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Studies into the preparation of 1-deoxy-1-thiocyanato-D-glycopyranosyl cyanides and the anomeric effect of the thiocyanate group†

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Abstract—The reaction of per-*O*-acetylated 1-bromo-1-deoxy-α-D-arabinopyranosyl cyanide with thiocyanate ions gave the corresponding 1-deoxy-1-thiocyanato-α- and β-D-arabinopyranosyl cyanides. In the reaction of the per-*O*-acetylated 1-bromo-1-deoxy-β-D-xylopyranosyl cyanide and its per-*O*-benzoylated β-D-glucopyranosyl analogue the corresponding 2-hydroxy-glycal esters formed in addition to the anomeric pair of thiocyanato-cyanides. The formation of 2,3,4,6-tetra-*O*-benzoyl-α-D-glucopyranosyl thiocyanate was demonstrated in the reaction of benzobromoglucose with thiocyanate ions. The equilibrium constant between 2,3,4,6-tetra-*O*-acetyl-1-deoxy-1-thiocyanato-α- and β-D-galactopyranosyl cyanides was determined. Based on this value, the equilibrium ratio for the 2,3,4,6-tetra-*O*-acetyl-α- and β-D-galactopyranosyl thiocyanates was calculated to be 94:6, and the anomeric effect of the SCN group was estimated to exceed 3 kcal/mol. X-Ray crystallographic data support *endo*- and *exo*-anomeric effects of the SCN moiety.

1. Introduction

As part of an ongoing project directed towards the application of anomerically bifunctional monosaccharide derivatives[1,2] to the synthesis of glycosylidene-spiro-heterocycles[3,4] related to (+)-hydantocidin and inhibitors of glycogen phosphorylase enzymes,[5–7] we recently reported the preparation of galactopyranosyl-idene-spiro-thiazolines and -thiazolidines.[8] These bicyclic compounds were obtained by treatment of 1-deoxy-1-thiocyanato-D-galactopyranosyl cyanides **2** and **3** with hydrogen sulfide. The starting materials **2** and **3** were prepared from 1-bromo-1-deoxy-β-D-galactopyranosyl cyanide **1** using silver or potassium thiocyanate.[8] In this reaction, formation of thiocyanates was observed regardless of the cation present. This finding contrasts with the literature reports on acetylated D-glycopyranosyl bromides, which are known to give β-D-glycosyl isothiocyanates with silver thiocyanate, whilst β-D-glycosyl thiocyanates are formed with the potassium salt.[9,10] The formation of the anomeric pair of thiocyanates **2** and **3**, from which **3** was shown to be the thermodynamically more stable product in an equilibration experiment,[8] had no reported precedent or analogy in the D-glycopyranosyl bromide series. Pursuing these observations we extended the reaction to other sugars and re-examined the formation of D-glucopyranosyl thiocyanates and isothiocyanates.

2. Results and discussion

Per-*O*-acylated 1-bromo-1-deoxy-glycopyranosyl cyanides with α-D-*arabino*[11] **8**, β-D-*gluco*[7] **11**, and β-D-*xylo*[11] **12** configurations were reacted with 2 equiv. of potassium thiocyanate in nitromethane at 90°C. From the reaction of **8** the anomeric pair **9** and **10** could be isolated and no by-products were detected. In contrast, **11** and **12** gave the 1-cyano-2-hydroxy-glycal esters **20** and the known **21**,[12] in addition to the expected pairs of **14** and **17** and **15** and **18**. Compounds **9** and **10** were separated by column chromatography but, despite much effort, only **17**, **20**, and **21** could be obtained in pure form from the other products.

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† Dedicated to Professor Gérard Descotes in appreciation of his outstanding achievements in carbohydrate chemistry.

