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Conformational Energetics of Sugar Thioureas and Synthesis of Glycosyl Thioureido Sugars[1]

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Abstract: The rate and outcome of the reaction of 6-deoxy-6-isothiocyanatoaldopyranoside derivatives with ammonia depend strongly on the nature of the hydroxyl protecting groups and solvent. In pyridine as solvent, the expected thioureas are obtained as the sole reaction products. A marked preference for the *E* configuration at the sugarNH—C(=S) bond is observed for silylated as compared to acetylated derivatives. Rotational barrier calculations, temperature-induced NH shifts, and other NMR data indicate a strict relationship between the *E* rotamer population and the existence of an intramolecular NH···O-5 hydrogen bond that fits a pseudo γ-turn. Competition between inter- and intra-molecular hydrogen bonding rather than steric factors probably explain these results. Acetal and trimethylsilyl ether derivatives have been further used in the preparation of fully unprotected derivatives. The procedure has been extended to the first synthesis of (1→6)-linked glycosyl phosphosugar analogues incorporating thiourea bridges as phosphate surrogates.

(1→6)-Linked oligo(glycosyl phosphates) are common constituents of lipophosphoglycans produced by yeasts, protozoa and bacteria, being responsible for their antigenic activity.[2] Hence, the chemical synthesis of structurally related fragments and analogues is an important goal for the development of efficient diagnostic tests and vaccines.[3] Keeping in mind the promising results obtained by replacement of the phosphodiester backbone in oligonucleotides by nonionic, achiral isosteric groups in the so-called "antisense approach",[4] we have undertaken the synthesis of glycosyl phosphosugar analogues incorporating thiourea bridges as phosphate surrogates, i.e. glycosyl thioureidosugars. Substitution of the phosphate diester group by thiourea in glycosyl phosphosugars may result, however, in important differences in their conformational properties as a consequence of the existence of two slow-rotating pseudoamide NH—C(=S) bonds and of the high hydrogen-bond donor character of the NH thiourea protons.

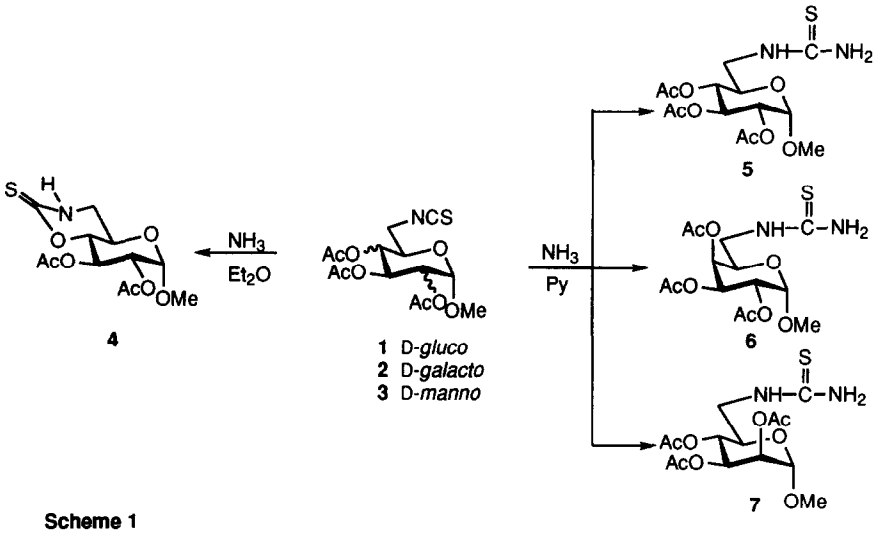
Ureido and thioureido sugars in which a nitrogen atom is linked to a secondary carbon atom of a rigid pyranose framework have been shown to exist exclusively in the anti-*Z* conformation at the sugar—NH—C(=X) moiety, both in solution and in the solid state, with the NH protons involved in intermolecular hydrogen bonding.[5] In contrast a *Z*/*E* conformational equilibrium was found for thioureido groups located at methylene carbon atoms of sugar derivatives.[6] Dynamic NMR data supported a direct relationship between the rotameric population of the *E* rotamer and the existence of an intramolecular hydrogen bond analogous to that characteristic of peptide γ-turns (C_7 conformation).[7]

As a part of our continuing interest in the chemistry of *N*-thiocarbonyl amino sugars,[6,8] we have now prepared a series of 6-deoxy-6-thioureidoaldopyranoses with different hydroxyl protecting groups and

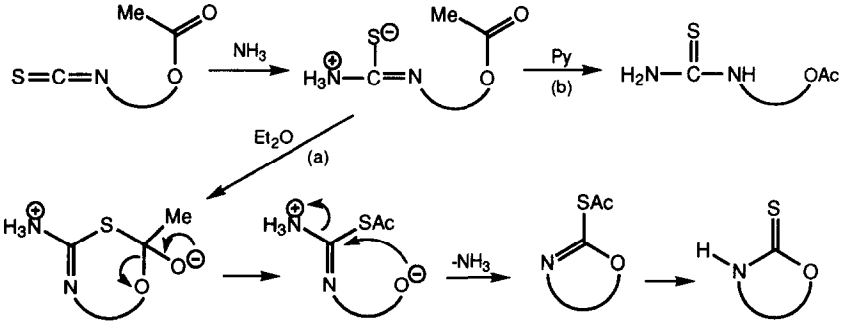
studied their conformational behaviour in solution. The use of isopropylidene and trimethylsilyl groups in the synthesis of fully unprotected thioamido and thioureidoaldoses is also reported. The approach has been further extended to the first synthesis of (1→6)-linked glycosyl thioureido sugars.

Synthesis of methyl 2,3,4-tri-*O*-acetyl-6-deoxy-6-thioureidoaldopyranosides.

Methyl 6-deoxy-6-isothiocyanatoaldopyranoside peracetates (**1-3**) have previously been reported.[9] Their condensation with ammonia in ether at 0 °C, by analogy with the preparation of peracetyl glycosylthioureas[10] was, however, unsuccessful. Thus, from the α-D-*gluco* isothiocyanate (**1**) the crystalline tetrahydrooxazine-2-thione **4** was isolated in 82% yield, instead of the expected thiourea **5** (Scheme 1).



Scheme 1



Scheme 2

This surprising transformation requires selective deacetylation at O-4 and subsequent ring closure, an effect that cannot be adscribed to a general ammonolysis mechanism.[10] The reaction probably proceeds

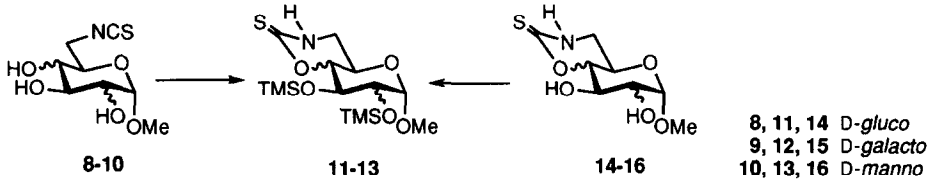
through intramolecular nucleophilic catalysis involving intramolecular attack on the ester group by the sulphur atom of a zwitterionic intermediate (Scheme 2). This mechanistic pathway (a) is analogous to that proposed for the neighbouring group participation of carbonyl groups in ester hydrolysis.[11]

It is noteworthy that this reaction allows access to selectively *O*-acetylated enantiopure 2-thioxotetrahydro-1,3-oxazines suitable for further *N*-functionalization. Previous attempts to prepare these compounds from the fully unprotected cyclic thiocarbamates were unsuccessful as the OH and NH groups exhibited identical reactivity towards acetylation and deacetylation reactions.[9]

Nevertheless, the target sugar thioureas **5-7** were obtained in high yield when the condensation reaction was performed in pyridine (Scheme 1), which probably catalyses the tautomerization process (b).

Synthesis of methyl 2,3,4-tri-*O*-trimethylsilyl-6-deoxy-6-thioureidoaldopyranosides.

In a first approach, the synthesis of the per-*O*-trimethylsilyl 6-deoxy-6-isothiocyanatoaldopyranoside precursors was attempted by trimethylsilylation of the fully unprotected isothiocyanates **8-10**. However, in contrast to that reported for their conventional acetylation,[9] only low yields of the desired compounds were isolated using either hexamethyldisilazane-trimethylsilyl chloride-pyridine[12] or bis-(*N*,*O*-trimethylsilyl)acetamide-tetrabutylammonium fluoride-DMF[13] as silylating systems. The major reaction products were the *O*-silylated six-membered cyclic thiocarbamates **11-13**, whose structures were confirmed by unequivocal synthesis from the unprotected derivatives **14-16** (Scheme 3).



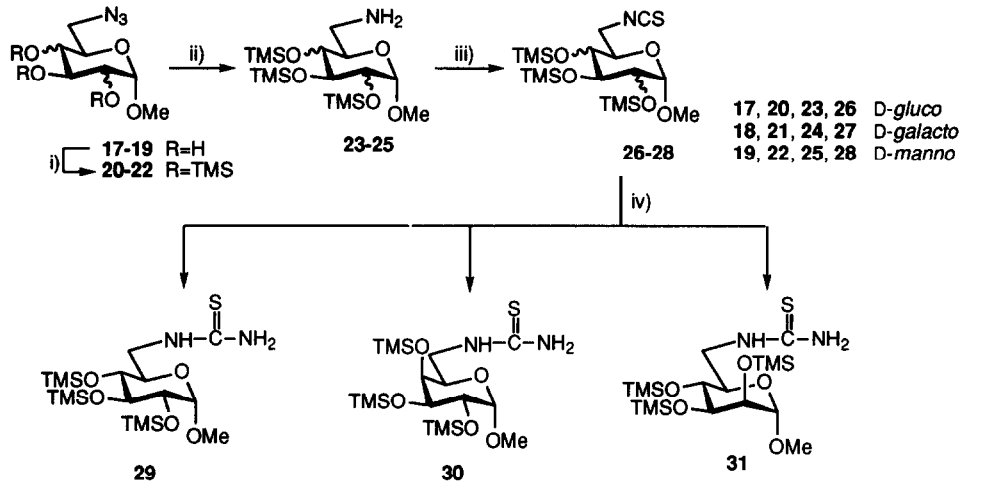
8-10 **11-13** **14-16**

8, 11, 14 D-*gluco*
9, 12, 15 D-*galacto*
10, 13, 16 D-*manno*

Scheme 3

To overcome this problem, a stepwise synthesis from the corresponding azides **17-19** was devised (Scheme 4). Trimethylsilylation (→**20-22**) and Staudinger reduction[14] afforded the respective *O*-protected amines (**23-25**) which were subsequently subjected to isothiocyanation reactions (→**26-28**). This latter transformation deserves further comment. The reaction of an amine with thiophosgene is probably the most useful isothiocyanation method, as it usually provides clean and very fast reactions.[15] Notwithstanding, in our case the reaction of the silylated amines **23-25** with thiophosgene afforded the isothiocyanates in rather moderate yields (23-65 %), probably due to partial hydrolysis of the trimethylsilyl groups under the slightly acidic reaction conditions. These results were optimized by using 1,1'-thiocarbonyldiimidazole-pyridine or carbon disulphide-dicyclohexylcarbodiimide as isothiocyanation reagents.

The condensation of the isothiocyanates **26-28** with ammonia in ether resulted in low conversion rates and yields even after long reaction times. In contrast, an almost instantaneous reaction (→**29-31**) was observed when using pyridine as solvent, similarly to that above commented for peracetylated derivatives.



i) BSA/TBAF; ii) Ph_3P/NH_4OH; iii) CS_2-DCC; iv) NH_3-Py

Scheme 4

Comparative conformational analysis of per-*O*-acetyl (5-7) and per-*O*-trimethylsilyl (29-31) thioureas.

Variable temperature ^1H NMR spectra for thioureas **5-7** and **29-31** (see Experimental) evidenced the existence of several decoalescence phenomena. It must be noticed that, in addition to the *Z*/*E* rotameric interconversion, a degenerate process resulting from slow rotation at the C(=S)—NH_2 bond must be considered. Therefore, both NH_2 protons are magnetically different in the *Z* and *E* rotamers.

Signals for the *Z* and *E* conformers were clearly visible at subambient temperatures. Their assignment was based on known spectroscopic correlations and NOE experiments as reported previously.[6] Interestingly, significant differences for the relative rotameric populations were observed between per-*O*-acetylated and per-*O*-trimethylsilylated derivatives in CDCl3 solutions, the *Z* rotamer being predominant in the first case and the *E* rotamer in the second one (Table 1). In order to evaluate the contribution of hydrogen bonding to the conformational stability, the rotational barrier heights about the pseudoamide bonds and the temperature coefficients for the NH proton chemical shifts were determined.

Although total line shape analysis is by far the most reliable method to obtain $\Delta G^{\neq}$ values, approximate equations based on spectral parameters provide accurate enough values in the case of two-site chemical exchange processes.[6,16] Thus, at temperatures close to but below coalescence, the rate constants (k) for the hindered rotations can be obtained by application of eq (1), where ΔW is the line widening due to chemical exchange.[17] Substitution of these values in Eyring's equation (2) results in the $\Delta G^{\neq}$ values for the $Z \rightarrow E$, $E \rightarrow Z$, and $E \rightarrow E$ exchanges shown in Table 1.[18]

$$k = \pi\Delta W \quad (1)$$

$$\Delta G^{\neq} = -RT(\ln k_B/h - k/T) \quad (2)$$

Table 1. Rotameric Populations, Rotational Barrier Heights, and Temperature Coefficients (τ) for Compounds **5-7** and **29-31**.

	5	**6**	**7**	**29**	**30**	**31**
Z:E ratio[a]	1:0.81	1:0.35	1:0.81	1:2.7	1:1.5	1:3
$\Delta G^{\neq}$[b] (T^c)						
$\Delta G^{\neq}_{E\rightarrow Z}$	13.4 (263)	13.2 (263)	14.0 (263)	14.3 (263)	14.4 (298)	14.8 (298)
$\Delta G^{\neq}_{Z\rightarrow E}$	13.3 (263)	13.7 (263)	13.9 (263)	14.1 (263)	14.2 (298)	14.5 (298)
$\Delta G^{\neq}_{E\rightarrow E}$	12.2 (233)	12.6 (248)	12.7 (248)	13.5 (263)	13.0 (248)	12.9 (248)
τ[d]						
NH (*Z*)	0.008	0.008	0.007	0.017	0.009	0.007
NH (*E*)	0.024	0.010	0.008	0.011	0.021	0.005
NH_2 (*E*)[e]	0.037	---	0.008	0.019	0.007	0.007
NH_2 (E)[f]	0.005	---	0.004	0.003	0.003	0.002

[a] Obtained by digital integration of ^1H NMR signals at 263 K. [b] In Kcal mol^{-1}, calculated according to eq (1) and (2). The estimated errors do not exceed 0.3 Kcal mol^{-1}. [c] In K. [d] $-d\delta/dT$ ppm K^{-1}. [e] pro-*Z*. [f] pro-*E*.

In both acetylated (**5-7**) and silylated derivatives (**29-31**) decoalescence of the signal for the diasterotopic NH_2 protons in the *E* rotamer (T_c ~255 K) was prior to that for the *Z* rotamer, indicative of higher rotational barriers. Although a beginning of decoalescence was observed in the latter at 233 K, the loss of spectral resolution due to agregation did not allow determination of $\Delta G^{\neq}$ for the $Z\rightarrow Z$ degenerate rotation. Nevertheless, the values for $\Delta G^{\neq}$ ($E\rightarrow E$) are higher, by ~2 Kcal mol^{-1}, to those expected for C(=S)—NH_2 rotations in *N*-alkylthioureas[19] (10-11 Kcal mol^{-1}), supporting the existence of intramolecular hydrogen bonding involving one of the NH_2 protons of the *E* rotamer.

