}S_3$: C, 36.10; H, 4.81; N, 2.48; S, 17.00. Found: C, 36.27; H, 4.70; N, 2.67; S, 17.26%.

4.5.2. 1,6-Anhydro-2,3,4-tri-*O*-benzoyl-*N*-(2,2-diethoxycarbonylvinyl)-β-D-glucopyranosylamine, 18. Column chromatography (CH$_2$Cl$_2$/MeOH, 100:1) gave **18** as a solid. Yield 80%; mp 166–168 (ether–hexane); $[\alpha]_D^{26}$ −69 (*c* 1.0, CH$_2$Cl$_2$); FABMS *m*/*z* 666 [(M+Na)$^+$]; IR 2961, 1717, 1699, 1364, 1262, 1088, 1026, 710 cm^{-1}; ^{1}H NMR (500 MHz, CDCl$_3$) δ 8.17–7.27 (m, 15H, 3 Ph), 7.84 (s, 1H, HC=), 5.65 (s, 1H, H-1), 5.54 (s, 1H, H-3), 5.14 (s, 1H, H-2), 5.08 (s, 1H, H-4), 4.99 (d, 1H, $J_{5,6b}=6.4$, H-5), 4.31–4.18 (m, 4H, 2 CH_2CH$_3$), 3.82 (d, 1H, $J_{6a,6b}=10.9$, H-6a), 3.70 (dd, 1H, H-6b), 1.33–1.26 (m, 6H, 2 CH$_2$CH_3); ^{13}C NMR (125.7 MHz, CDCl$_3$) δ 166.4, 166.2, 165.1, 165.0, 164.5 (5 CO), 144.6 (HC=), 133.7–127.8 (18 C, 3 Ph), 97.8 (=C), 89.4 (C-1), 75.7 (C-5), 69.6 (C-4), 68.8 (2 C, C-2, C-3), 60.9, 60.3 (2 CH$_2$CH$_3$), 48.1 (C-6), 14.3, 14.1 (2 CH$_2$$CH_3$). Anal. calcd for $C_{35}H_{33}NO_{11}$: C, 65.31; H, 5.17; N, 2.18. Found: C, 64.87; H, 4.98; N, 2.30%.

4.5.3. 1,6-Anhydro-2,3,4-tri-*O*-acetyl-*N*-(2,2-diethoxycarbonylvinyl)-β-D-glucopyranosylamine, 20. Column chromatography (ether/hexane, 12:1) gave **20** as an amorphous solid. Yield 80%; $[\alpha]_D^{28}$ −135 (*c* 1.1, CH$_2$Cl$_2$); FABMS *m*/*z* 480 [(M+Na)$^+$]; IR 2984, 1746, 1605, 1371, 1221, 1163, 1047 cm^{-1}; ^{1}H NMR (500 MHz, CDCl$_3$) δ 7.62 (s, 1H, HC=), 5.38 (bs, 1H, H-1), 4.86 (m, 1H, H-3), 4.73 (d, 1H, $J_{5,6b}=6.7$, H-5), 4.66 (m, 2H, H-2, H-4), 4.29–4.15 (m, 4H, 2 CH_2CH$_3$), 3.61 (d, 1H, $J_{6a,6b}=10.7$, H-6a), 3.40 (dd, 1H, H-6b), 2.17 (s, 6H, 2 Ac), 2.14 (s, 3H, Ac), 1.32, 1.27 (each, t, 3H, $J_{H,H}=7.1$, 2 CH$_2$CH_3); ^{13}C NMR (125.7 MHz, CDCl$_3$) δ 169.7, 169.4, 168.9, 166.4, 166.3 (5 CO), 144.0 (HC=), 97.7 (=C), 89.0 (C-1), 75.6 (C-5), 69.2 (C-4), 68.4 (C-3), 68.2 (C-2), 60.8, 60.3 (2 CH$_2$CH$_3$), 47.7 (C-6), 20.8, 20.7, 20.4 (3 Ac), 14.2, 14.1 (2 CH$_2$$CH_3$). Anal. calcd for $C_{20}H_{27}NO_{11}$: C, 52.51; H, 5.95; N, 3.06. Found: C, 52.59; H, 6.14; N, 3.05%.