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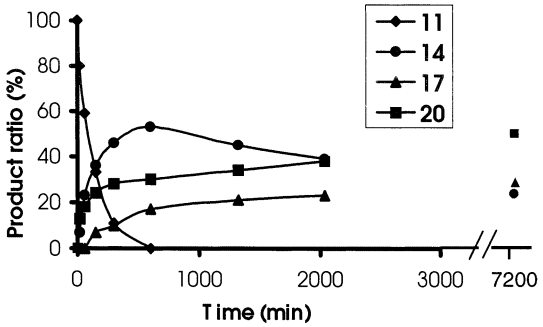


Figure 1. Composition of the reaction mixture of 2,3,4,6-tetra-*O*-benzoyl-1-bromo-1-deoxy-β-D-glucopyranosyl cyanide **11** with 2 equiv. of KSCN in nitromethane at 90°C.

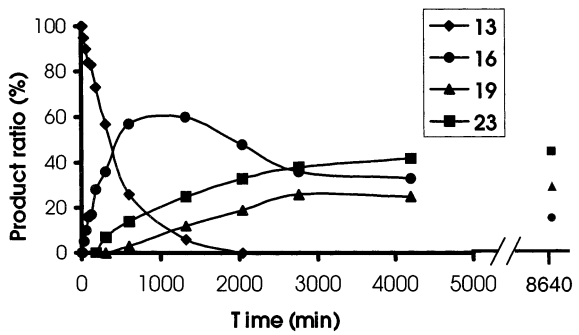


Figure 2. Composition of the reaction mixture of 2,3,4,6-tetra-*O*-benzoyl-α-D-glucopyranosyl bromide **13** with 3 equiv. of KSCN in the presence of 0.2 equiv. of 18-crown-6 in acetone at rt.

The elimination products **20** and **21** formed only in the reactions of the D-*gluco* and D-*xylo* configured starting materials, respectively. Similarly, in accord with earlier observations in the preparation of 1-deoxy-1-fluoro-D-glycopyranosyl cyanides,[2] the appearance of elimination products only in the D-*gluco* and D-*xylo* configurations can be explained by the sterically crowded position of the C-(2) proton in the D-*arabino* and the D-*galacto* compounds. In these derivatives the axially oriented 4-acetoxy group hinders the approach of the base/nucleophile to the axial C-(2)H. This proton is prone to elimination if the 4-acetoxy group is equatorial. A deeper insight into the formation of the D-*gluco* derivatives **14**, **17**, and **20** can be obtained from Fig. 1.

It can be seen that formation of the elimination product **20** continued after the starting material **11** was completely consumed. This suggests that **20** can form not only from **11** but also from either of the anomers **14** or **17**, most probably from the latter in which the *trans*-diaxial arrangement of C-(2)H and the SCN group fulfils the stereoelectronic requirement for β-elimination. It also follows from this that, contrary to the D-*galacto* anomers **2** and **3**, equilibration between **14** and **17** is not possible.

Structural elucidation of the new compounds was accomplished by NMR methods. Compounds **9** and **10** (D-*arabino*) have the $^1C_4$ conformation, while **14** and **17** (D-*gluco*) and **15** and **18** (D-*xylo*) exist in the $^4C_1$ form as depicted. The ^{13}C NMR spectra indicated the presence of both the cyano (111.4–113.6 ppm) and the thiocyanato (104.7–108.4 ppm) moieties. In the given conformations the configurations of the anomeric carbons were assigned on the basis of the $^3J_{H\text{-}2,CN}$ heteronuclear couplings showing 6.6–8.1 Hz values for *trans*-diaxial arrangements and 2.1–3.5 Hz for *gauche* relationships.[1]