The temperature-induced NH shift variations (Table 1) were in further support of this hypothesis. The assignment of the NH resonances is straightforward: the sugar-NH protons resonate as triplets or doublets at lower field than the singlets for the NH_2 protons. The *Z*, *E*, pro-*E*, and pro-*Z* orientations were confirmed by NOE experiments. Results clearly indicate that the pro-*E* NH_2 proton of the *E* rotamer is much less accessible to the solvent, or to intermolecular interactions, than the rest of the pseudoamide protons, and is presumably involved in intramolecular hydrogen bonding. As a matter of fact, the corresponding temperature coefficients are almost identical to those which are characteristic for amide protons in γ-turns.[20]

The involvement of the pyranoid ring oxygen atom in this interaction was induced from molecular models as well as ^1H NMR data. Although overlapping of signals prevented determination of all $J_{5,6}$ values, they could be precisely measured for compounds **6** and **7**. Thus, the observed $J_{5,6a}$ and $J_{5,6b}$ values for the *E* rotamers are indicative[21] of almost exclusive *gauche-trans* (gt) dispositions that would be fitted by the pro-*E*·NH_2···O-5 hydrogen bond (Figure 1). In contrast, the homologous *J* values for the *Z* rotamers agree with the expected gg/gt and gg/gt/tg equilibria for the substituted methylene arm in 4,5-*trans*- and 4,5-*cis*-hexopyranoid structures, respectively.[21]

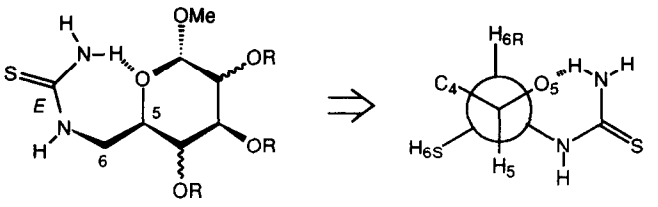


Figure 1. Intramolecular hydrogen bonding in the *E* rotamer of methyl 6-deoxy-6-thioureido hexopyranosides showing the *gauche-trans* (gt) disposition at the C_5—C_6 linkage.

The ensemble of discussed results permit the assumption that the presence of the *E* rotamer in solutions of 6-deoxy-6-thioureido-hexopyranosides is strictly related to the existence of the above NH···O intramolecular hydrogen bond, independently of the nature of the hydroxyl protecting group. The observed increase in the relative population of *E* rotamer when changing from acetyl to trimethylsilyl must be, thus, a consequence of a higher availability of the corresponding NH proton, which cannot be explained in terms of steric effects. Most probably, a competition between inter- and intra-molecular H-bonding in peracetyl derivatives is responsible. This effect may also apply for the slightly lower values of $\Delta G^{\neq} E \rightarrow E$ and slightly higher values for the temperature coefficients of the pro-*E* NH_2 proton for **5-7** as compared to **29-31**.

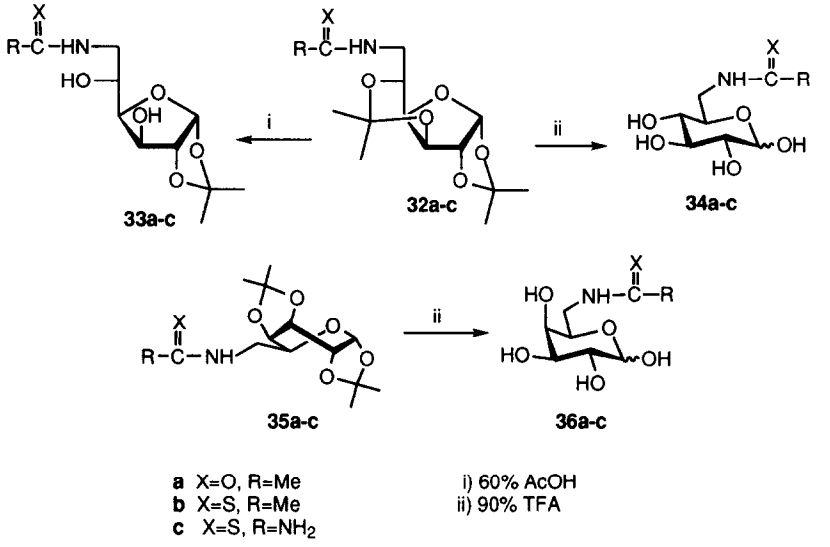
In conclusion, the stereochemistry of NH—C(=S) thiourea linkages in sugar thioureas can be modulated by acting on the configuration of the sugar template and on the nature of the hydroxyl protecting group. Structural changes favouring intramolecular NH···O interactions that fit pseudo γ-turns would favour the *E* rotamer, which offers an interesting tool to control the conformational and complexing properties of artificial hosts incorporating carbohydrate and thiourea moieties.[6b]

6-Deoxy-6-thioamido(thioureido)aldoses from isopropylidene derivatives.

Fully unprotected primary thiocarbonylamino sugars are interesting because of the biological significance of the parent amino sugars and the related phosphate esters. Thus, 6-amino-6-deoxyaldoses are constituents of a series of aminoglycoside antibiotics,[22] whereas aldose 6-phosphates are intimately involved in the metabolism of carbohydrates in plants as well as in the intracellular transport and binding of the lysozomal enzymes to the cell surface.[23,24]

Per-*O*-acyl thioureyleneoligosaccharides have previously been prepared.[5c,25] In our hands, their deprotection was, however, either unsuccessful or low yielding. A review of the current literature[15] revealed that transient *O*-acyl protection is generally inconvenient for the preparation of fully unprotected *N*-thiocarbonyl amino sugar derivatives. Although the direct *N*-thioacylation of free amino sugars has been recently reported,[26] the direct condensation of free amino sugars with unprotected sugar isothiocyanates is, in our case, unsuitable since both unprotected glycosyl isothiocyanates[27] and 6-deoxy-6-isothiocyanatoaldoses[9] are unstable. Even when blocking of the anomeric position in the latter preserves their stability under neutral or acidic conditions,[8b,9] in the presence of the amine formation of intramolecular cyclic thiocarbamates is faster than intermolecular nucleophilic addition. A more comprehensive approach suitable for the preparation of thioureido sugars, and eventual selective manipulation of the hydroxyl groups, requires the development of efficient *O*-protection, *O*-deprotection methodologies.

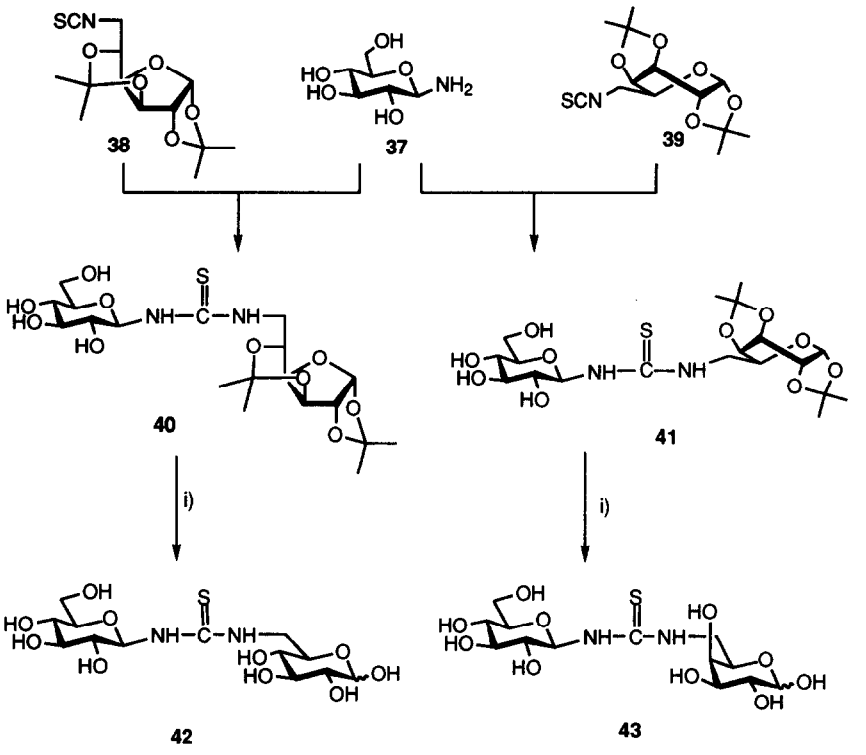
In order to test the stability of thiocarbonylamino functionalities under the acidic conditions needed for deacetonation, we first attempted the selective cleavage of the 1,3-dioxane ring in 6-deoxy-1,2:3,5-di-*O*-isopropylidene-6-thioamido(thioureido)-α-D-glucofuranose[6,8d] (**32b,c**). For comparative purposes, the homologous acetamide (**32**) was included in this study. Treatment with 60% aqueous acetic acid afforded the 1,2-*O*-isopropylidene derivatives (**33a-c**) in virtually quantitative yield in all cases (Scheme 5). Moreover, increase of the protonic strength by using 90% aqueous trifluoroacetic acid resulted in total deprotection (→**34a-c**) without any appreciable decomposition, and a similar behaviour was observed for 1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose derivatives (**35a-c**→**36a-c**, Scheme 5).



Scheme 5

The tautomeric equilibria in the thioamide and thiourea series paralleled that of the corresponding amides, with 1:2 α-pyranose:β-pyranose ratios. No isomers containing a nitrogen atom in the ring were detected, in contrast to that observed for 3-deoxy-3-thioureido sugars.[28] However, while the acetamide (**34a**, **36a**) and thioacetamide derivatives (**34b**, **36b**) exhibited signals in their ^{1}H and ^{13}C NMR spectra (see Experimental) for single *Z*-rotamers at the NH—C(=S) bond, the thioureas (**34c**, **36c**) showed broad signals indicative of *E*/*Z* rotameric equilibria, as previously observed for the protected precursors.[6,8d] A rapid interconversion was obtained at 50 °C.

According to the above results, the synthesis of reducing (1→6)-linked glycosyl thioureidosugars may be devised either by condensation of a glycosyl isothiocyanate acetonide with a 6-amino-6-deoxy sugar or, conversely, by condensation of a glycosylamine with an acetalated 6-deoxy-6-isothiocyanato aldose. Since glycosylamines can be obtained in a single step from reducing sugars[10,29] and the primary hydroxyl group of D-glucose and D-galactose diacetonides can be exchanged by isothiocyanate through efficient synthetic sequences,[9,30] in a first approach we examined the latter route.



i) 90% TFA

Scheme 6

Condensation of β-D-glucopyranosylamine (**37**) with 6-deoxy-1,2:3,5-di-*O*-isopropylidene-6-isothiocyanato-α-D-glucofuranose (**38**) and 6-deoxy-1,2:3,4-di-*O*-isopropylidene-6-isothiocyanato-α-D-galactopyranose (**39**) in pyridine-water yielded, after 48 h, the partially protected 6-[*N'*-(β-D-glucopyranosyl)thioureido]aldoses **40** and **41** in 30-35% yield (Scheme 6). The rather modest yields are probably due to hydrolysis, to some extent, of the glycosylamine **37** with splitting of ammonia. In agreement with that, the corresponding 6-deoxy-6-thioureido derivatives **32c** and **35c** were also isolated from the reaction mixtures.

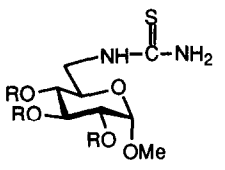
Hydrolysis of the acetal groups with TFA-H_2O afforded the target glucosyl thioureido sugars **42** and **43** in virtually quantitative yield (Scheme 6), whose structures were confirmed by analytical and spectroscopic data (see Experimental).

The ^1H and ^{13}C NMR spectra of **42** and **43** also evidenced the existence of chemical exchange processes causing signal broadening, which was particularly evident for the H-6,6' and C-6 resonances. Taking into consideration that aldopyranose derivatives bearing a thioureido group at a secondary carbon atom have been shown to exist in the exclusive *Z*-configuration,[5c] a rotameric equilibrium between the *E,Z* and *Z,Z* rotamers is probably responsible. At 50 °C, signals for the α- and β-anomers at the reducing end in

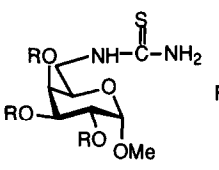
1:2.3 ratio were observed. The resonances for C-6 and C-1' were downfield shifted by 10-15 ppm as compared with the respective ^{13}C chemical shifts for C-6' and C-1, in agreement with the presence of the (1→6) thiourea bridge. The β-anomeric configuration for the *N'*-(D-glucopyranosyl) substituent was confirmed by the high $J_{1',2'}$ value (9.3-9.4 Hz). The $^4C_1$(D) conformation for both pyranose rings was induced from the vicinal $^3J_{H,H}$ values.

Methyl 6-deoxy-6-thioureidoaldopyranosides from trimethylsilyl ether derivatives.

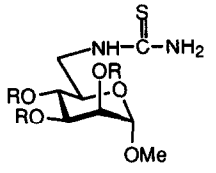
Alkyl glycopyranoside 6-phosphates have been used in biological studies to increase the concentration of the corresponding aldose 6-phosphate in the vicinity of the membrane-bound receptor. Recently, a high scale synthesis of this family of compounds based on the use of trimethylsilyl ether derivatives as intermediates has been reported.[24] Using a similar approach, we have now prepared the thioureido isosters having the α-D-*gluco*, α-D-*galacto*, and α-D-*manno* configuration, respectively. The trimethylsilyl groups in **29-31** were efficiently removed by treatment with 10% acetic acid at 60 °C, yielding the unprotected thioureidoglycosides **44-46** as the sole reaction products, as seen from the ^1H and ^{13}C NMR spectra of the crude reaction mixtures.



29,44



30,45



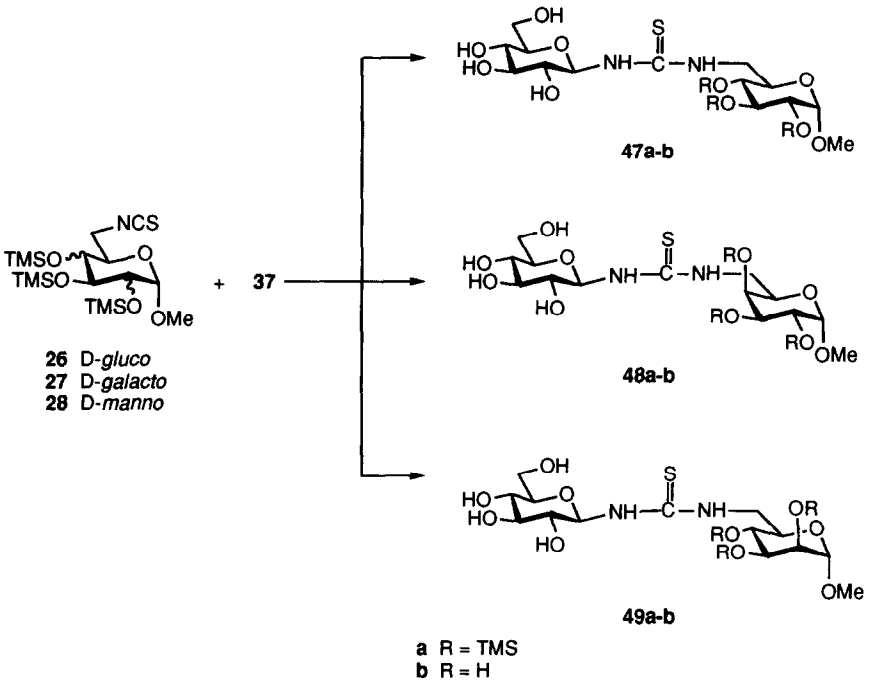
31,46

29-31 R = TMS
44-46 R = H

The same protocol has been extended to the preparation of methyl (*N'*-glucosyl)thioureidoglycopyranosides. Condensations of methyl 6-deoxy-6-isothiocyanato-2,3,4-tri-*O*-trimethylsilyl-α-D-glycopyranosides with β-D-glucopyranosylamine (**27**) afforded the partially protected thioureas **47a-49a** in 60-65% yield, which were analogously transformed into the target unprotected pseudodisaccharides **47b-49b** (Scheme 7).