4.5.4. 1,6-Anhydro-*N*-(2,2-diethoxycarbonylvinyl)-2,3,4-tri-*O*-mesyl-β-D-galactopyranosylamine, 21. Column chromatography (EtAcO/hexane, 3:1) gave **21** as an amorphous solid. Yield 69%; $[\alpha]_D^{26}$ −19 (*c* 1.1, CH$_2$Cl$_2$); FABMS *m*/*z* 588 [(M+Na)$^+$]; IR 3362, 2907, 2807, 1715, 1456, 1373, 1086, 1024 y 746 cm^{-1}; ^{1}H NMR (300 MHz, CDCl$_3$) δ 7.56 (s, 1H, HC=), 5.49 (bs, 1H, H-1), 5.18 (m, 1H, H-3), 5.12 (t, 1H, $J_{3,4}=J_{4,5}=4.5$, H-4), 4.95 (bs, 1H, H-2), 4.78 (m, 1H, H-5), 4.28–4.15 (m, 4H, 2 CH$_2$CH$_3$), 3.89 (δ, 1H, $J_{6a,6b}=10.5$, H-6a), 3.41 (m, 1H, H-6b), 3.22, 3.21, 3.19 (each, s, 3H, 3 Ms), 1.38–1.25 (m, 6H, 2 CH$_2$CH$_3$); ^{13}C NMR (75.4 MHz, CDCl$_3$) δ 166.5, 166.1 (2 CO), 145.0 (HC=), 98.5 (=C), 87.9 (C-1), 74.5 (C-5), 74.3 (C-2), 72.1 (C-3), 67.3 (C-4), 61.1, 60.6 (2 CH$_2$CH$_3$), 47.5 (C-6), 38.8, 38.3 (2 Ms), 14.1, 14.0 (2 CH$_2$CH$_3$). HRCIMS calcd for $C_{17}H_{28}NO_{14}S_3$: 566.0672. Found 566.0682.

4.5.5. 1,6-Anhydro-2,3,4-tri-*O*-benzoyl-*N*-(2,2-diethoxycarbonylvinyl)-β-D-galactopyranosylamine, 22. Column chromatography (EtAcO/hexane, 2:1) gave **22** as an amorphous solid. Yield 80%; $[\alpha]_D^{26}$ +5 (*c* 0.7, CH$_2$Cl$_2$); FABMS *m*/*z* 666 [(M+Na)$^+$]; IR 3063, 2980, 1736, 1691, 1601, 1452, 1260, 1163, 1096, 1024, 878, 708 cm^{-1}; ^{1}H NMR (500 MHz, CDCl$_3$) δ 8.14–7.26 (m, 15H, 3 Ph), 7.84 (s, 1H, HC=), 5.91 (dd, 1H, $J_{2,3}=1.3$, $J_{3,4}=5.5$, H-3), 5.74 (m, 1H, H-4), 5.59 (s, 1H, H-1), 5.32 (d, 1H, H-2), 4.88 (m, 1H, H-5), 4.32–4.19 (m, 4H, 2 CH_2CH$_3$), 3.00 (d, 1H, $J_{6a,6b}=10.5$, H-6a), 3.63 (dd, $J_{5,6b}=6.4$ H, H-6b), 1.34, 1.28 (each t, each 3H, $J_{H,H}=$ 7.1, 2 CH$_2$CH_3); ^{13}C NMR (125.7 MHz, CDCl$_3$) δ 166.5, 166.3, 165.1, 164.9, 164.8 (5 CO), 144.7 (HC=), 133.8–128.3 (18 C, 3 Ph), 97.6 (=C), 89.3 (C-1), 74.1 (C-5), 71.3 (C-2), 67.3 (C-3), 65.2 (C-4), 60.8, 60.3 (2 CH$_2$CH$_3$), 47.3 (C-6), 14.3, 14.2 (2 CH$_2$$CH_3$). Anal. calcd for $C_{35}H_{33}NO_{11}$: C, 65.31; H, 5.17; N, 2.18. Found: C, 64.94; H, 5.54; N, 2.20%.