Since each reaction described above gave anomeric pairs of the thiocyanato-cyanides and products of elimination in some cases it seemed pertinent to examine more closely the formation of glycosyl (iso)thiocyanates. Glycosyl thiocyanates were prepared, for example, from acylated glycopyranosyl bromides with potassium thiocyanate in acetone,[13] and the presence of 18-crown-6 proved to be advantageous.[14] The corresponding isothiocyanates were obtained with silver thiocyanate in benzene or toluene,[15] or under the aforementioned conditions after prolonged reaction time,[14] as well as by several other modifications of the original protocol.[16–19] In these reports neither anomerisation of the kinetically formed 1,2-*trans* glycosyl thiocyanates nor competing eliminations were mentioned. In order to study these aspects of the reaction, benzobromoglucose[20] **13** was subjected to treatment with KSCN–18-crown-6.[21] As expected, the corresponding thiocyanate **16** and isothiocyanate **23** could be isolated by column chromatography after relatively short and long reaction times, respectively. However, we also obtained fractions which were chromatographically homogeneous, but their NMR spectrum showed the presence of two compounds. Unfortunately, we were unable to find suitable chromatographic conditions for their separation. From the proton spectrum it was clear that an α-D- (δ 6.49 ppm, $J_{1,2}=5.5$ Hz) and a β-D-glucopyranosyl (δ 5.36 ppm, $J_{1,2}=8.8$ Hz) derivative were present in the sample. The ^{13}C spectrum showed resonances for both a thiocyanate (δ 108.3 ppm) and an isothiocyanate (δ 144.6 ppm) group. A ^{13}C–^1H HMBC measurement indicated unambiguously that the mixture contained the α-D-glucopyranosyl thiocyanate **19** and the β-D-glucopyranosyl isothiocyanate **23**. Monitoring the reaction (Fig. 2) showed that **19** was present in the mixture in significant amounts.

Subjecting the β-D-glucopyranosyl thiocyanate **16** to the same reaction conditions (Fig. 3) revealed that **19** may be an intermediate in the isomerisation of **16** to **23**. However, this is probably not the only pathway to **23** from **13**, because the isothiocyanate **23** appears earlier than **19** in that reaction (Fig. 2). No traces of the possible elimination product **22** could be detected in these mixtures. These experiments showed that direct equilibration of **16** and **19** was not possible because of the formation of the more stable **23**. Since under the same conditions glycopyranosyl isothiocyanates can be made in many sugar configurations, it can be concluded that the equilibrium between α- and β-D-glycopyranosyl thiocyanates cannot be observed and determined directly.