The ^1H and ^{13}C NMR data for **47b-49b** showed similar features to those above commented for their reducing counterparts **42** and **43** and confirmed the proposed structures.

In conclusion, both acetal and trimethylsilyl groups were found to be very convenient for transient hydroxyl protection in the synthesis of glycosyl thioureidosugars, as the corresponding 6-deoxy-6-isothiocyanatosugar derivatives can be easily obtained in a single five-step procedure from commercial precursors. The groups are stable under the nucleophilic addition reaction conditions, and they are easily removed by acid hydrolysis compatible with the stability of the thiourea group. The procedure also yields pure thioamido- and thioureido-monosaccharide derivatives.



Scheme 7

EXPERIMENTAL

General methods. Melting points were determined with a Gallenkamp apparatus and are uncorrected. A Perkin-Elmer Model 141 MC polarimeter and 1 cm cells were used for measurement of specific rotations at room temperature. UV spectra were obtained on a Philips PU 8710 spectrophotometer. IR spectra were recorded on a Bomem Michelson MB-120 FTIR spectrophotometer. ^{1}H NMR (and ^{13}C NMR) spectra were recorded at 500 (125.5) and 300 (75.5) MHz with, respectively, Bruker AMX 500 and AMX 300 spectrometers. Chemical shifts are given in ppm, and tetramethylsilane was the internal or external standard. Temperature measurements were based on the chemical shift separation of the protons of a methanol sample and the use of known temperature-shift correlations.[31] The samples were thermically equilibrated at the corresponding temperature before measurement. Mass spectra were taken on a Kratos MS-80 RFA instrument. In the EI mode, opperating conditions were: ionising energy, 35 eV; ionising current, 100 μA; accelerating voltage, 4 kV; resolution, 1000 (10% valley definition). In the FAB mode, the primary beam consisted of Xe atoms with a maximum energy of 8 keV. The samples were dissolved in glycerol, thioglycerol, or *m*-nitrobenzyl alcohol, and the positive ions were separated and accelerated over a potential of 7 kV. TLC was performed with E. Merck precoated TLC plates, Silica gel 30F-245, with visualization by UV light and by charring with 10% sulphuric acid. Flash and column chromatography were carried out with

Silica gel 60 (E. Merck, 230-400 mesh). Gel-permeation chromatography (GPC) was performed on a column (29.5 x 3.0 cm) of Bio-Gel P-2 by elution with 1:1 H_2O-MeOH.

Materials. The methyl 6-deoxy-6-isothiocyanato-α-D-glycopyranosides **1-3** and the corresponding bicyclic oxazines **14-16** were prepared as reported previously.[9] Methyl 6-azido-6-deoxy-α-D-gluco(galacto)(manno)pyranosides (**17-19**) were obtained by Zemplén deacetylation of the known peracetates and used without further characterization.[9] Di-*O*-isopropylidene D-glucose and D-galactose acetamides (**32a, 35a**), thioacetamides (**32b, 35b**), thioureas (**32c, 35c**), and isothiocyanates (**38, 39**) were prepared from the corresponding amino sugar diacetonides as reported previously.[6,8d] β-D-Glucopyranosylamine (**37**) was obtained from D-glucose by treatment with methanolic ammonia.[19a]

(5R)-(2,3-Di-O-acetyl-4-deoxy-1-O-methyl-α-D-xylopyranoso)[5,4-e]-1,3-oxazine-2-thione[32] (**4**). Dry (KOH) ammonia was bubbled into a solution of **1** (0.7 g, 1.99 mmol) in ether (5 mL) at 0 °C for 10 min, and then at room temperature for 20 min. The crystalline product was collected and washed with ether. Yield 0.52 g (82%), $[\alpha]_D$ +32.8 (*c* 0.6, $CHCl_3$), λ_{max} ($CHCl_3$) 258.4 nm (ε_{mM} 15.6); ν_{max} 3345, 1753, 1562, and 1221 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ 8.65 (bs, 1H, NH), 5.61 (t, 1H, $J_{2,3} = J_{3,4}$ 10.0 Hz, H-3), 4.95 (d, 1H, $J_{1,2}$ 3.6 Hz), 4.87 (dd, 1H, H-2), 4.18 (td, 1H, $J_{4,5} = J_{5,6b}$ 10.0, $J_{5,6a}$ 5.9 Hz, H-5), 4.09 (t, 1H, H-4), 3.61 (dd, 1H, $J_{6a,6b}$ 11.6 Hz, H-6a), 3.44 (s, 3H, OMe), 3.31 (dd, 1H, H-6b), 2.11, and 2.09 (2s, 6H, 2 Ac). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 185.9 (C=S), 170.1, 169.5 (C=O), 97.4 (C-1), 77.2 (C-4), 70.8 (C-2), 67.8 (C-3), 59.5 (C-5), 55.7 (OMe), 44.8 (C-6), 20.7, and 20.5 (*Me*CO). EIMS: *m/z* 319 (15%, M^+). *Anal.* Calcd for $C_{12}H_{17}NO_7S$: C, 45.14; H, 5.36; N, 4.38; S, 10.02. Found: C, 45.11; H, 5.38; N, 4.30; S, 9.94.

General procedure for the preparation of acetylated deoxythioureido sugars (5-7). Dry (KOH) ammonia was bubbled into a solution of the corresponding isothiocyanate (**1-3**, 100 mg, 0.28 mmol) in pyridine (5 mL) at 0 °C for 10 min, and then at room temperature for 20 min. Evaporation of the solvent and column chromatography (3:1 EtOAc-hexane) of the residue afforded the corresponding thioureas as amorphous solids:

Methyl 2,3,4-tri-O-acetyl-6-deoxy-6-thioureido-α-D-glucopyranoside (**5**). Yield 94 mg (90%), $[\alpha]_D$ +116 (*c* 1.1, $CHCl_3$), R_f 0.39, λ_{max} ($CHCl_3$) 253 nm (ε_{mM} 12.8); ν_{max} 3447, 3356, 1750, and 1227 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$, 313 K): δ 7.04 (bs, 1H, NH), 6.40 (s, 2H, NH_2), 5.46 (t, 1H, $J_{2,3} = J_{3,4}$ 9.9 Hz, H-3), 4.93 (t, 1H, $J_{4,5}$ 9.9 Hz, H-4), 4.92 (d, 1H, $J_{1,2}$ 3.6 Hz, H-1), 4.85 (dd, 1H, H-2), 3.99 (ddd, 1H, $J_{5,6a}$ 2.8, $J_{5,6b}$ 5.2 Hz, H-5), 3.71 (bs, 2H, H-6a, H-6b), 3.40 (s, 3H, OMe), 2.08, 2.07, and 2.00 (3s, 9H, 3 OAc); (248 K): δ 7.52 (t, NH *Z*), 7.18 (t, NH *E*), 6.74 (bs, NH_2 *E*), 6.61 (s, NH_2 *Z*). ^{13}C NMR (75.5 MHz, $CDCl_3$, 313 K): δ 184.4 (C=S), 170.2, 170.1, 169.8 (C=O), 96.7 (C-1), 70.8 (C-2), 69.8 (C-4), 69.4 (C-3), 68.1 (C-5), 55.5 (OMe), 45.0 (C-6), 20.6, and 20.4 (*Me*CO). EIMS: *m/z* 378 (3%, M^+), 347 (15, M^+-MeO), 318 (60, M^+-AcOH). *Anal.* Calcd for $C_{14}H_{22}N_2O_8S$: C, 44.44; H, 5.86; N, 7.40; S, 8.47. Found: C, 44.28; H, 5.84; N, 7.38; S, 8.27.

Methyl 2,3,4-tri-O-acetyl-6-deoxy-6-thioureido-α-D-galactopyranoside (**6**). Yield 91 mg (86%), $[\alpha]_D$ +93.7 (*c* 1, CH_2Cl_2), R_f 0.39, λ_{max} (CH_2Cl_2) 252 nm (ε_{mM} 25.2); ν_{max} 3435, 3356, 1753, and 1227 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$, 313 K): δ 6.75 (bs, 1H, NH), 6.23 (s, 2H, NH_2), 5.45 (bd, 1H, H-4), 5.36 (dd, 1H, $J_{2,3}$ 10.8, $J_{3,4}$ 3.3 Hz, H-3), 5.19 (dd, 1H, $J_{1,2}$ 3.6 Hz, H-2), 5.05 (d, 1H, H-1), 4.29 (m, 1H, H-5),

3.72 (bs, 1H, H-6a), 3.54 (bs, 1H, H-6b), 3.47 (s, 3H, OMe), 2.24, 2.14, and 2.06 (3s, 9H, 3OAc); (248 K): δ 7.36 (bs, NH *E*), 7.22 (bs, NH *Z*), 6.89, 6.80 (2bs, NH_2 *E*), 6.66 (s, NH_2 *Z*), 3.79 (ddd, $J_{5,6a}$ 7.3, $J_{6a,6b}$ 14.0 Hz, H-6a *Z*), 3.71 (ddd, $J_{5,6b}$ 7.3 Hz, H-6b *Z*), 3.45 (m, $J_{5,6a}$ 10.5 Hz, H-6a *E*), 2.80 (ddd, $J_{5,6b}$ 2.0, $J_{6a,6b}$ 14.0 Hz, H-6b *E*). ^{13}C NMR (75.5 MHz, $CDCl_3$, 313 K): δ 184.2 (C=S), 170.8, 170.1, 169.9 (C=O), 97.6 (C-1), 69.0 (C-2,4), 68.0 (C-3), 647.7 (C-5), 55.4 (OMe), 44.3 (C-6), 20.5, 20.4, and 20.3 (*Me*CO). EIMS: *m/z* 378 (3%, M^+), 347 (10, M^+-MeO), 318 (25, M^+-AcOH). FABMS: *m/z* 401 (100%, $[M+Na]^+$). *Anal.* Calcd for $C_{14}H_{22}N_2O_8S$: C, 44.44; H, 5.86; N, 7.40; S, 8.47. Found: C, 44.28; H, 5.77; N, 7.43; S, 8.19.

Methyl 2,3,4-tri-O-acetyl-6-deoxy-6-thioureido-α-D-mannopyranoside (**7**). Yield 84 mg (80%), $[\alpha]_D$ +55.4 (*c* 1, CH_2Cl_2), R_f 0.31, λ_{max} (CH_2Cl_2) 252.8 nm (ε_{mM} 24.9); ν_{max} 3437, 3356, 1753, and 1227 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$, 313 K): δ 6.77 (bs, 1H, NH), 6.24 (bs, 2H, NH_2), 5.40 (dd, 1H, $J_{2,3}$ 3.4, $J_{3,4}$ 9.9 Hz, H-3), 5.20 (t, 1H, $J_{4,5}$ 9.9 Hz, H-4), 5.28 (dd, 1H, $J_{1,2}$ 1.7 Hz, H-2), 4.75 (d, 1H, H-1) 3.98 (m, 1H, H-5), 3.77 (bs, 2H, H-6a, H-6b), 3.46 (s, 3H, OMe), 2.22, 2.15, and 2.05 (3s, 9H, 3 OAc); (248 K): δ 7.32 (t, NH *E*), 7.18 (t, NH *Z*), 6.81, 6.63 (2bs, NH_2 *E*), 6.58 (s, NH_2 *Z*), 4.13 (dd, $J_{5,6a}$ 0, $J_{6a,6b}$ 13.2 Hz, H-6a *Z*), 3.60 (dt, $J_{5,6b}$ 6.0 Hz, H-6b *Z*), 3.40 (m, $J_{5,6a}$ 10.2, $J_{5,6b}$ 2.7 Hz, H-6a, H-6b *E*). ^{13}C NMR (125.5 MHz, $CDCl_3$, 313 K): δ 184.2 (C=S), 170.1, 169.7, 169.6 (C=O), 98.3 (C-1), 69.2 (C-2,5), 68.7 (C-3), 67.1 (C-4), 55.2 (OMe), 45.3 (C-6), 20.5, 20.4, and 20.3 (MeCO). FABMS: *m/z* 401 (100%, $[M+Na]^+$). *Anal.* Calcd for $C_{14}H_{22}N_2O_8S$: C, 44.44; H, 5.86; N, 7.40; S, 8.47. Found: C, 44.35; H, 6.11; N, 7.54; S, 8.32.

General procedure for the preparation of di-*O*-silylated bicyclic 1,3-oxazine-2-thiones[33] (11-13). Compounds **11-13** were isolated in 40-45 % yield after column chromatography (Et_2O-hexane 1:15) from the reaction mixtures of the corresponding unprotected methyl 6-deoxy-6-isothiocyanato-α-D-glycopyranosides[9] **8-10** (100 mg, mmol) with *N,O*-bis(trimethylsilyl)acetamide-tetrabutylammonium fluoride in DMF or hexamethyldisilazane-trimethylsilyl chloride in pyridine, following the protocoles described below. The silylated isothiocyanates **26-28** were also obtained (12-17%) from these reactions. The oxazines **11-13** were additionally prepared in 87-92 % yield by silylation of the unprotected bicyclic precursors[9] **14-16**.

(5R)-(4-Deoxy-1-O-methyl-2,3-di-O-trimethylsilyl-α-D-xylopyranoso)[5,4-e]-1,3-oxazine-2-thione (**11**). $[\alpha]_D$ +6 (*c* 1, CH_2Cl_2), λ_{max} (CH_2Cl_2) 256 nm (ε_{mM} 14.6); ν_{max} 3208, 1551, 1252, 1068, and 841 cm^{-1} .^1H NMR (500 MHz, $CDCl_3$): δ 8.30 (bs, 1H, NH), 4.62 (d, 1H, $J_{1,2}$ 3.6, H-1), 4.00 (td, 1H, $J_{4,5}$ = $J_{5,6b}$ 8.8, $J_{5,6a}$ 6.1 Hz, H-5), 3.96 (t, 1H, $J_{2,3}$ = $J_{3,4}$ 8.8 Hz, H-3), 3.78 (t, 1H, H-4), 3.59 (dd, 1H, H-2), 3.52 (ddd, 1H, $J_{6a,NH}$ 4.8, $J_{6a,6b}$ 8.8 Hz, H-6a), 3.43 (s, 3H, OMe), 3.22 (t, 1H, H-6b), 0.23, and 0.18 (2s, 18H, 2 $OSiMe_3$). ^{13}C NMR (125.5 MHz, $CDCl_3$): δ 186.7 (C=S), 100.8 (C-1), 80.6 (C-4), 76.8 (C-2), 76.6 (C-3), 59.4 (C-5), 55.7 (OMe), 45.0 (C-6), 0.5, and 0.0 (2 $OSiMe_3$). EIMS: *m/z* 379 (15%, M^+). *Anal.* Calcd for $C_{14}H_{29}NO_5SSi_2$: C, 44.29; H, 7.70; N, 3.69; S, 8.45; Si, 14.80. Found: C, 44.11; H, 7.54; N, 3.58; S, 8.47; Si, 14.54.