4.5.6. 1,6-Anhydro-*N*-(2,2-diethoxycarbonylvinyl)-2,3,4-tri-*O*-mesyl-β-D-mannopyranosylamine, 24. Column chromatography (EtAcO/hexane, 2:1) gave **24** as an

amorphous solid. Yield 68%; $[\alpha]_D^{28}$ −113 (*c* 1.0, CH_2Cl_2); FABMS *m/z* 588 [(M+Na)$^+$]; IR 3412, 3025, 2938, 1692, 1607, 1466, 1366, 1267, 1177, 1090, 1030, 964, 851, 741 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.64 (s, 1H, HC=), 5.43 (bs, 1H, H-1), 5.20 (m, 1H, H-3), 5.01 (dd, 1H, $J_{1,2}=2.4$, $J_{2,3}=5.1$, H-2), 4.95 (m, 1H, H-4), 4.90 (d, 1H, $J_{5,6b}=6.9$, H-5), 4.27–4.16 (m, 4H, 2 CH_2CH$_3$), 3.74 (d, 1H, $J_{6a,6b}=11.1$, H-6a), 3.36 (dd, 1H, H-6b), 3.25, 3.20, 3.19 (each, s, 3H, 3 Ms), 1.32, 1.27 (each, t, 3H, $J_{H,H}=7.1$, 2 CH$_2$CH_3); ^{13}C NMR (125.7 MHz, $CDCl_3$) δ 166.4, 166.3 (2 CO), 144.4 (HC=), 98.2 (=C), 89.5 (C-1), 76.4 (C-5), 76.1 (C-4), 71.5 (C-3), 69.7 (C-2), 61.0, 60.4 (2 *C*H$_2$CH$_3$), 47.1 (C-6), 38.7, 38.6, 38.5 (3 Ms), 14.2, 14.1 (2 CH$_2$*C*H$_3$). Anal. calcd for $C_{17}H_{27}NO_{14}S_3$: C, 36.10; H, 4.81; N, 2.48. Found: C, 36.45; H, 4.97; N, 2.39%.

4.5.7. 1,6-Anhydro-2,3,4-tri-*O*-benzoyl-*N*-(2,2-diethoxycarbonylvinyl)-β-D-mannopyranosylamine, 25. Column chromatography (ether/hexane, 1:1) gave **25** as an amorphous solid. Yield 93%; $[\alpha]_D^{21}$ −2 (*c* 0.7, CH_2Cl_2); FABMS *m/z* 666 [(M+Na)$^+$]; IR 3063, 2980, 2903, 1726, 1682, 1601, 1452, 1263, 1206, 1107, 1024, 856, 708 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.15–7.26 (m, 15H, 3 Ph), 7.84 (s, 1H, HC=), 5.93 (d, $J_{2,3}=5.3$, 1H, H-3), 5.67 (d, 1H, H-2), 5.50 (bs, 1H, H-1), 5.28 (bs, 1H, H-4), 4.97 (d, 1H, $J_{5,6b}=6.5$, H-5), 4.29 (q, 2H, $J_{H,H}=7.1$, CH_2CH$_3$), 4.16–4.07 (m, 2H, CH_2CH$_3$), 3.87 (d, 1H, $J_{6a,6b}=10.9$, H-6a), 3.82 (dd, 1H, H-6b), 1.29, 1.14 (each t, each 3H, 2 CH$_2$CH_3); ^{13}C NMR (125.7 MHz, $CDCl_3$) δ 166.7, 166.3, 165.2, 165.0, 164.8 (5 CO), 144.8 (HC=), 133.7–128.3 (18 C, 3 Ph), 97.0 (=C), 89.5 (C-1), 76.3 (C-5), 72.2 (C-4), 67.6 (C-3), 67.5 (C-2), 60.9, 60.0 (2 *C*H$_2$CH$_3$), 47.6 (C-6), 14.3, 14.2 (2 CH$_2$*C*H$_3$). Anal. calcd for $C_{35}H_{33}NO_{11}$: C, 65.31; H, 5.17; N, 2.18. Found: C, 65.03; H, 5.07; N, 2.37%.