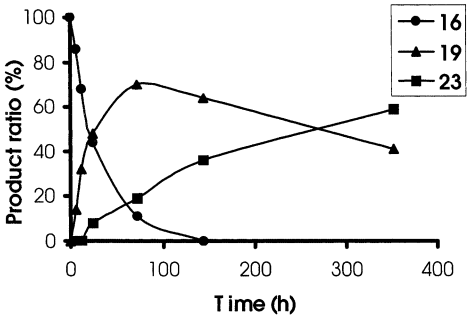


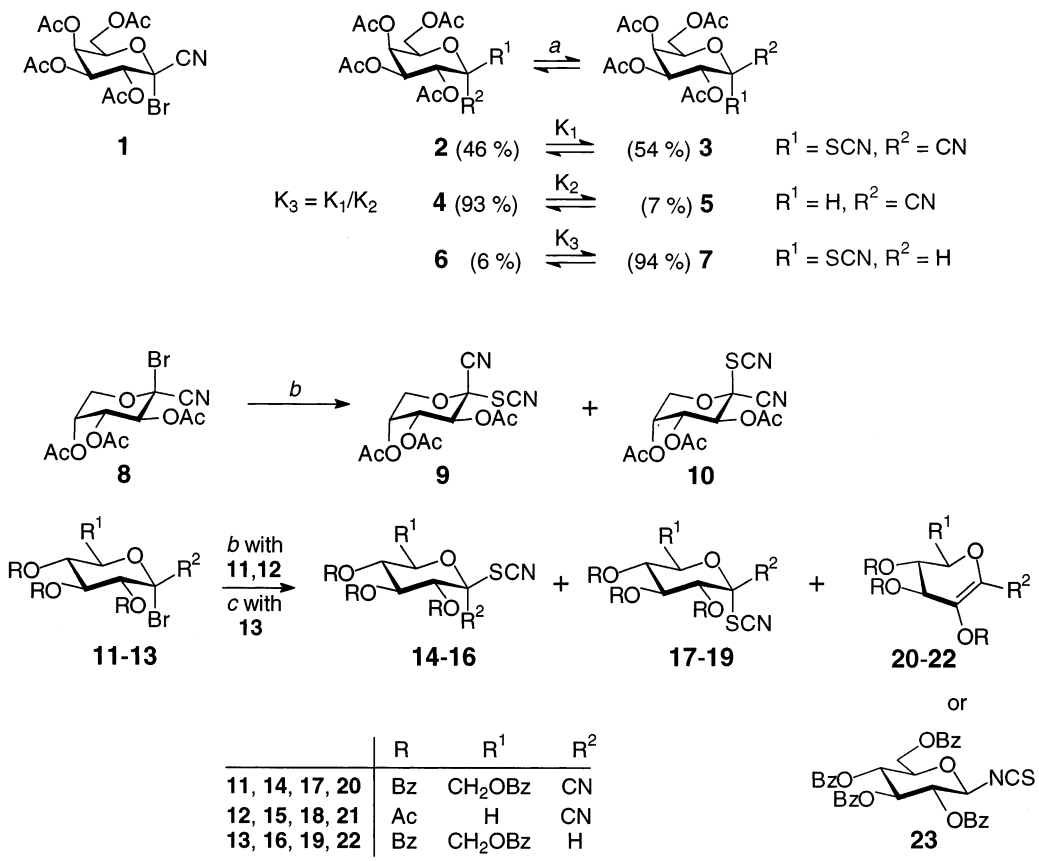
Figure 3. Composition of the reaction mixture of 2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl thiocyanate **16** with 3 equiv. of KSCN in the presence of 0.2 equiv. of 18-crown-6 in acetone at rt.

An indirect possibility to establish the above type equilibrium is offered by the equilibrated mixture of **2** and **3**, where no by-products were detected. Considering the known equilibrium ratio of the anomeric pair of the corresponding glycosyl cyanides **4** and **5**[22] ($K_2=0.0705$) allows the ratio for **6** and **7** to be calculated. To this end, **2** and **3** were equilibrated to obtain K_1 under conditions used for the determination of K_2 (Scheme 1). Compound **2** was incubated at 40°C in carbon tetrachloride with either 1 or 6 equivalents of tetrabutylammonium thiocyanate. Equilibrium was reached after 25 days in the first case and after 6 days in the second. The anomeric ratios obtained from the proton NMR spectra were 47:53 and 45:55, respectively, which were averaged for the calculation of K_1. The calculated value of K_3 indicates that the SCN group has a strong axial preference at the anomeric centre. Consequently, this group has a considerable anomeric effect (AE). An estimation of its numerical value[23] ($AE_{SCN}=RT\ln K_3+A_{SCN}$) can be made by taking into account the conformational energy (A) of the SCN moiety in cyclohexyl thiocyanate[24] ($A_{SCN}=1.23$ kcal/mol, determined at −79°C in CS_2–TMS 9:1) as modified to the corresponding tetrahydropyran-2-yl thiocyanate according to Franck's proposal[25] (1.92 kcal/mol). Thus the anomeric effect of the SCN group must be larger than 3 kcal/mol in the D-*galacto* configured pair of **6** and **7**.