(5R)-(4-Deoxy-1-O-methyl-2,3-di-O-trimethylsilyl-β-L-arabinopyranoso)[5,4-e]-1,3-oxazine-2-thione (**12**). $[\alpha]_D$ +158.6 (*c* 1, CH_2Cl_2), λ_{max} (CH_2Cl_2) 257.6 nm (ε_{mM} 6.3); ν_{max} 3262, 1552, 1252, 1061 and 843 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 8.69 (bs, 1H, NH), 4.68 (d, 1H, $J_{1,2}$ 3.6, H-1), 4.42 (d, 1H, $J_{3,4}$ 2.9, $J_{4,5}$ 0 Hz, H-4), 4.28 (bd, 1H, $J_{5,6a}$ 3.9 Hz, H-5), 4.05 (dd, 1H, $J_{2,3}$ 9.3 Hz, H-3), 3.95 (dd, 1H, H-2), 3.58 (dd, 1H, $J_{6a,6b}$ 13.8 Hz, H-6a), 3.46 (s, 3H, OMe), 3.49 (dd, 1H, $J_{5,6b}$ 1.3 Hz, H-6b), 0.19, and 0.18

(2s, 18H, 2 SiMe3). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 186.3 (C=S), 100.9 (C-1), 78.4 (C-4), 69.1 (C-2,3), 58.3 (C-5), 55.8 (OMe), 44.6 (C-6), 0.3, and 0.2 (2 SiMe3). FABMS: *m/z* 402 (30%, $[M+Na]^+$). *Anal.* Calcd for $C_{14}H_{29}NO_5SSi_2$: C, 44.29; H, 7.70; N, 3.69; S, 8.45; Si, 14.80. Found: C, 44.11; H, 7.58; N, 3.79; S, 8.10; Si, 15.07.

*(5R)-(4-Deoxy-1-*O*-methyl-2,3-di-*O*-trimethylsilyl-α-D-lyxopyranoso)[5,4-e]-1,3-oxazine-2-thione* (**13**). $[\alpha]_D$ -30.5 (*c* 1, CH_2Cl_2), λ_{max} (CH_2Cl_2) 256 nm (ε_{mM} 16.2); ν_{max} 3201, 1541 1252, 1063, and 843 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 7.44 (d, 1H, $J_{6a,NH}$ 3.5 Hz, NH), 4.56 (d, 1H, $J_{1,2}$ 1.8, H-1), 4.19 (t, 1H, $J_{3,4} = J_{4,5}$ 9.6 Hz, H-4), 3.95 (dd, 1H, $J_{2,3}$ 3.1 Hz, H-3), 3.90 (td, 1H, $J_{5,6b}$ 9.6, $J_{5,6a}$ 6.0 Hz, H-5), 3.88 (dd, 1H, H-2), 3.47 (ddd, 1H, $J_{6a,6b}$ 9.6 Hz, H-6a), 3.38 (s, 3H, OMe), 3.35 (t, 1H, H-6b), 0.23, and 0.14 (2s, 18H, 2 SiMe3) ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 186.7 (C=S), 102.7 (C-1), 78.3 (C-4), 72.8 (C-2), 68.8 (C-3), 60.9 (C-5), 55.1 (OMe), 44.7 (C-6), and 0.2 (2 SiMe3). FABMS: *m/z* 402 (100%, $[M+Na]^+$). *Anal.* Calcd for $C_{14}H_{29}NO_5SSi_2$: C, 44.29; H, 7.70; N, 3.69; S, 8.45; Si, 14.80. Found: C, 44.25; H, 7.55; N, 3.81; S, 8.41; Si, 14.95.

General procedure for the preparation of silylated azidodeoxy sugars (20-22). The following protocols were followed:

a) To a solution of methyl 6-azido-6-deoxy-α-D-gluco(galacto)(manno)pyranoside (**17-19**, 0.73 g, 3.32 mmol) in DMF (5 mL) at 15 °C was added, under nitrogen, *N,O*-bis(trimethylsilyl)acetamide (BSA, 2.5 mL, 10 mmol) and tetrabutylammonium fluoride (TBAF, 1 M in THF, 0.05 mL, 0.05 mmol). After stirring 20 min at room temperature, the excess of BSA was quenched with 2-propanol (2.5 mL), and the solvents were evaporated. The residue was dissolved in Et_2O (20 mL), washed with brine (3 x 15 mL), dried ($MgSO_4$) and concentrated. The resulting syrupy residue was purified by column chromatography (Et_2O-hexane 1:15).

b) To a solution of the corresponding azide **17-19** (0.73 g, 3.32 mmol) in pyridine (25 mL) was added a mixture of trimethylsilyl chloride and hexamethyldisilazane (1:2, 15 mL). The reaction mixture was stirred at room temperature for 40-60 min, monitoring by TLC (Et_2O-hexane 1:15). The solvents were concentrated and the residue was chromatographed with the above solvent.

Both procedures reported similar yields (85-92 %) and were used indistinctly in the preparation of the following compounds:

*Methyl 6-azido-6-deoxy-2,3,4-tri-*O*-trimethylsilyl-α-D-glucopyranoside* (**20**). $[\alpha]_D$ +87.8 (*c* 1.1, CH_2Cl_2), R_f 0.56; ν_{max} 2957, 2917, 2101, 1252, 1161, and 843 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 4.55 (d, 1H, $J_{1,2}$ 3.6, H-1), 3.65 (t, 1H, $J_{2,3} \approx J_{3,4}$ 8.9 Hz, H-3), 3.61 (ddd, 1H, $J_{4,5}$ 9.6, $J_{5,6b}$ 5.8, $J_{5,6a}$ 1.9 Hz, H-5), 3.41 (dd, 1H, H-2), 3.33 (dd, 1H, $J_{6a,6b}$ 13.1 Hz, H-6a), 3.32 (t, 1H, H-4), 3.30 (s, 3H, OMe), 3.26 (dd, 1H, H-6b), and 0.10 (s, 27H, 3 SiMe3). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 99.7 (C-1), 74.7 (C-3), 73.5 (C-2), 72.9 (C-4), 70.7 (C-5), 54.9 (OMe), 51.5 (C-6), 1.2, 0.9, and 0.4 (SiMe3). FABMS: *m/z* 458 (60%, $[M+Na]^+$). *Anal.* Calcd for $C_{16}H_{37}N_3O_5Si_3$: C, 44.10; H, 8.56; N, 9.64; Si, 19.34. Found: C, 44.10; H, 8.51; N, 9.51; Si, 19.50.

*Methyl 6-azido-6-deoxy-2,3,4-tri-*O*-trimethylsilyl-α-D-galactopyranoside* (**21**). $[\alpha]_D$ +62.5 (*c* 1.1, CH_2Cl_2), R_f 0.47; ν_{max} 2957, 2903, 2103, 1250, 1180, and 843 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 4.65 (d, 1H, $J_{1,2}$ 3.5, H-1), 3.91 (dd, 1H, $J_{2,3}$ 9.3 Hz, H-2), 3.84 (ddd, 1H, $J_{4,5}$ 1.0, $J_{5,6a}$ 7.9, $J_{5,6b}$ 5.8 Hz, H-5), 3.82 (dd, 1H, $J_{3,4}$ 2.8 Hz, H-3), 3.78 (dd, 1H, H-4), 3.52 (dd, 1H, $J_{6a,6b}$ 12.4 Hz, H-6a), 3.42 (s, 3H, OMe),

3.15 (dd, 1H, H-6b), 0.16, and 0.14 (2s, 27H, 3 SiMe3). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 100.6 (C-1), 73.1 (C-3), 70.5 (C-5), 69.9 (C-2), 69.2 (C-4), 55.4 (OMe), 51.5 (C-6), 0.5, 0.4, and 0.2 (SiMe3). FABMS: *m/z* 458 (50%, $[M+Na]^+$). *Anal.* Calcd for $C_{16}H_{37}N_3O_5Si_3$: C, 44.10; H, 8.56; N, 9.64; Si, 19.34. Found: C, 44.24; H, 8.38; N, 9.64; Si, 19.27.

*Methyl 6-azido-6-deoxy-2,3,4-tri-*O*-trimethylsilyl-α-D-mannopyranoside* (**22**). $[\alpha]_D$ +43.9 (*c* 0.9, CH_2Cl_2), R_f 0.65; ν_{max} 2957, 2913, 2099, 1252, and 841 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 4.49 (d, 1H, $J_{1,2}$ 1.9, H-1), 3.81 (t, 1H, $J_{3,4} = J_{4,5}$ 9.1 Hz, H-4), 3.76 (dd, 1H, $J_{2,3}$ 2.66 Hz, H-2), 3.70 (dd, 1H, H-3), 3.64 (ddd, 1H, $J_{5,6a}$ 2.6, $J_{5,6b}$ 7.0 Hz, H-5), 3.42 (dd, 1H, $J_{6a,6b}$ 12.9 Hz, H-6a), 3.40 (s, 3H, OMe), 3.32 (dd, 1H, H-6b), 0.14, and 0.12 (2s, 27H, 3 SiMe3). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 101.7 (C-1), 73.3 (C-2,5), 72.3 (C-3), 69.0 (C-4), 54.7 (OMe), 51.3 (C-6), 0.6, 0.5, and 0.2 (SiMe3). FABMS: *m/z* 458 (60%, $[M+Na]^+$). *Anal.* Calcd for $C_{16}H_{37}N_3O_5Si_3$: C, 44.10; H, 8.56; N, 9.64; Si, 19.34. Found: C, 43.95; H, 8.60; N, 9.64; Si, 19.50.

General procedure for the preparation of silylated aminodeoxy sugars (23-25). To a solution of the corresponding azide **20-22** (1.02 g, 2.35 mmol) in a mixture of dioxane-MeOH (5:1, 30 mL) was added triphenylphosphine (2.05 g, 7.8 mmol) under N_2 at room temperature. After 1 h, concentrated NH_4OH (30%, 3.22 mL) was added and the solution was stirred for 24 h. The solvents were evaporated and the residue was purified by column chromatography using first EtOAc-hexane 4:1 and then EtOAc-EtOH-H_2O 45:5:3.

*Methyl 6-amino-6-deoxy-2,3,4-tri-*O*-trimethylsilyl-α-D-glucopyranoside* (**23**). Yield 0.88 g, 92%, $[\alpha]_D$ +93.0 (*c* 1.0, CH_2Cl_2), R_f 0.18; ν_{max} 3339, 1250, and 843 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 4.54 (d, 1H, $J_{1,2}$ 3.6 Hz, H-1), 3.69 (t, 1H, $J_{2,3} = J_{3,4}$ 8.9 Hz, H-3), 3.41 (ddd, 1H, $J_{4,5}$ 9.6, $J_{5,6a}$ 2.7, $J_{5,6b}$ 7.7 Hz, H-5), 3.41 (dd, 1H, H-2), 3.23 (dd, 1H, H-4), 2.93 (dd, 1H, $J_{6a,6b}$ 13.1 Hz, H-6a), 3.30 (s, 3H, OMe), 2.61 (dd, 1H, H-6b), 1.50 (bs, 2H, NH_2), 0.10, and 0.09 (s, 27H, 3 SiMe3). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 99.6 (C-1), 74.8 (C-3), 73.8 (C-2), 73.7 (C-4), 72.6 (C-5), 54.6 (OMe), 43.2 (C-6), 1.2, 1.0, and 0.4 (SiMe3). FABMS: *m/z* 432 (60%, $[M+Na]^+$), 410 (25, $[M+H]^+$). *Anal.* Calcd for $C_{16}H_{39}NO_5Si_3$: C, 46.90; H, 9.59; N, 3.42; Si, 20.56. Found: C, 46.78; H, 9.28; N, 3.51; Si, 20.41.

*Methyl 6-amino-6-deoxy-2,3,4-tri-*O*-trimethylsilyl-α-D-galactopyranoside* (**24**). Yield 0.88 g, 92%, $[\alpha]_D$ +95.1 (*c* 0.9, CH_2Cl_2), R_f 0.22; ν_{max} 3394, 1254, and 841 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 4.72 (d, 1H, $J_{1,2}$ 3.6 Hz, H-1), 3.98 (dd, 1H, $J_{2,3}$ 9.2 Hz, H-2), 3.87(dd, 1H, $J_{3,4}$ 2.8 Hz, H-3), 3.84 (dd, 1H, $J_{4,5}$ 0.8 Hz, H-4), 3.68 (ddd, 1H, $J_{5,6a}$ 8.4, $J_{5,6b}$ 4.5 Hz, H-5), 3.44 (s, 3H, OMe), 3.01 (dd, 1H, $J_{6a,6b}$ 13.0 Hz, H-6a), 2.73 (dd, 1H, H-6b), 1.40 (bs, 2H, NH_2), and 0.20 (s, 27H, 3 SiMe3). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 100.5 (C-1), 73.6 (C-4), 72.4 (C-5), 70.8 (C-3), 69.5 (C-2), 55.1 (OMe), 43.0 (C-6), 0.6, 0.4, and 0.2 (SiMe3). FABMS: *m/z* 432 (50%, $[M+Na]^+$), 410 (100, $[M+H]^+$). *Anal.* Calcd for $C_{16}H_{39}NO_5Si_3$: C, 46.90; H, 9.59; N, 3.42; Si, 20.56. Found: C, 47.02; H, 9.55; N, 3.22; Si, 20.41.

*Methyl 6-amino-6-deoxy-2,3,4-tri-*O*-trimethylsilyl-α-D-mannopyranoside* (**25**). Yield 0.75 g, 78%, $[\alpha]_D$ +48.2 (*c* 1.1, CH_2Cl_2), R_f 0.30; ν_{max} 3396, 1259, and 850 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ 4.48 (d, 1H, $J_{1,2}$ 1.9, H-1), 3.77 (t, 1H, $J_{2,3}$ 1.9 Hz, H-2), 3.74 (dd, 1H, $J_{5,6a}$ 8.6, $J_{6a,6b}$ 13.1 Hz, H-6a), 3.72 (dd, 1H, $J_{3,4}$ 8.6 Hz, H-3), 3.67 (t, 1H, $J_{4,5}$ 8.6 Hz, H-4), 3.42 (td, 1H, $J_{5,6a}$ 2.7 Hz, H-5), 3.34 (s, 3H, OMe), 3.00 (dd, 1H, H-6b), 2.30 (bs, 2H, NH_2), and 0.13 (s, 27H, 3 SiMe3). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 101.7 (C-1), 74.8 (C-5), 73.5 (C-2), 72.4 (C-3), 69.7 (C-4), 54.5 (OMe), 43.2 (C-6), 0.7, 0.5, and 0.2

(SiMe3). FABMS: *m/z* 432 (15%, $[M+Na]^+$), 410 (90, $[M+H]^+$). *Anal.* Calcd for $C_{16}H_{39}NO_5Si_3$: C, 46.90; H, 9.59; N, 3.42; Si, 20.56. Found: C, 46.95; H, 9.28; N, 3.31; Si, 20.59.