4.6. General procedure for the preparation of compounds 19, 23, and 26

To a solution of the corresponding *O*-benzoylated (140 mg, 0.218 mmol) **18**, **22**, and **25** in anhydrous methanol (41.3 mL), at rt under argon, was added NaMeO/MeOH 1 M (104 μL). The process was controlled by TLC CH_2Cl_2/MeOH (15:1) until total deacylation of starting material. After 4 h, the reaction mixture was neutralized with acid resin Amberlite IR-120(H$^+$), filtered and the solvent was evaporated to dryness. The residue was purified by column chromatography (CH_2Cl_2/MeOH, 15:1).

4.6.1. 1,6-Anhydro-*N*-(2,2-diethoxycarbonylvinyl)-β-D-glucopyranosylamine, 19. Yield 90%; amorphous solid; $[\alpha]_D^{26}$ −9 (*c* 1.0, CH_2Cl_2); FABMS *m/z* 354 [(M+Na)$^+$]; IR 3391, 2980, 2932, 1697, 1597, 1395, 1275, 1208, 1096, 1045, 889, 735 cm^{-1}; ^{1}H NMR (500 MHz, MeOD) δ 7.74 (s, 1H, HC=), 5.32 (bs, 1H, H-1), 4.58 (m, 1H, H-5), 4.19, 4.13 (each q, each 2H, $J_{H,H}=7.1$, 2 CH_2CH$_3$), 3.57 (m, 1H, H-2), 3.70 (m, 1H, H-3), 3.54 (m, 1H, H-6a), 3.51 (m, 1H, H-4), 3.40 (m, 1H, H-6b), 1.28, 1.26 (each t, each 3H, 2 CH$_2$CH_3); ^{13}C NMR (125.7 MHz, $CDCl_3$) δ 169.1, 168.8 (2 CO), 147.5 (HC=), 95.8 (=C), 93.2 (C-1), 79.7 (C-5), 73.7 (C-3), 72.0 (C-4), 71.6 (C-2), 61.9, 61.2 (2 *C*H$_2$CH$_3$), 49.5–48.5 (C-6), 14.7, 14.5 (2 CH$_2$*C*H$_3$). Anal. calcd for $C_{14}H_{21}NO_8$: C, 50.75; H, 6.39; N, 4.23. Found: C, 50.36; H, 6.43; N, 4.19%.

4.6.2. 1,6-Anhydro-*N*-(2,2-diethoxycarbonylvinyl)-β-D-galactopyranosylamine, 23. 97%; amorphous solid; $[\alpha]_D^{26}$ −54 (*c* 1.0, MeOH); FABMS *m/z* 354 [(M+Na)$^+$]; IR 3410, 2982, 2903, 1697, 1605, 1393, 1275, 1208, 1099, 1072, 866, 758 cm^{-1}; ^{1}H NMR (500 MHz, MeOD) δ 7.72 (s, 1H, HC=), 5.24 (bs, 1H, H-1), 4.41 (m, 1H, H-5), 4.20, 4.13 (each q, each 2H, $J_{H,H}=7.1$, 2 CH_2CH$_3$), 3.96 (t, 1H, $J_{3,4}=J_{4,5}=4.6$, H-4), 3.87 (m, 1H, H-3), 3.80 (bs, 1H, H-2), 3.70 (m, 1H, H-6a), 3.33 (m, 1H, H-6b), 1.29, 1.24 (each t, each 3H, 2 CH$_2$CH_3); ^{13}C NMR (125.7 MHz, $CDCl_3$) δ 169.2, 168.9 (2 CO), 147.6 (HC=), 95.3 (=C), 92.6 (C-1), 78.1 (C-5), 72.8 (C-2), 72.1 (C-3), 65.4 (C-4), 61.8, 61.1 (2 *C*H$_2$CH$_3$), 48.5 (C-6), 14.7, 14.5 (2 CH$_2$*C*H$_3$). HREIMS calcd for $C_{14}H_{21}NO_8$: 331.1267. Found 331.1263. Anal. calcd for $C_{14}H_{21}NO_8$: C, 50.75; H, 6.39; N, 4.23. Found: C, 50.35; H, 6.51; N, 4.26%.