An X-ray crystallographic structure determination of **3** (Fig. 4) indicated a dihedral angle of 51° for O1–C1–S1–C8, which reveals the operation of an *exo*-anomeric effect with respect to the SCN group (the same parameter in **2** was found[8] to be −72°). The bond lengths and angles around the anomeric centre of **2** and **3** (Fig. 4) are also consistent with the operation of these anomeric effects.[23]

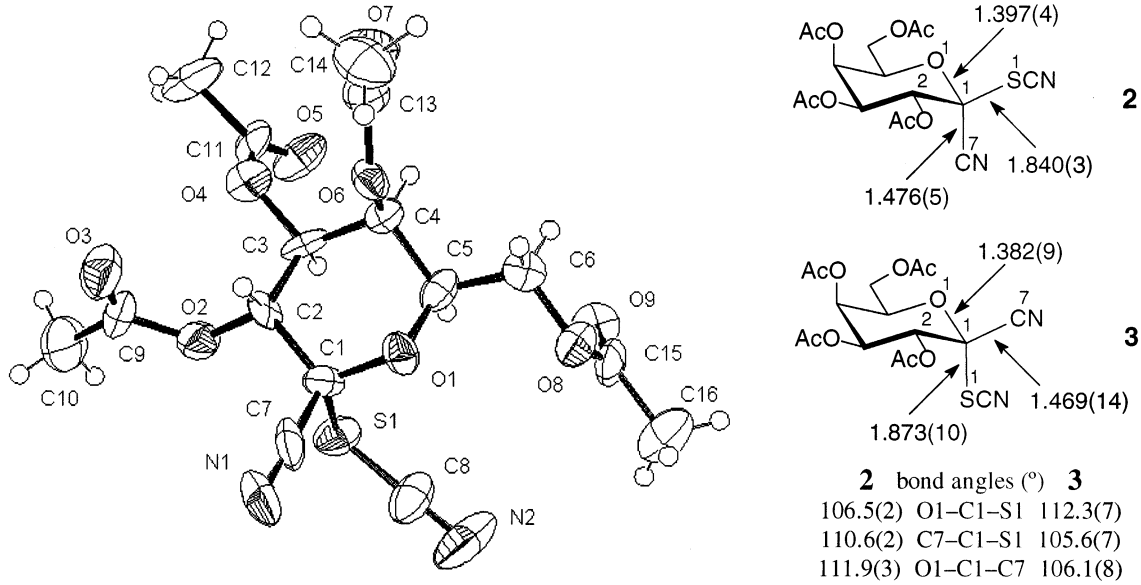
3. Conclusion

In conclusion, the study of the reaction of several 1-bromo-1-deoxy-D-glycopyranosyl cyanides with thiocyanate ion showed that anomeric pairs of 1-deoxy-1-thiocyanato-D-glycopyranosyl cyanides can be prepared and separated in the D-*arabino* (and the D-*galacto*[8])



	R	R^1	R^2
11, 14, 17, 20	Bz	CH_2OBz	CN
12, 15, 18, 21	Ac	H	CN
13, 16, 19, 22	Bz	CH_2OBz	H

Scheme 1. (*a*) Bu_4NSCN, CCl_4, 40°C; (*b*) KSCN, CH_3NO_2, 90°C; (*c*) KSCN, 18-crown-6, acetone, rt.



2	bond angles (°)	3
106.5(2)	O1–C1–S1	112.3(7)
110.6(2)	C7–C1–S1	105.6(7)
111.9(3)	O1–C1–C7	106.1(8)

Figure 4. ORTEP drawing of 2,3,4,6-tetra-*O*-acetyl-1-deoxy-1-thiocyanato-β-D-galactopyranosyl cyanide **3** and bond lengths (Å) and angles in **2** and **3**.

configuration, while elimination products accompany the anomers in the D-*gluco* and D-*xylo* configurations. The presence of per-*O*-benzoylated α-D-glucopyranosyl thiocyanate was demonstrated in the reaction of benzobromoglucose with thiocyanate ion. The equilibration of 1-deoxy-1-thiocyanato-D-galactopyranosyl cyanides allowed the anomeric ratio for the α- and β-D-galactopyranosyl thiocyanates to be calculated and, thereby, the anomeric effect of the SCN group to be estimated. X-Ray crystallography revealed the operation of an *exo*-anomeric effect in both isomers.