General procedure for the preparation of silylated deoxyisothiocyanato sugars (26-28). The following protocols were followed:

a) To a heterogeneous mixture of the corresponding amine **23-25** (2.15 g, 5.26 mmol) in CH_2Cl_2 (30 mL), water (30 mL), and $CaCO_3$ (1.97 g, 21.0 mmol) $CSCl_2$ (0.9 g, 0.6 mL, 7.9 mmol) was added. The mixture was vigorously stirred for 40-70 min at room temperature and filtered. The organic layer was separated, washed with water, dried (MgSO4), concentrated, and the residue purified by column chromatography using Et_2O-hexane 1:15 as eluent.

b) *N,N'*-Dicyclohexylcarbodiimide (1.1 g, 5.3 mmol) and CS_2 (2.6 mL, 43 mmol) were added to a solution of **23-25** (2.15g, 5.26 mmol) in Et_2O (10 mL) at -10 °C with stirring. The solution was kept at room temperature for 20-40 min, the solvent was evaporated and the residue purified as indicated in a).

c) To a solution of **23-25** (2.15 g, 5.26 mmol) in pyridine (10 mL) at 0 °C was added 1,1'-thiocarbonyldiimidazole (1.7 g, 8.8 mmol). The mixture was stirred for 4 h at room temperature, concentrated and purified as indicated in a).

*Methyl 6-deoxy-6-isothiocyanato-2,3,4-tri-*O*-trimethylsilyl-α-D-glucopyranoside* (**26**). Yield: 1.5 g, 65% (a); 1.9 g, 82% (b); 1.6 g, 70% (c), $[\alpha]_D$ +76.9 (*c* 1.1, CH_2Cl_2), R_f 0.5; ν_{max} 2097, 1252, and 843 cm^{-1}. ^1H NMR (500 MHz, CDCl3): δ 4.53 (d, 1H, $J_{1,2}$ 3.6, H-1), 3.68 (t, 1H, $J_{2,3} = J_{3,4}$ 8.8 Hz, H-3), 3.67 (s, 3H, OMe), 3.52 (ddd, 1H, $J_{4,5}$ 9.5, $J_{5,6b}$ 5.2, $J_{5,6a}$ 2.8 Hz, H-5), 3.47 (dd, 1H, $J_{6a,6b}$ 14.5 Hz, H-6a)3.41 (dd, 1H, H-2), 3.41 (dd, 1H, H-6b), 3.28 (dd, 1H, H-4), 0.53, and 0.50 (2s, 27H, 3 SiMe3) ^{13}C NMR (125.5 MHz, CDCl3): δ 133.2 (NCS), 99.6 (C-1), 74.4 (C-3), 73.2 (C-2), 72.6 (C-4), 69.6 (C-5), 54.8 (OMe), 46.1 (C-6), 1.0, 0.6, and 0.1 (SiMe3). EIMS: *m/z* 451 (5%, M^+) *Anal.* Calcd for $C_{17}H_{37}NO_5SSi_3$: C, 45.19; H, 8.25; N, 3.10; S, 7.10; Si, 18.65. Found: C, 45.10; H, 8.11; N, 3.36; S, 7.11; Si, 18.50.

*Methyl 6-deoxy-6-isothiocyanato-2,3,4-tri-*O*-trimethylsilyl-α-D-galactopyranoside* (**27**). Yield: 1.3 g, 56%, (a); 1.9 g, 80%, (b); 1.5 g, 65%, (c). $[\alpha]_D$ +72.8 (*c* 1.2, CH_2Cl_2), R_f 0.38; ν_{max} 2091, 1250, and 841 cm^{-1}. ^1H NMR (500 MHz, CDCl3): δ 4.64 (d, 1H, $J_{1,2}$ 3.4 Hz, H-1), 3.98 (dd, 1H, $J_{2,3}$ 9.3 Hz, H-2), 3.93 (t, 1H, $J_{5,6a} = J_{5,6b}$ 6.9, $J_{4,5}$ 0 Hz, H-5), 3.84 (m, 2H, H-3,4), 3.67 (dd, 1H, $J_{6a,6b}$ 14.1, Hz, H-6b), 3.42 (s, 3H, OMe), 0.17, and 0.16 (2s, 27H, 3OSiMe3). ^{13}C NMR (125.5 MHz, CDCl3): δ 132.4 (NCS), 100.6 (C-1), 72.5, 72.3 (C-3,4), 69.2 (C-2), 69.1 (C-4), 55.5 (OMe), 45.2 (C-6), 0.4, 0.3, and 0.1 (Si*Me*3) . EIMS: *m/z* 451 (30%, M^+), 392 (100, M^+-HSCN). *Anal.* Calcd for $C_{17}H_{37}NO_5SSi_3$: C, 45.19; H, 8.25; N, 3.10; S, 7.10; Si, 18.65. Found: C, 45.12; H, 8.05; N, 3.24; S, 6.87; Si, 18.56.

*Methyl 6-deoxy-6-isothiocyanato-2,3,4-tri-*O*-trimethylsilyl-α-D-mannopyranoside* (**28**). Yield: 0.6 g, 23%,(a); 1.3 g, 52%, (b); 1.1 g, 45%, (c). $[\alpha]_D$ +47.8 (*c* 1.0, CH_2Cl_2), R_f 0.52; ν_{max} 2957, 2924, 2099, 1252, and 839 cm^{-1}. ^1H NMR (300 MHz, CDCl3): δ 4.58 (d, 1H, $J_{1,2}$ 2.1 Hz, H-1), 3.87 (t, 1H, $J_{3,4} = J_{4,5}$ 8.8 Hz, H-4), 3.83 (t, 1H, $J_{2,3}$ 2.1 Hz, H-2), 3.78 (dd, 1H, H-3), 3.75-3.66 (m, 3H, H-5,6a,6b), 3.44 (s, 3H, OMe), and 0.19 (s, 27H, 3 SiMe3). ^{13}C NMR (125.5 MHz, CDCl3): δ 132.4 (NCS), 101.8 (C-1), 73.1 (C-2), 72.3 (C-5), 72.1 (C-3), 68.9 (C-4), 55.0 (OMe), 46.5 (C-6), 0.6, 0.5, and 0.2 (SiMe3). EIMS: *m/z* 451 (5%, M^+). *Anal.* Calcd for $C_{17}H_{37}NO_5SSi_3$: C, 45.19; H, 8.25; N, 3.10; S, 7.10; Si, 18.65. Found: C, 45.04; H, 8.15; N, 3.11; S, 7.14; Si, 18.59.

General procedure for the preparation of silylated deoxythioureido sugars (29-31). Dry (KOH) ammonia was bubbled into a solution of the corresponding isothiocyanate **26-28** (100 mg, 0.22 mmol) in pyridine (5 mL) at 0 °C for 10 min, and then at room temperature for 20 min. Evaporation of the solvent and column chromatography (EtOAc-hexane 3:2) of the residue gave the following compounds:

Methyl 6-deoxy-6-thioureido-2,3,4-tri-O-*trimethylsilyl-α-D-glucopyranoside* (**29**). Yield 98 mg (95%), $[\alpha]_D$ +60.0 (*c* 0.7, CH_2Cl_2), R*f* 0.68, λ_{max} (CH_2Cl_2) 253 nm (ε_{mM} 14.8); ν_{max} 3318,, 1547, 1252, 1076, and 843 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$, 313 K): δ 6.65 (bs, 1H, NH), 6.26 (bs, 2H, NH_2), 4.60 (d, 1H, $J_{1,2}$ 3.6 Hz, H-1), 3.76 (t, 1H, $J_{2,3} = J_{3,4}$ 8.5 Hz, H-3), 3.68 (dt, 1H, $J_{4,5} = J_{5,6b}$ 8.5 , $J_{5,6a}$ 2.5 Hz, H-5), 3.48 (dd, 1H, H-2), 3.30 (t, 1H, H-4), 3.40-3.20 (m, 2H, H-6a,6b), 3.36 (s, 3H, OMe), 0.14, 0.13, and 0.12 (3s, 27H, 3 SiMe3); (248 K): δ 7.48 (bs, 1H, NH *Z*), 7.07 (s, 1H, NH *E*), 6.92 (bs 1H, NH_2 *E*, pro-*Z*), 6.83 (bs, 1H, NH_2 *E*, pro-*E*), 6.73 (bs, 1H, NH2a *Z*), 6.53 (bs, 1H, NH2b *Z*). ^{13}C NMR (75.5 MHz, $CDCl_3$, 313 K): δ 184.0 (C=S), 99.9 (C-1), 74.6 (C-3), 73.8 (C-2), 73.6 (C-4), 71.0 (C-5), 55.2 (OMe), 47.5 (C-6), 1.1, 1.0, and 0.4 (SiMe3). FABMS: *m/z* 491 (100%, $[M+Na]^+$). *Anal.* Calcd for $C_{17}H_{40}N_2O_5SSi_3$: C, 43.55; H, 8.60; N, 5.97; S, 6.84; Si, 17.97. Found: C, 43.62; H, 8.62; N, 5.61; S, 6.74; Si, 18.08.

Methyl 6-deoxy-6-thioureido-2,3,4-tri-O-*trimethylsilyl-α-D-galactopyranoside* (**30**). Yield 94 mg (91%), $[\alpha]_D$ +59.7 (*c* 0.9, CH_2Cl_2), R*f* 0.60, λ_{max} (CH_2Cl_2) 253 nm (ε_{mM} 28.1); ν_{max} 3325, 1541, 1252, 1053, and 839 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$, 313 K): δ 7.42 (dd, 1H, $J_{NH,6a}$ 4.6, $J_{NH,6b}$ 6.4 Hz, NH), 6.99 (bs, 2H, NH_2), 4.62 (d, 1H, $J_{1,2}$ 3.4 Hz, H-1), 3.89 (m, 1H, H-5), 3.88 (dd, 1H, $J_{2,3}$ 9.0 Hz, H-2), 3.82 (m, 1H, H-4), 3.78 (dd, 1H, $J_{3,4}$ 2.7 Hz, H-4), 3.47 (m, 2H, H-6a,6b), 3.23 (s, 3H, OMe), 0.09, 0.08, and 0.07 (3s, 27H, 3 SiMe3); (248 K): δ 7.48 (bt, 1H, NH *E*), 7.09 (s, 1H, NH_2 *E*, pro-*Z*), 7.01 (bs, 1H, NH *Z*), 6.34 (bs, 1H, NH_2 *E*, pro-*E*), 6.13 (bs, 1H, NH_2 *Z*). ^{13}C NMR (75.5 MHz, $CDCl_3$, 313K): δ 184.3 (C=S), 100.7 (C-1), 74.2 (C-4), 70.5, 69.2 (3C, C-2,3,5), 55.6 (OMe), 46.9 (C-6), 0.6, 0.4, and 0.2 (SiMe3). FABMS: *m/z* 491 (40%, $[M+Na]^+$). *Anal.* Calcd for $C_{17}H_{40}N_2O_5SSi_3$: C, 43.55; H, 8.60; N, 5.97; S, 6.84; Si, 17.97. Found: C, 43.29; H, 8.45; N, 5.79; S, 6.47; Si, 18.11.

Methyl 6-deoxy-6-thioureido-2,3,4-tri-O-*trimethylsilyl-α-D-mannopyranoside* (**31**). Yield 73 mg (71%), $[\alpha]_D$ +19.5 (*c* 0.9, CH_2Cl_2), R*f* 0.70, λ_{max} (CH_2Cl_2) 253 nm (ε_{mM} 19.8); ν_{max} 3289, 1559, 1252, 1071, and 843 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$, 313 K): δ 6.80 (bs, 1H, NH), 6.35 (bs, 2H, NH_2), 4.46 (d, 1H, $J_{1,2}$ 1.8 Hz, H-1), 3.78 (dd, 1H, $J_{2,3}$ 1.9 Hz, H-2), 3.73 (m, 2H, H-3,4), 3.65 (m, 2H, H-5, H-6a), 3.31 (m, 1H, H-6b), 3.34 (s, 3H, OMe), 0.16, and 0.15 (2s, 27H, 3 SiMe3); (263 K): δ 7.13 (bs, 1H, NH *Z*), 6.94 (s, 1H, NH_2 *E*, pro-*Z*), 6.66 (bt, 1H, NH *E*), 6.22 (bs, 1H, NH_2 *E*, pro-*E*), 6.06 (bs, 1H, NH_2 *Z*). ^{13}C NMR (75.5 MHz, $CDCl_3$, 313 K): δ 183.9 (C=S), 101.6 (C-1), 73.2 (C-3), 72.1 (2C, C-2,5), 69.3 (C-4), 54.9 (OMe), 45.9 (C-6), 0.6, 0.4, and 0.1 (SiMe3). FABMS: *m/z* 491 (60%, $[M+Na]^+$). *Anal.* Calcd for $C_{17}H_{40}N_2O_5SSi_3$: C, 43.55; H, 8.60; N, 5.97; S, 6.84; Si, 17.97. Found: C, 43.47; H, 8.46; N, 5.98; S, 6.51; Si, 18.09.

General procedure for regioselective deprotection of isopropylidene derivatives. A solution of the corresponding 1,2:3,5-di-*O*-isopropylidene-α-D-glucofuranose derivative (**32a-c**, 0.76 mmol) in 60% aqueous AcOH was heated at 60 °C for 2 h, monitoring by TLC (EtOAc-EtOH-H_2O 45:5:3), then concentrated under reduced pressure and coevaporated several times with water. The residue was extracted

with EtOAc (3 x 15 mL), the organic extracts were dried ($MgSO_4$) and concentrated. The following compounds were prepared by this procedure:

6-Acetamido-6-deoxy-1,2-O-isopropylidene-α-D-glucofuranose (**33a**). Yield from **32a**: 0.17 g (85%), $[\alpha]_D$ +4.1 (*c* 0.9, MeOH), lit.,[22] $[\alpha]_D$ +4.7 (MeOH), ν_{max} 3405, 3312, 1643, and 1537 cm^{-1}. ^1H NMR (300 MHz, CD_3OD): δ 5.86 (δ, 1H, $J_{1,2}$ 3.6 Hz, H-1), 4.46(d, 1H, $J_{2,3}$ 0 Hz, H-2), 4.18 (d, 1H, $J_{3,4}$ 1.5 Hz, H-3), 3.90 (m, 2H, H-4,5), 3.58 (dd, 1H, $J_{5,6a}$ 2.9, $J_{6a,6b}$ 13.4 Hz, H-6a), 3.21 (dd, 1H, H-6b), 1.96 (s, 3H, *Me*CO), 1.44, and 1.29 (2s, 6H, 2Me). ^{13}C NMR (75.5 MHz, CD_3OD): δ 173.9 (C=O), 112.7 (*C*Me_2), 106.4 (C-1), 86.5 (C-2), 82.6(C-4), 75.3 (C-3), 68.7 (C-5), 44.8 (C-6), 27.0, 26.4 (C*Me*$_2$), and 22.5 (*Me*CO).