4.6.3. 1,6-Anhydro-*N*-(2,2-diethoxycarbonylvinyl)-β-D-mannopyranosylamine, 26. 97%; amorphous solid; $[\alpha]_D^{21}$ −138 (*c* 0.66, MeOH); FABMS *m/z* 354 [(M+Na)$^+$]; IR 3376, 2980, 2907, 1674, 1597, 1379, 1275, 1209, 1078, 1038, 866, 766 cm^{-1}; ^{1}H NMR (500 MHz, MeOD) δ 7.80 (s, 1H, HC=), 5.13 (bs, 1H, H-1), 4.55 (m, 1H, $J_{5,6b}=7.1$, H-5), 4.19, 4.13 (each q, each 2H, $J_{H,H}=7.1$, 2 CH_2CH$_3$), 3.88 (m, 2H, H-2, H-3), 3.77 (bs, 1H, H-4), 3.62 (d, 1H, $J_{6a,6b}=10.5$, H-6a), 3.26 (dd, 1H, H-6b), 1.29, 1.24 (each t, each 3H, 2 CH$_2$CH_3); ^{13}C NMR (125.7 MHz, $CDCl_3$) δ 169.4, 169.2 (2 CO), 148.1 (HC=), 95.0 (=C), 93.7 (C-1), 79.5 (C-5), 73.1 (C-4), 71.9 (C-2), 67.1 (C-3), 61.9, 61.2 (2 *C*H$_2$CH$_3$), 48.5 (C-6), 14.7, 14.5 (2 CH$_2$*C*H$_3$). HREIMS calcd for $C_{14}H_{21}NO_8$: 331.1267. Found 331.1268. Anal. calcd for $C_{14}H_{21}NO_8$: C, 50.75; H, 6.39; N, 4.23. Found: C, 50.36; H, 6.28; N, 4.34%.

4.7. General procedure for the preparation of compounds 27–29

To a solution of the corresponding 1,6-anhydro-*N*-(2,2-diethoxycarbonylvinyl)-β-D-glycopyranosylamine **19**, **23**, **26** (38 mg, 0.115 mmol) in dichloromethane (14.0 mL), CH_2Cl_2 saturated with chlorine at 0°C was added. The reaction mixture was kept for 15 min at 0°C until total consumption of the starting material (TLC), and evaporated, then washed with dry dichloromethane (2× 2.2 mL). The residue was dried and used without further purification.

4.7.1. 1,6-Anhydro-β-D-glucopyranosylamine, 27. Amorphous solid FABMS *m/z* 162 [(M+H)$^+$].

4.7.2. 1,6-Anhydro-β-D-galactopyranosylamine, 28. Amorphous solid FABMS *m/z* 162 [(M+H)$^+$].

4.7.3. 1,6-Anhydro-β-D-mannopyranosylamine, 29. Amorphous solid FABMS *m/z* 162 [(M+H)$^+$].

4.8. General procedure for the preparation of compounds 33–35

A solution of the corresponding 1,6-anhydro compound **27**–**29** (63 mg, 0.39 mmol) in acetic acid (3.5 mL) was treated with NaH_3BCN (33 mg, 0.51 mmol). The mixture was stirred for 24 h at rt and then evaporated to dryness. The residue (tetrahydroxyazepinium acetate, **30**–**32**) was washed with dichloromethane, filtered and purified by ion-exchange chromatography (Dowex® 50 W-X8 NH_4^+ form.) elude first with water and then with a NH_4OH gradient, 0→1N. The fractions containing the product were concentrated.