4. Experimental

Melting points were measured in open capillary tubes or on a Kofler hot-stage and are uncorrected. Optical rotations were determined with a Perkin–Elmer 241 polarimeter at room temperature. NMR spectra were recorded with Bruker WP 200 SY (200/50 MHz for $^1H/^{13}C$) or Avance DRX 500 (500/125 MHz for $^1H/^{13}C$) spectrometers for $CDCl_3$ solutions unless otherwise stated. Chemical shifts are referenced to Me_4Si (^1H) or to the residual solvent signals (^{13}C). TLC was performed on DC-Alurolle Kieselgel 60 F_{254} (Merck), and the plates were visualised after gentle heating. For column chromatography Kieselgel 60 (Merck, particle size 0.063–0.200 mm) was used. Organic solutions were dried over anhydrous $MgSO_4$ and concentrated in vacuo at 40–50°C (water bath). Nitromethane was distilled from P_4O_{10} directly in the reaction flask or was stored over 3 Å molecular sieves. Monitoring of the reactions was performed by taking aliquot samples from the reaction mixtures which were investigated by ^1H NMR after work-up.

4.1. General procedure for the reaction of acetylated 1-bromo-1-deoxy-D-glycopyranosyl cyanides 8, 11, and 12 with thiocyanate ion

1-Bromo-1-deoxy-D-glycopyranosyl cyanide (1 mmol) was dissolved in nitromethane (14 mL) and dry potassium thiocyanate (0.194 g, 2 mmol) was added. The mixture was stirred at 90°C (bath temp.) until complete disappearance of the starting material (TLC ethyl acetate–hexane 2:1, 5–7 h). The mixture was then filtered and the solvent removed from the filtrate. The residue was dissolved in chloroform, washed with water, dried, the solvent evaporated, and the syrupy crude product purified by column chromatography (eluent ethyl acetate–hexane 1:2 or 1:3).

4.2. 2,3,4-Tri-*O*-acetyl-1-deoxy-1-thiocyanato-β-D-arabinopyranosyl cyanide 9

Yield 23%; mp 91–92°C (from EtOH); $[\alpha]_D = -237$ (*c* 1.02, $CHCl_3$); ν_{SCN} (KBr): 2158 cm^{-1}; ^1H NMR: δ 5.50 (1H, d, $J = 9.5$ Hz, H-2), 5.46–5.40 (1H, m, H-4), 5.27 (1H, dd, $J = 9.5$, 3.2 Hz, H-3), 4.28 (1H, dd, $J = 13.6$, 3.7 Hz, H-5), 4.17 (1H, dd, $J = 13.6$, 1.5 Hz, H-5′); ^{13}C NMR: δ 111.4 (CN, $^3J_{H\text{-}2,CN} = 7.2$ Hz), 105.2 (SCN), 83.6 (C-1), 68.5, 67.9, 66.3 (C-2 to C-4), 67.7 (C-5). Anal. calcd for $C_{13}H_{14}N_2O_7S$ (342.32): C, 45.61; H, 4.12; N, 8.18. Found: C, 45.34; H, 4.18; N, 8.15%.

4.3. 2,3,4-Tri-*O*-acetyl-1-deoxy-1-thiocyanato-α-D-arabinopyranosyl cyanide 10

Yield 19%; mp 151–153°C (from EtOH); $[\alpha]_D = -115$ (*c* 1.02, $CHCl_3$); ν_{SCN} (KBr): 2168 cm^{-1}; ^1H NMR: δ 5.87 (1H, d, $J = 9.5$ Hz, H-2), 5.45–5.40 (1H, m, H-4), 5.14 (1H, dd, $J = 9.4$, 2.8 Hz, H-3), 4.22–4.15 (2H, m,

H-5,5′); ^{13}C NMR: δ 113.6 (CN, $^{3}J_{\text{H-2,CN}}=2.1$ Hz), 105.3 (SCN), 85.6 (C-1), 67.5, 67.1, 66.3 (C-2 to C-4), 65.1 (C-5). Anal. calcd for $C_{13}H_{14}N_2O_7S$ (342.32): C, 45.61; H, 4.12; N, 8.18. Found: C, 45.40; H, 4.20; N, 8.16%.