6-Deoxy-1,2-O-isopropylidene-6-thioacetamido-α-D-glucofuranose (**33b**). Yield from **32b**: 0.18 g (84%), $[\alpha]_D$ +5.6 (*c* 0.9, MeOH), λ_{max} (MeOH) 270 nm (ε_{mM} 3.2); ν_{max} 3449, 3304, 1530, and 1071 cm^{-1}. ^1H NMR (300 MHz, CD_3OD): δ 5.88 (d, 1H, $J_{1,2}$ 3.7 Hz, H-1), 4.47 (d, 1H, $J_{2,3}$ 0 Hz, H-2), 4.21 (d, 1H, $J_{3,4}$ 2.6 Hz, H-3), 4.14 (td, 1H, $J_{4,5} = J_{5,6b}$ 8.2, $J_{5,6a}$ 2.9 Hz, H-5), 4.00 (dd, 1H, $J_{6a,6b}$ 13.9 Hz, H-6a), 3.96 (dd, 1H, H-4), 3.59 (dd, 1H, H-6b), 2.50 (s, 3H, MeCS), 1.45 and 1.30 (2s, 6H, 2 Me). ^{13}C NMR (75.5 MHz, CD_3OD): δ 202.4 (C=S), 112.6 (*C*Me_2), 106.3 (C-1), 86.4 (C-2), 82.9 (C-4), 75.3 (C-3), 67.5 (C-5), 51.4 (C-6), 33.1 (*Me*CS), 27.0, and 26.3 (C*Me*$_2$). FABMS: *m/z* 300 (100%, $[M+Na]^+$), 278 (10, $[M+H]^+$). *Anal.* Calcd for $C_{11}H_{19}NO_5S$: C, 47.62; H, 6.90; N, 5.05; S, 11.56. Found: C, 47.71; H, 6.78; N, 5.13; S, 11.58.

6-Deoxy-1,2-O-isopropylidene-6-thioureido-α-D-glucofuranose (**33c**). Yield from **32c**: 0.19 g (90%), $[\alpha]_D$ -12.4 (*c* 1.0, MeOH), λ_{max} (MeOH) 241 nm (ε_{mM} 12.5); ν_{max} 3426, 3343, 1640, 1557, and 1084 cm^{-1}. ^1H NMR (300 MHz, CD_3OD, 323 K): δ 5.88 (d, 1H, $J_{1,2}$ 3.7 Hz, H-1), 4.47 (d, 1H, $J_{2,3}$ 0 Hz, H-2), 4.21 (d, 1H, $J_{3,4}$ 2.5 Hz, H-3), 3.99 (m, 2H, H-4, H-5), 3.45 (m, 2H, H-6a, H-6b), 1.45, and 1.29 (2s, 6H, 2 Me). ^{13}C NMR (75.5 MHz, CD_3OD, 323 K): δ 186.0 (C=S), 112.9 (*C*Me_2), 106.4 (C-1), 86.6 (C-2), 83.0 (C-4), 75.4 (C-3), 68.7 (C-5), 50.5 (C-6), 29.5, and 28.8 (C*Me*$_2$). FABMS: *m/z* 301 (100%, $[M+Na]^+$), 279 (45, $[M+H]^+$). *Anal.* Calcd for $C_{10}H_{18}N_2O_5S$: C, 43.15; H, 6.52; N, 10.00; S, 11.52. Found: C, 43.07; H, 6.37; N, 10.21; S, 11.28.

General procedure for total deprotection of isopropylidene derivatives. A solution of the corresponding di-*O*-isopropylidene derivative (8.6 mmol) in TFA-water (9:1, 15 mL) was kept at 30 °C under reduced pressure in a rotary evaporator until evolution of acetone ceased (~15 min). Further concentration and coevaporation several times with water gave:

6-Acetamido-6-deoxy-D-glucopyranose (**34a**). Yield from **32a**: 0.18 g (95%), α:β ratio 1:2 (H-1 integration), $[\alpha]_D$ +38.9 (*c* 1.0, H_2O), lit.,[22] $[\alpha]_D$ +42 (*c* 2.0, H_2O), lit.,[23] $[\alpha]_D$+32.2 (*c* 3.5, H_2O); ν_{max} 3347, 3254, 1632, 1582, and 1061 cm^{-1}. ^1H NMR (500 MHz, D_2O): δ 5.14 (d, $J_{1,2}$ 3.8 Hz, H-1α), 4.17 (d, $J_{1,2}$ 7.9 Hz, H-1β), 3.81 (ddd, $J_{4,5}$ 9.4, $J_{5,6a}$ 2.8, $J_{5,6b}$ 6.6 Hz, H-5α), 3.64 (t, $J_{2,3} = J_{3,4}$ 9.4 Hz, H-3), 3.55 (dd, $J_{5,6a}$ 2.7, $J_{6a,6b}$ 14.3 Hz, H-6aβ), 3.49 (dd, $J_{5,6a}$ 2.8, $J_{6a,6b}$ 14.4 Hz, H-6aα), 3.47 (dd, H-2α), 3.43 (ddd, $J_{4,5}$ 9.0, $J_{5,6b}$ 6.9 Hz, H-5β), 3.42 (t, $J_{2,3} = J_{3,4}$ 9.0 Hz, H-3β), 3.37 (dd, H-6bα), 3.32 (dd, H-6bβ), 3.23 (t, H-4α,β), 3.18 (dd, H-2β), and 1.96 (NAc). ^{13}C NMR (75.5 MHz, D_2O): δ.174.6 (CO), 95.9 (C-1β), 92.1 (C-1α), 75.5 (C-3β), 74.2 (C-2β), 74.0 (C-5β), 72.6 (C-3α), 71.5 (C-2α), 71.1 (C-4α), 71.0 (C-4β), 69.7 (C-5α), 40.3 (C-6β), 40.1 (C-6α), and 21.8 (Me). FABMS: *m/z* 244 (100%, $[M+Na]^+$).

6-Acetamido-6-deoxy-D-galactopyranose (**36a**). Yield from **35a**: 0.18 g (95%), α:β ratio 1:2 (H-1 integration), $[\alpha]_D$ +75.4 (*c* 1.0, H_2O), lit.,[24] $[\alpha]_D$ +81 (*c* 1.24, H_2O); ν_{max} 3391, 1633, 1582, and 1059

cm^{-1}. ^1H NMR (300 MHz, D_2O): δ 4.85 (δ, $J_{1,2}$ 3.5 Hz, H-1α), 4.17 (d, $J_{1,2}$ 7.9 Hz, H-1β), 3.72 (dd, $J_{4,5}$ 0, $J_{5,6a}$ 5.0, $J_{5,6b}$ 9.3 Hz, H-5α), 3.55 (d, $J_{3,4}$ 2.8 Hz, H-4α) 3.49 (d, $J_{3,4}$ 3.4, $J_{4,5}$ 0 Hz, H-4β), 3.43 (dd, $J_{2,3}$ 7.8 Hz, H-3α), 3.41 (dd, H-2α), 3.33 (dd, $J_{5,6a}$ 4.8, $J_{5,6b}$ 9.3 Hz, H-5β), 3.25 (dd, $J_{2,3}$ 9.9 Hz, H-3β), 3.11 (dd, $J_{6a,6b}$ 14.5 Hz, H-6aβ), 3.10 (dd, H-2β), 3.07 (dd, $J_{6a,6b}$ 14.5 Hz, H-6aα), 2.98 (dd, H-6bα,β), 1.70 (NAc).^{13}C NMR (75.5 MHz, D_2O): δ 176.6 (CO), 98.4 (C-1β), 94.3 (C-1α), 74.6 (C-3β,5β), 73.7 (C-2β), 71.5 (C-3α), 71.0 (C-4α), 70.9 (C-4β), 70.2 (C-2α), 70.1 (C-5α), 42.1 (C-6α), 42.0 (C-6β), and 23.4 (Me). FABMS: *m/z* 244 (100%, $[M+Na]^+$). *Anal.* Calcd for $C_8H_{15}NO_6$: C, 43.44; H, 6.83; N, 6.33. Found: C, 43.31; H, 6.69; N, 6.18.

6-Deoxy-6-thioacetamido-D-glucopyranose (**34b**). Yield from **32b**: 0.20 g (98%), α:β ratio 1:2 (H-1 integration), $[\alpha]_D$ +25.0 (*c* 1.0, H_2O), R_f (EtOAc-EtOH-H_2O 45:5:3) 0.28, λ_{max} (H_2O) 260 nm (ε_{mM} 10.9); ν_{max} 3372, 1551, and 1049 cm^{-1}. ^1H NMR (300 MHz, D_2O): δ 4.97 (d, $J_{1,2}$ 3.7 Hz, H-1α), 4.40 (d, $J_{1,2}$ 7.9 Hz, H-1β), 3.90-3.70 (m, H-5a, H-6aα), 3.80 (m, H-5β), 3.62 (dd, $J_{5,6b}$ 7.5, $J_{6a,6b}$ 14.6 Hz, H-6bα), 3.53 (dd, $J_{5,6a}$ 7.6, $J_{6a,6b}$ 14.0 Hz, H-6aβ), 3.46 (dd, $J_{5,6b}$ 9.5 Hz, H-6bβ), 3.44 (t, $J_{2,3} = J_{3,4}$ 9.8 Hz, H-3α), 3.31 (dd, H-2α), 3.25 (t, $J_{2,3}=J_{3,4}$ 9.4 Hz, H-3β), 3.10 (t, $J_{4,5}$ 9.4 Hz, H-4β), 3.08 (t, $J_{4,5}$ 9.8 Hz, H-4α), 3.02 (dd, H-2β), and 2.28 (Me). ^{13}C NMR (75.5 MHz, D_2O): δ 202.3 (CS), 95.9 (C-1β), 92.1 (C-1α), 75.4 (C-3β), 74.1 (C-2β), 73.1 (C-5β), 72.4 (C-3α), 71.4 (C-2α), 71.3 (C-4α), 71.2 (C-4β), 68.9 (C-5α), 47.2 (C-6β), 47.1 (C-6α), and 32.4 (Me). FABMS: *m/z* 260 (90%, $[M+Na]^+$). *Anal.* Calcd for $C_8H_{15}NO_5S$: C, 40.50; H, 6.37; N, 5.90; S, 13.51. Found: C, 40.54; H, 6.28; N, 5.74; S, 13.28.

6-Deoxy-6-thioacetamido-D-galactopyranose (**36b**). Yield from **35b**: 0.20 g (98%), α:β ratio 1:2 (H-1 integration), $[\alpha]_D$ +86.7 (*c* 0.7, H_2O), R_f (EtOAc-EtOH-H_2O 45:5:3) 0.26, λ_{max} (H_2O) 260 nm (ε_{mM} 10.5); ν_{max} 3381, 1564, and 1067 cm^{-1}. ^1H NMR (300 MHz, D_2O): δ 4.95 (d, $J_{1,2}$ 3.6 Hz, H-1α), 4.22 (d, $J_{1,2}$ 7.9 Hz, H-1β), 4.03 (dd, $J_{4,5}$ 0, $J_{5,6b}$ 4.5, $J_{5,6a}$ 8.6 Hz, H-5α), 3.70-3.58 (m, H-5β, H-6aβ), 3.68 (d, $J_{3,4}$ 3.8 Hz, H-4α), 3.64 (m, H-6aα), 3.63 (d, $J_{3,4}$ 3.4, $J_{4,5}$ 0 Hz, H-4β), 3.57 (dd, $J_{2,3}$ 10.0 Hz, H-3α), 3.50 (dd, H-2α), 3.45 (m, H-6bα, H-6bβ), 3.36 (dd, $J_{2,3}$ 9.9 Hz, H-3β), 3.21 (dd, H-2β), and 2.23 (Me). ^{13}C NMR (75.5 MHz, D_2O): δ,.204.2 (CS β), 204.1 (CS α), 98.5 (C-1β), 94.4 (C-1α), 74.7 (C-3β), 73.8 (C-5β), 73.7 (C-2β), 71.8 (C-3α), 71.2 (C-4β), 71.1 (C-4α), 70.3 (C-2α), 69.3 (C-5α), 48.8 (C-6), and 34.4 (Me). FABMS: *m/z* 260 (30%, $[M+Na]^+$). *Anal.* Calcd for $C_8H_{15}NO_5S$: C, 40.50; H, 6.37; N, 5.90; S, 13.51. Found: C, 40.60; H, 6.42; N, 5.98; S, 13.28.

6-Deoxy-6-thioureido-D-glucopyranose (**34c**). Yield from **32c**: 0.20 g (96%), α:β ratio 1:2 (H-1 integration), $[\alpha]_D$ +15.0 (*c* 1.0, H_2O), R_f (EtOAc-EtOH-H_2O 45:5:3) 0.52, λ_{max} (H_2O) 238 nm (ε_{mM} 8.2); ν_{max} 3308, 1637, 1568, and 1060 cm^{-1}. ^1H NMR (300 MHz, D_2O, 323 K): δ 4.90 (d, $J_{1,2}$ 3.8 Hz, H-1α), 4.33 (d, $J_{1,2}$ 7.9 Hz, H-1β), 3.62 (ddd, $J_{4,5}$ 9.8, $J_{5,6a}$ 3.2, $J_{5,6b}$ 6.5 Hz, H-5α), 3.45-3.20 (m, H-6aα, H-6aβ, H-6bα, H-6bβ), 3.39 (t, $J_{2,3} = J_{3,4}$ 9.8 Hz, H-3α), 3.23 (dd, H-2α), 3.21 (m, H-5β), 3.18 (t, $J_{2,3} = J_{3,4}$ 9.3 Hz, H-3β), 3.02 (t, $J_{4,5}$ 9.3 Hz, H-4β), 3.00 (t, H-4α), and 2.93 (dd, H-2β). ^{13}C NMR (75.5 MHz, D_2O, 323 K): δ 183.0 (CS), 98.3 (C-1β), 94.5 (C-1α), 77.8 (C-3β), 76.6 (C-2β), 76.5 (C-5β), 74.9 (C-3α), 73.8 (C-2α), 73.3 (C-5α), 73.1 (C-4β), 72.2 (C-4α), and 47.4 (C-6). FABMS: *m/z* 261 (100%, $[M+Na]^+$). *Anal.* Calcd for $C_7H_{14}N_2O_5S$: C, 35.29; H, 5.92; N, 11.76; S, 13.46. Found: C, 34.90; H, 5.69; N, 11.59; S, 13.50.

6-Deoxy-6-thioureido-D-galactopyranose (**36c**). Yield from **35**: 0.20 g (95%), α:β ratio 1:2 integration), $[\alpha]_D$ +9.0 (*c* 0.5, H_2O), λ_{max} (H_2O) 239 nm (ε_{mM} 15.8); ν_{max} 3327, 1630, 1562, and 1067

cm^{-1}. ^1H NMR (300 MHz, D_2O, 323 K): 5.48 (d, $J_{1,2}$ 3.6 Hz, H-1α), 4.81 (d, $J_{1,2}$ 7.8 Hz, H-1β), 4.44 (bt, $J_{4,5}$ 0, $J_{5,6a} = J_{5,6b}$ 6.9 Hz, H-5α), 4.20 (bd, $J_{3,4}$ 3.1 Hz, H-4α), 4.15 (d, $J_{3,4}$ 3.4, $J_{4,5}$ 0 Hz, H-4β), 4.10 (dd, $J_{2,3}$ 10.2 Hz, H-3α), 4.07 (dd, H-2α), 4.04 (m, H-6aα, H-5β, H-6aβ), 3.88 (dd, $J_{2,3}$ 9.9 Hz, H-3β), 3.80 (m, H-6bα, H-6bβ), and 3.73 (dd, H-2β). ^{13}C NMR (75.5 MHz, D_2O, 323 K): δ 181.4 (CS β), 178.5 (CS α), 98.4 (C-1β), 94.3 (C-1α), 74.6 (C-3β,5β), 73.8 (C-2β), 71.5 (C-5α), 71.0 (C-2α,3α,4α), 70.2 (C-4β), and 46.5 (C-6). FABMS: *m/z* 261 (100%, $[M+Na]^+$), 239 (60%, $[M+H]^+$). *Anal.* Calcd for $C_7H_{14}N_2O_5S$: C, 35.29; H, 5.92; N, 11.76; S, 13.46. Found: C, 34.94; H, 5.74; N, 11.51; S, 13.50.