4.8.1. (3*R*,4*R*,5*R*,6*S*)-3,4,5,6-Tetrahydroxyazepine, 33. Yield 58%; $[\alpha]_D^{26}$ −7 (*c* 1.4, MeOH); EIMS *m*/*z* 163 [$M^{+\bullet}$]; IR 3464, 2874, 1682, 1559, 1385, 1314, 1101, 1020, and 949 cm^{-1}; ^1H NMR (500 MHz, MeOD) δ 3.92 (ddd, 1H, $J_{5,6}=1.8$, $J_{6,7a}=6.0$, $J_{6,7b}=3.3$, H-6), 3.76 (dd, 1H, $J_{3,4}=5.6$, $J_{4,5}=7.1$, H-4), 3.68 (dd, 1H, H-5), 3.57 (ddd, 1H, $J_{2a,3}=6.5$, $J_{2b,3}=3.3$, H-3), 2.98 (dd, 1H, $J_{7a,7b}=14.1$, H-7a), 2.93 (dd, 1H, $J_{2a,2b}=14.3$, H-2a), 2.88 (dd, 1H, H-2b), and 2.84 (dd, 1H, H-7b); ^{13}C NMR (125.7 MHz, MeOD) δ 77.6 (C-5), 77.0 (C-4), 75.2 (C-3), 73.0 (C-6), 51.8 (C-7), and 50.9 (C-2), HREIMS calcd for $C_6H_{13}NO_4$: 163.0845. Found 163.0842.

4.8.2. (3*R*,4*S*,5*R*,6*S*)-3,4,5,6-Tetrahydroxyazepine, 34. Yield 58%; IR 3389, 2920, 1603, 1568, 1418, 1265, 1096, 1044, and 955 cm^{-1}; ^1H NMR (500 MHz, MeOD) δ 3.96 (d, 2H, $J_{3,4}=6.3$, H-4, H-5), 3.83 (m, 2H, H-3, H-6), 3.15 (dd, 2H, $J_{2b,3}=J_{6,7b}=4.0$, $J_{2a,2b}=J_{7a,7b}=$ 14.3, H-2b, H-7b), 2.87 (dd, 2H, $J_{2a,3}=J_{6,7a}=4.7$, H-2a, H-7a,); ^{13}C NMR (125.7 MHz, MeOD) δ 74.0 (C-4, C-5), 69.9 (C-3, C-6), and 50.9 (C-2, C-7). HRCIMS calcd for $C_6H_{14}NO_4$: 164.0923. Found 164.0923.

4.8.3. (3*R*,4*R*,5*R*,6*R*)-3,4,5,6-Tetrahydroxyazepine, 35. Yield 58%; IR 3389, 2920, 1645, 1549, 1377, 1314, 1099, 1032, and 870 cm^{-1}; ^1H NMR (500 MHz, MeOD) δ 4.13 (td, 2H, $J_{2,3}=J_{6,7}=3.9$, $J_{3,4}=J_{5,6}=1.1$, H-3, H-6), 3.81 (d, 2H, H-4, H-5), and 3.17 (d, 4H, H-2a, H-2b, H-7a, H-7b); ^{13}C NMR (125.7 MHz, MeOD) δ 73.0 (C-4, C-5), 67.6 (C-3, C-6), and 47.9 (C-2, C-7). HRCIMS calcd for $C_6H_{14}NO_4$: 164.0923. Found 164.0924.

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19. For the numbering of the perhydroazepine derivatives **30**–**35** we have considered C-3 as a carbon atom having *R* configuration. In the cases of compounds **32** and **35**, where both possible C-3 centres have (*R*)-configuration, for homogeneity reasons, we have considered C-3 the carbon coming from C-5 of the sugar ring (see Scheme 1).
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