General procedure for the preparation of partially acetalated glucosyl thioureidoaldoses (40, 41). To a solution of the corresponding sugar isothiocyanate (**38** or **39**, 1.38 g, 4.6 mmol) in pyridine-water (3:1, 4 mL) was added Et_3N (0.1 mL) and β-D-glucopyranosylamine (**37**, 1.24 g, 6.9 mmol). The solution was stirred at room temperature for 48 h, monitoring by TLC (EtOAc-EtOH-H_2O 45:5:3), then concentrated and purified by column chromatography with the same eluent to give the following compounds:

6-Deoxy-6-[N'-(β-D-glucopyranosyl)thioureido]-1,2:3,5-di-O-isopropylidene-α-D-glucofuranose (**40**). Yield 0.68 g (31%), $[\alpha]_D$ -1.0 (*c* 1.0, MeOH), R_f 0.22, λ_{max} (MeOH) 246 nm (ε_{mM} 12.1); ν_{max} 3344, 1553, 1381, and 1090 cm^{-1}. ^1H NMR (500 MHz, CD_3OD, 323 K): δ 5.95 (d, 1H, $J_{1,2}$ 3.6 Hz, H-1), 5.17 (bd, 1H, $J_{1',2'}$ 8.9 Hz, H-1'), 4.54 (d, 1H, $J_{2,3}$ 0 Hz, H-2), 4.28 (dd, 1H, $J_{3,4}$ 3.8, $J_{4,5}$ 6.9 Hz, H-4), 4.21 (d, 1H, H-3), 4.08 (bs, 1H, H-6a), 3.92 (bd, 1H, H-6b), 3.83 (dd, 1H, $J_{5',6'a}$ 2.3, $J_{6'a,6'b}$ 11.9 Hz, H-6'a), 3.76 (td, 1H, $J_{5,6a}$ 4.5, $J_{5,6b}$ 6.9 Hz, H-5), 3.65 (dd, 1H, $J_{5',6'b}$ 5.5 Hz, H-6'b), 3.41 (t, 1H, $J_{2',3'} = J_{3',4'}$ 8.9 Hz, H-3'), 3.36 (ddd, 1H, $J_{4',5'}$ 8.9 Hz, H-5'), 3.29 (t, 1H, H-4'), 3.26 (t, 1H, H-2'), 1.45, 1.34, 1.33, and 1.29 (4s, 12H, 4Me). ^{13}C NMR (75.5 MHz, CD_3OD, 323 K): δ 185.2 (C=S), 113.5 (*C*Me_2 dioxolane), 107.7 (C-1), 102.2 (*C*Me_2 dioxane), 85.2 (C-2,1'), 81.8 (C-4), 79.2 (C-5'), 78.9 (C-3'), 76.2 (C-3), 74.2 (C-2'), 71.9 (C-4'), 71.5 (C-5), 62.7 (C-6'), 48.1 (C-6), 27.5, 26.8, 24.5, and 24.4 (*C*Me_2). FABMS: *m/z* 503 (100%, $[M+Na]^+$), 481 (10, $[M+H]^+$). *Anal.* Calcd for $C_{19}H_{32}N_2O_{10}S$: C, 47.49; H, 6.71; N, 5.83; S, 6.67. Found: C, 47.57; H, 6.75; N, 5.80; S, 6.49.

6-Deoxy-6-[N'-(β-D-glucopyranosyl)thioureido]-1,2:3,4-di-O-isopropylidene-α-D-galactopyranose (**41**). Yield 0.77 g (35%), $[\alpha]_D$ -43.7 (*c* 0.8, CH_2Cl_2), R_f 0.26, λ_{max} (CH_2Cl_2) 252 nm (ε_{mM} 13.2); ν_{max} 3335, 1553, 1381, and 1069 cm^{-1}. ^1H NMR (300 MHz, CD_3OD, 323 K): δ 5.47 (d, 1H, $J_{1,2}$ 4.9 Hz, H-1), 5.12 (bd, 1H, $J_{1,2}$ 8.7 Hz, H-1'), 4.62 (dd, 1H, $J_{2,3}$ 2.4, $J_{3,4}$ 7.8 Hz, H-3), 4.32 (dd, 1H, H-2), 4.25 (dd, 1H, $J_{4,5}$ 1.8 Hz, H-4), 4.16 (ddd, 1H, $J_{5,6a}$ 2.3, $J_{5,6b}$ 7.1 Hz, H-5), 3.85 (dd, 1H, $J_{5',6'a}$ 6.1, $J_{6'a,6'b}$ 11.9 Hz, H-6'a), 3.83 (dd, 1H, $J_{6a,6b}$ 11.9 Hz, H-6a), 3.67 (dd, 1H, $J_{5',6'b}$ 4.8 Hz, H-6'b), 3.58 (dd, 1H, H-6b), 3.58 (t, 1H, $J_{2',3'} = J_{3',4'}$ 8.7 Hz, H-3'), 3.41 (m, 1H, H-5'), 3.35 (t, 1H, $J_{4',5'}$ 8.7 Hz, H-4'), 3.27 (t, 1H, H-2'), 1.49, 1.42, 1.34, and 1.31 (4s, 12H, 4Me). ^{13}C NMR (75.5 MHz, CD_3OD, 323 K): δ 185.1 (C=S), 110.7, 110.2 (*C*Me_2), 97.7 (C-1), 85.2 (C-1'), 79.1 (C-5'), 78.9 (C-3'), 74.2 (C-2'), 72.8 (C-2), 72.2 (C-3), 72.1 (C-4), 71.6 (C-4'), 67.6 (C-5), 62.8 (C-6'), 46.0 (C-6), 26.5, 26.4, 25.3, and 24.7 (*C*Me_2). FABMS: *m/z* 503 (100%, $[M+Na]^+$), 481 (33, $[M+H]^+$). *Anal.* Calcd for $C_{19}H_{32}N_2O_{10}S$: C, 47.49; H, 6.71; N, 5.83; S, 6.67. Found: C, 47.43; H, 6.51; N, 5.79; S, 6.51

General procedure for the preparation of glucosyl thioureidoaldoses (42, 43). A solution of the partially acetalated thioureidoaldose (**40** or **41**, 0.35 g, 0.73 mmol) in TFA-water (9:1, 10 mL) was kept at 30

°C under reduced pressure in a rotary evaporator until evolution of acetone ceased (10 min). Further concentration and coevaporation several times with water gave a residue which was purified by GPC, yielding the following compounds:

*6-Deoxy-6-[*N'*-(β-*D*-glucopyranosyl)thioureido]-*D*-glucopyranose* (**42**). Yield 0.28 g (97%), α:β ratio 1:2.3 (H-1 integration), $[\alpha]_D$ -65.8 (*c* 1.0, H_2O), R*f* (BuOH-AcOH-H_2O 2:1:1) 0.36, λ_{max} (H_2O) 247 nm (ε_{mM} 5.5); ν_{max} 3289, 1559, and 1071cm^{-1}. ^{1}H NMR (500 MHz, D_2O, 323 K): δ 5.63 (bs, 1H, H-1'), 5.51 (d, $J_{1,2}$ 3.6 Hz, H-1α), 4.93 (d, 1H, $J_{1,2}$ 7.9 Hz, H-1β), 4.30-3.95 (m, H-6a,H-6b),4.26 (ddd, $J_{4,5}$ 8.6, $J_{5,6a}$ 3.1, $J_{5,6b}$ 7.2 Hz, H-5α), 4.18 (dd, 1H, $J_{5',6'a}$ 5.1, $J_{6'a,6'b}$ 12.2 Hz, H-6'a), 4.03 (dd, J5',6'b 5.1 Hz, H-6'b), 4.03 (dd, $J_{2,3}$ 10.1, $J_{3,4}$ 8.6 Hz, H-3α), 3.90 (ddd, $J_{5,6a}$ 3.1, $J_{5,6b}$ 6.6, $J_{4,5}$ 9.4 Hz, H-5β), 3.86 (t, $J_{1',2'}$ = $J_{2',3'}$ = $J_{3',4'}$ 9.3 Hz, H-2', H-3'), 3.85 (m, 1H, H-5'), 3.82 (dd, H-2α), 3.78 (t, $J_{2,3}$ = $J_{3,4}$ 9.4 Hz, H-3β), 3.72 (t, $J_{4',5'}$ 9.3 Hz, H-4'), 3.63 (t, H-4β), and 3.62 (t, H-4α). ^{13}C NMR (125.5 MHz, D_2O, 323 K): δ,183.1 (C=S), 95.8 (C-1β), 92.0 (C-1α), 83.4 (C-1'α,β), 77.1 (C-3'α,β), 76.4 (C-2'α,β), 75.3 (C-3β), 74.0 (C-2β), 73.8 (C-5β), 72.4 (C-3α), 72.0 (C-5'α,β), 71.4 (C-4β), 71.0 (C-2α), 70.8 (C-4α), 69.6 (C-5α), 69.3 (C-4'α,β), 60.6 (C-6'α,β), and 45.2 (C-6α,β). FABMS: *m/z* 423 (90%, $[M+Na]^+$), 405 (10, $[M+Na-H_2O]^+$). *Anal.* Calcd for $C_{13}H_{24}N_2O_{10}S$: C, 38.99; H, 6.04; N, 6.99; S, 8.01. Found: C, 38.64; H, 6.32; N, 6.64; S, 8.12.

*6-Deoxy-6-[*N'*-(β-*D*-glucopyranosyl)thioureido]-*D*-galactopyranose* (**43**). Yield 0.27 g (95%), α:β ratio 1:2.3 (H-1 integration), $[\alpha]_D$ +28.6 (*c* 1.0, H_2O), R*f* (BuOH-AcOH-H_2O 2:1:1) 0.28, λ_{max} (H_2O) 243 nm (ε_{mM} 9.9); ν_{max} 3289, 1559, and 1071cm^{-1}. ^{1}H NMR (500 MHz, D_2O, 323 K): δ 5.54 (d, $J_{1,2}$ 3.8 Hz, H-1α), 4.85 ($J_{1,2}$ 7.9 Hz, H-1β), 4.77 (bs, 1H, H-1'), 4.58 (m, H-5α), 4.17 (dd, 1H, $J_{5',6'a}$ 2.3, $J_{6'a,6'b}$ 12.4 Hz, H-6'a), 4.20 (dd, $J_{4,5}$ 0, $J_{3,4}$ 3.5 Hz, H-4β), 4.13 (dd, $J_{3,4}$ 3.0, $J_{2,3}$ 10.4 Hz, H-3α), 4.08 (dd, H-2a), 4.01 (dd, 1H, $J_{5',6'b}$ 5.4 Hz, H-6'b), 3.98-3.90 (m, H-6a, H-6b), 3.92 (dd, $J_{2,3}$ 9.9 Hz, H-3β), 3.85 (t, 2H, $J_{1',2'}$ = $J_{2',3'}$ = $J_{3',4'}$ 9.4 Hz, H-2', H-3'), 3.82 (ddd, 1H, $J_{4',5'}$ 9.4 Hz, H-5'), 3.77 (dd, $J_{2,3}$ 9.9 Hz, H-2β), 3.75 (m, H-5β), and 3.71 (t, 1H, H-4'). ^{13}C NMR (125.5 MHz, D_2O, 323K): δ, 183.2 (C=S), 96.3 (C-1β), 92.2 (C-1α), 83.2 (C-1'α,β), 77.1 (C-3'α,β), 76.4 (C-2'α,β), 72.5 (C-3β), 71.9 (C-5β, C-5'α,β), 71.7 (C-2β), 69.5, 68.1 (C-2α,3α), 69.2 (C-4'α,β), 68.9 (C-4β), 60.6 (C-6'α,β), and 44.8 (C-6α,β). FABMS: *m/z* 423 (20%, $[M+Na]^+$). *Anal.* Calcd for $C_{13}H_{24}N_2O_{10}S$: C, 38.99; H, 6.04; N, 6.99; S, 8.01. Found: C, 38.72; H, 5.84; N, 7.01; S, 8.38.

General procedure for the preparation of methyl thioureidoaldosides (44-46). To a solution of the corresponding thioureido derivative (**29-31**, 70 mg, 0.15 mmol) in CH_2Cl_2-MeOH-H_2O (4:2:1, 7 mL) was added 10% aqueous AcOH (0.7 mL). The reaction mixture was stirred at 60 °C for 3 h, then concentrated and coevaporated several times with toluene. The resulting residue was purified by GPC and freeze-dried from an aqueous solution to give the following compounds:

*Methyl 6-deoxy-6-thioureido-α-*D*-glucopyranoside* (**44**). Yield 37 mg (98%), $[\alpha]_D$ +92.0 (*c* 0.8, H_2O), R*f* (CH_2Cl_2-MeOH 4:1) 0.49, λ_{max} (H_2O) 237 nm (ε_{mM} 12.0); ν_{max} 3320, 1561, and 1047 cm^{-1}. ^{1}H NMR (300 MHz, Me_2SO-*d*6, 313 K): δ 7.34 (bs, 1H, NH), 6.97 (bs, 2H, NH_2), 4.55 (d, 1H, $J_{1,2}$ 3.7 Hz, H-1), 3.78 (m, 1H, H-6a), 3.44 (m, 1H, H-5), 3.40 (t, 1H, $J_{2,3}$ = $J_{3,4}$ 8.8 Hz, H-3), 3.29 (s, 3H, OMe), 3.23 (m, 1H, H-6b), 3.13 (bs, 1H, H-2), and 3.00 (t, 1H, $J_{4,5}$ 8.8 Hz, H-4). ^{13}C NMR (75.5 MHz, CD_3OD, 313 K): δ 185.2 (C=S), 101.3 (C-1), 74.3 (C-3), 73.5 (C-2), 72.5 (C-5), 71.7 (C-4), 55.6 (OMe), and 46.7 (C-6).

FABMS: *m/z* 275 (30%, $[M+Na]^+$), 253 (100%, $[M+H]^+$), 221 (50, MH^+-MeOH). *Anal.* Calcd for $C_8H_{16}N_2O_5S$: C, 38.08; H, 6.39; N, 11.10; S, 12.71. Found: C, 38.07; H, 6.28; N, 11.13; S, 12.71.

Methyl 6-deoxy-6-thioureido-α-D-galactopyranoside (**45**). Yield 36 mg (96%), $[\alpha]_D$ +116.7 (*c* 0.9, H_2O), R_f (BuOH-AcOH-H_2O 2:1:1) 0.72, λ_{max} (H_2O) 204 nm (ε_{mM} 11.8); ν_{max} 3418, 1559, and 1074 cm^{-1}. ^1H NMR (300 MHz, D_2O, 313 K): δ 4.99 (d, 1H, $J_{1,2}$ 3.0 Hz, H-1), 4.17 (m, 1H, H-5), 4.11 (m, 1H, H-4), 3.97 (m, 2H, H-2, H-3), 3.70 (m, H-6a, H-6b) and 3.55 (s, 3H, OMe). ^{13}C NMR (75.5 MHz, D_2O, 313 K): δ 182.9 (C=S), 100.0 (C-1), 70.0 (C-4), 70.0, 68.7 (C-2,3), 69.2 (C-5), 55.6 (OMe), and 45.4 (C-6). FABMS: *m/z* 275 (80%, $[M+Na]^+$), 253 (50, $[M+H]^+$), 221 (100, $[M+H-MeOH]^+$). *Anal.* Calcd for $C_8H_{16}N_2O_5S$: C, 38.08; H, 6.39; N, 11.10; S, 12.71. Found: C, 37.88; H, 6.22; N, 11.16; S, 12.50.

Methyl 6-deoxy-6-thioureido-α-D-mannopyranoside (**46**). Yield 34 mg (91%), $[\alpha]_D$ +13.0 (*c* 1.0, H_2O), R_f (BuOH-AcOH-H_2O 2:1:1) 0.71, λ_{max} (H_2O) 239 nm (ε_{mM} 5.8); ν_{max} 3333, 1569, and 1083 cm^{-1}. ^1H NMR (300 MHz, D_2O, 313 K): δ 4.92 (d, 1H, $J_{1,2}$ 1.6 Hz, H-1), 4.10 (dd, 1H, $J_{2,3}$ 3.4 Hz, H-2), 3.92 (dd, 1H, $J_{3,4}$ 9.4 Hz, H-3), 3.91-3.86 (m, 2H, H-6a, H-6b), 3.86 (m, 1H, H-5), 3.75 (t, 1H, $J_{4,5}$ 9.4 Hz, H-4), and 3.55 (s, 3H, OMe). ^{13}C NMR (75.5 MHz, D_2O, 313 K): δ 180.1 (C=S), 100.7 (C-1), 70.6 (C-3), 69.7 (C-2,5), 67.8 (C-4), 55.5 (OMe), and 45.5 (C-6). FABMS: *m/z* 275 (70%, $[M+Na]^+$), 253 (20, $[M+H]^+$), 221 (50, $[M+H-MeOH]^+$). *Anal.* Calcd for $C_8H_{16}N_2O_5S$: C, 38.08; H, 6.39; N, 11.10; S, 12.71. Found: C, 37.71; H, 6.14; N, 11.00; S, 12.39.

General procedure for the preparation of partially silylated glucosyl thioureidoaldosides (47a-49a). To a solution of the corresponding sugar isothiocyanate (**26-28**, 250 mg, 0.55 mmol) in pyridine (6 mL) was added Et_3N (0.15 mL) and β-D-glucopyranosylamine (**37**, 100 mg, 0.55 mmol). The solution was stirred at room temperature monitoring by TLC (EtOAc-EtOH-H_2O 45:5:3), then concentrated and purified by column chromatography with the same eluent.

Methyl 6-deoxy-6-[N'-(β-D-glucopyranosyl)thioureido]-2,3,4-tri-O-trimethylsilyl-α-D-glucopyranoside (**47a**). Yield 212 mg (62%), $[\alpha]_D$ +48.3 (*c* 1.0, MeOH), R_f 0.66, λ_{max} (MeOH) 245 nm (ε_{mM} 12.9); ν_{max} 3331, 2957, 2917, 1547, 1257, 1082, and 852 cm^{-1}. ^1H NMR (500 MHz, CD_3OD, 313 K): δ 5.20 (bs, 1H, H-1'), 4.63 (d, 1H, $J_{1,2}$ 3.6 Hz, H-1), 3.82 (dd, 1H, $J_{5',6'a}$ 2.3, $J_{6'a,6'b}$ 11.9 Hz, H-6'a), 3.72 (t, 1H $J_{2,3}$=$J_{3,4}$ 8.8 Hz, H-3), 3.63 (dd, 1H, $J_{5',6'b}$ 5.6 Hz, H-6'b), 3.63 (m, 1H, H-5), 3.50 (dd, 1H, H-2), 3.40 (t, 1H, $J_{2',3'}$ = $J_{3',4'}$ 9.1 Hz, H-3'), 3.34 (s, 3H, OMe), 3.30 (m, 3H, H-4, H-2', H-5'), 3.24 (t, 1H, $J_{4',5'}$ 9.1 Hz, H-4'), 0.20, 0.15, and 0.14 (3s, 27H, 3 $SiMe_3$). ^{13}C NMR (125.5 MHz, CD_3OD, 323 K): δ 186.1 (C=S), 101.3 (C-1), 85.3 (C-1'), 79.4 (C-5'), 79.0 (C-3'), 76.2 (C-3), 75.6 (C-4), 75.1 (C-2), 74.4 (C-2'), 71.7 (C-4'), 71.5 (C-5), 62.9 (C-6'), 55.8 (OMe), 49.8 (C-6), 1.5, 1.3, and 0.5 ($SiMe_3$) . FABMS: *m/z* 653 (40%, $[M+Na]^+$). *Anal.* Calcd for $C_{23}H_{50}N_2O_{10}SSi_3$: C, 43.78; H, 7.99; N, 4.44; S, 5.08; Si, 13.35. Found: C, 43.71; H, 7.85; N, 4.58; S, 4.94; Si, 13.54.

Methyl 6-deoxy-6-[N'-(β-D-glucopyranosyl)thioureido]-2,3,4-tri-O-trimethylsilyl-α-D-galactopyranoside (**48a**). Yield 222 mg (64%), $[\alpha]_D$ +57.0 (*c* 1.0, CH_2Cl_2), R_f 0.42, λ_{max} (MeOH) 254 nm (ε_{mM} 16.4); ν_{max} 3332, 2961, 2897, 1552, 1256 1101, and 847 cm^{-1}. ^1H NMR (300 MHz, CD_3OD, 313 K): δ 5.42 (bs, 1H, H-1'), 4.62 (d, 1H, $J_{1,2}$ 3.2 Hz, H-1), 3.45 (s, 3H, OMe), 0.26, and 0.25 (2s, 27H, 3 $SiMe_3$) ^{13}C NMR (75.5 MHz, CD_3OD, 323K): δ.183.8 (C=S), 102.0 (C-1), 85.0 (C-1'), 79.3 (C-5'), 78.9 (C-3'), 74.9, 71.4, 70.9 (C-2,3,5), 74.2 (C-2'), 72.1 (C-4), 69.8 (C-4'), 62.7 (C-6'), 55.9 (OMe), 47.2 (C-6),

0.9, 0.7, and 0.5 (SiMe3). FABMS: *m/z* 653 (80%, $[M+Na]^+$), 598 (20, M^+-MeOH). *Anal.* Calcd for $C_{23}H_{50}N_2O_{10}SSi_3$: C, 43.78; H, 7.99; N, 4.44; S, 5.08; Si, 13.35. Found: C, 43.47; H, 7.56; N, 4.15; S, 4.70; Si, 13.11.

*Methyl 6-deoxy-6-[*N'*-(β-*D*-glucopyranosyl)thioureido]-2,3,4-tri-*O*-trimethylsilyl-α-*D*-mannopyranoside* (**49a**). Yield 139 mg (40%), $[\alpha]_D$ +25.0 (*c* 1.0, MeOH), R*f* 0.34, λ_{max} (MeOH) 254 nm (ε_{mM} 14.6); ν_{max} 3325, 2967, 2912, 1541, 1252, 1053, and 839 cm^{-1}. ^1H NMR (300 MHz, CD_3OD, 313 K): δ 5.20 (bs, 1H, $J_{1,2}$ 8.8 Hz, H-1'), 4.50 (d, 1H, $J_{1,2}$ 1.9 Hz, H-1), 3.83 (dd, 1H, $J_{5',6'a}$ 2.3, $J_{6'a,6'b}$ 11.9 Hz, H-6'a), 3.81 (dd, 1H, $J_{2,3}$ 2.0 Hz, H-2), 3.70 (t, 1H, $J_{3,4} = J_{4,5}$ 8.2 Hz, H-4), 3.67 (dd, 1H, H-3), 3,62 (m, 1H, H-5), 3.61 (dd, 1H, $J_{5',6'b}$ 5.2 Hz, H-6'b), 3.41 (t, 1H, $J_{2',3'} = J_{3',4'}$ 8.8 Hz, H-3'), 3.36 (s, 3H, OMe), 3.34 (m, 4H, H-6a,6b,2', 5'), 3.24 (t, 1H, $J_{4',5'}$ 8.8 Hz, H-4'), 0.17, 0.15, and 0.14 (3s, 27H, 3 SiMe3). ^{13}C NMR (75.5 MHz, CD_3OD, 323 K): δ.185.9 (C=S), 103.2 (C-1), 85.3 (C-1'), 79.4 (C-5'), 79.0 (C-3'), 74.9 (C-2), 74.4 (C-2'), 73.9 (C-3), 73.7, 71.6 (C-4,5), 71.6 (C-4'), 62.9 (C-6'), 55.6 (OMe), 1.0, 0.7, and 0.5 (SiMe3). FABMS: *m/z* 653 (55%, $[M+Na]^+$), 599 (30, MH^+-MeOH). *Anal.* Calcd for $C_{23}H_{50}N_2O_{10}SSi_3$: C, 43.78; H, 7.99; N, 4.44; S, 5.08; Si, 13.35. Found: C, 43.60; H, 7.68; N, 4.27; S, 4.81; Si, 12.99.

General procedure for the preparation of glucosyl thioureidoaldosides (47b-49b). To a solution of the corresponding thioureido derivative (**47a-49a**, 100 mg, 0.16 mmol) in CH_2Cl_2-MeOH-H_2O (4:2:1, 7 mL) was added 10% aqueous AcOH (0.7 mL). The reaction mixture was stirred at 60 °C for 3 h, then concentrated and coevaporated several times with toluene. The resulting residue was purified by GPC and freeze-dried from an aqueous solution.

*Methyl 6-deoxy-6-[*N'*-(β-*D*-glucopyranosyl)thioureido]- α-*D*-glucopyranoside* (**47b**). Yield 64 mg (97%), $[\alpha]_D$ +42.8 (*c* 0.6, H_2O), R*f* (BuOH-AcOH-H_2O 4:5:1) 0.14, λ_{max} (H_2O) 243 nm (ε_{mM} 9.7); ν_{max} 3428, 1559, and 1045 cm^{-1}. ^1H NMR (500 MHz, D_2O, 313 K): δ 5.51 (bs, 1H, H-1'), 4.99 (d, 1H, $J_{1,2}$ 3.7 Hz, H-1), 4.22 (m, 1H, H-5), 4.06 (dd, 1H, $J_{5',6'a}$ 2.0, $J_{6'a',6'b'}$ 12.4 Hz, H-6'a), 3.99 (m, 2H, H-6a,6b), 3.91 (dd, 1H, $J_{5',6'b}$ 5.2 Hz, H-6'b), 3.85 (t, 1H, $J_{2,3} = J_{3,4}$ 9.4 Hz, H-3), 3.76 (t, 1H, $J_{2',3'} = J_{3',4'}$ 9.4 Hz, H-3'), 3.75 (m, 1H, H-2'), 3.74 (dd, 1H, H-2), 3.72 (ddd, 1H, $J_{4',5'}$ 9.4 Hz, H-5'), 3.61 (t, 1H, H-4'), 3.51 (t, 1H, $J_{4,5}$ 9.4 Hz, H-4), and 3.54 (s, 3H, OMe). ^{13}C NMR (75.5 MHz, D_2O, 323 K): δ 183.8 (C=S), 99.3 (C-1), 83.4 (C-1'), 77.3 (C-3'), 76.6 (C-2'), 72.9 (C-3), 72.2 (C-2), 71.3 (C-5'), 71.3, 69.8 (C-4,5), 69.3 (C-4'), 60.6 (C-6'), 55.2 (OMe), and 45.4 (C-6). FABMS: *m/z* 437 (60%, $[M+Na]^+$), 599 (30, $[M+H-MeOH]^+$). *Anal.* Calcd for $C_{14}H_{26}N_2O_{10}S$: C, 40.57; H, 6.32; N, 6.76; S, 7.74. Found: C, 40.24; H, 6.01; N, 6.57; S, 7.29.

*Methyl 6-deoxy-6-[*N'*-(β-*D*-glucopyranosyl)thioureido]- α-*D*-galactopyranoside* (**48b**). Yield 63 mg (96%), $[\alpha]_D$ +64.0 (*c* 1.0, H_2O), R*f* (BuOH-AcOH-H_2O 4:5:1) 0.12, λ_{max} (H_2O) 244 nm (ε_{mM} 15.4); ν_{max} 3289, 1559, and 1071cm^{-1}. ^1H NMR (300 MHz, D_2O, 313 K): δ 5.47 (bs, 1H, H-1'), 4.96 (d, 1H, $J_{1,2}$ 2.6 Hz, H-1), 4.24 (m, 1H, H-5), 4.02 (dd, 1H, $J_{5',6'a}$ 2.2, $J_{6'a,6'b}$ 12.4 Hz, H-6'a), 3.95 (m, 2H, H-2,3), 3.87-3.78 (m, 2H, H-6a,6b), 3.86 (dd, 1H, $J_{5',6'b}$ 5.1 Hz, H-6'b), 3.70 (t, 2H, $J_{1',2'} = J_{2',3'} = J_{3',4'}$ 9.1 Hz, H-2',3'), 3.67 (ddd, 1H, $J_{4',5'}$ 9.1 Hz, H-5'), 3.56 (t, 1H, H-4'), and 3.52 (s, 3H, OMe). ^{13}C NMR (75.5 MHz, D_2O, 323 K): δ 183.1 (C=S), 99.5 (C-1), 83.3 (C-1'), 77.3 (C-3'), 76.6 (C-2'), 72.1 (C-5'), 69.5 (C-4), 69.5, 68.2 (C-2,3), 69.3 (C-4'), 68.2 (C-5), 60.7 (C-6'), 55.2 (OMe), and 45.0 (C-6). FABMS: *m/z* 437 (100%, $[M+Na]^+$), 415 (10, $[M+H]^+$). *Anal.* Calcd for $C_{14}H_{26}N_2O_{10}S$: C, 40.57; H, 6.32; N, 6.76; S, 7.74. Found: C, 40.22; H, 6.16; N, 6.65; S, 7.37.

Methyl 6-deoxy-6-[N'-(β-D-glucopyranosyl)thioureido]- α-D-mannopyranoside (**49b**). Yield 60 mg (91%), $[\alpha]_D$ +37.7 (*c* 0.9, H_2O), R_f (BuOH-AcOH-H_2O 4:5:1) 0.17, λ_{max} (H_2O) 243 nm (ε_{mM} 15.4); ν_{max} 3327, 1559, and 1045 cm^{-1}. ^1H NMR (500 MHz, D_2O, 323 K): δ 5.47 (bs, 1H, H-1'), 4.90 (d, 1H, $J_{1,2}$ 1.8 Hz, H-1), 4.08 (m, 1H, H-6'a), 4.02 (m, 1H, H-6'b), 3.88 (m, 2H, H-2',3'), 3.85 (m, 1H, H-5'), 3.74 (t, 1H, $J_{3,4} = J_{4,5}$ 9.6 Hz, H-4), 3.71 (t, 1H, $J_{3',4'} = J_{4',5'}$ 7.2 Hz, H-4'), and 3.53 (s, 3H, OMe). ^{13}C NMR (125.5 MHz, D_2O, 323 K): δ 183.2 (C=S), 100.6 (C-1), 83.0 (C-1'), 76.9 (C-3'), 76.3 (C-2'), 71.8 (C-5'), 70.0 (C-3), 69.5 (C-2,5), 69.2 (C-4'), 67.8 (C-4), 60.4 (C-6'), 54.5 (OMe), and 45.2 (C-6). FABMS: *m/z* 437 (100%, $[M+Na]^+$), 415 (15, $[M+H]^+$). *Anal.* Calcd for $C_{14}H_{26}N_2O_{10}S$: C, 40.57; H, 6.32; N, 6.76; S, 7.74. Found: C, 40.32; H, 6.19; N, 6.44; S, 7.42.

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