4.4. 2,3,4,6-Tetra-*O*-benzoyl-1-deoxy-1-thiocyanato-α-D-glucopyranosyl cyanide 14

Could not be isolated in a pure state. Yield 46% for a mixture of **14**+**20**; ^{1}H NMR: δ 6.18 (1H, t, $J=9.5$ Hz, H-3), 5.88 (1H, t, $J=9.5$, 8.4 Hz, H-4), 5.84 (1H, d, $J=9.5$ Hz, H-2), 4.75–4.70 (3H, m, H-5,6,6′); ^{13}C NMR: δ 111.5 (CN, $^{3}J_{\text{H-2,CN}}=2.8$ Hz), 104.9 (SCN), 82.9 (C-1), 76.8, 71.3, 71.1, 67.3 (C-2 to C-5), 61.6 (C-6).

4.5. 2,3,4,6-Tetra-*O*-benzoyl-1-deoxy-1-thiocyanato-β-D-glucopyranosyl cyanide 17

Yield 7%; mp 197–199°C (from EtOH); $[\alpha]_D=+123$ (c 1.01, $CHCl_3$); ν_{SCN} (KBr): 2160 cm^{-1}; ^{1}H NMR: δ 6.31 (1H, d, $J=9.5$ Hz, H-2), 5.97 (1H, t, $J=9.5$ Hz, H-3), 5.84 (1H, t, $J=9.9$, 9.5 Hz, H-4), 4.81 (1H, ddd, $J=9.9$, 5.6, 2.1 Hz, H-5), 4.73 (1H, dd, $J=12.8$, 5.6 Hz, H-6), 4.60 (1H, dd, $J=12.8$, 2.1 Hz, H-6′); ^{13}C NMR: δ 113.5 (CN, $^{3}J_{\text{H-2,CN}}=8.1$ Hz), 104.7 (SCN), 85.2 (C-1), 73.6, 71.0, 70.0, 67.2 (C-2 to C-5), 61.8 (C-6). Anal. calcd for $C_{36}H_{26}N_2O_9S$ (662.67): C, 65.25; H, 3.95; N, 4.23. Found: C, 64.58; H, 3.96; N, 4.30%.

4.6. 2,3,4-Tri-*O*-acetyl-1-deoxy-1-thiocyanato-α-D-xylopyranosyl cyanide 15

Could not be isolated in pure state. Yield 45% for a mixture of **15**+**18**; ^{1}H NMR (assignments deduced from COSY experiments): δ 5.37 (1H, t, $J=8.5$ Hz, H-3), 5.22 (1H, d, $J=8.5$ Hz, H-2), 5.06 (1H, ddd, $J=9.8$, 8.5, 5.2 Hz, H-4), 4.40 (1H, dd, $J=12.3$, 5.2, H-5), 3.83 (1H, dd, $J=12.1$, 9.8 Hz, H-5′); ^{13}C NMR: δ 113.4 (CN, $^{3}J_{\text{H-2,CN}}=6.6$ Hz), 105.1 (SCN), 83.2 (C-1), 69.9, 68.7, 66.5 (C-2 to C-4), 65.4 (C-5).

4.7. 2,3,4-Tri-*O*-acetyl-1-deoxy-1-thiocyanato-β-D-xylopyranosyl cyanide 18

Could not be isolated in pure state. Yield 45% for a mixture of **15**+**18**; ^{1}H NMR (assignments deduced from COSY experiments): δ 5.62 (1H, d, $J=8.8$ Hz, H-2), 5.27 (1H, t, $J=8.5$ Hz, H-3), 5.12 (1H, ddd, $J=9.8$, 8.5, 5.5 Hz, H-4), 4.35 (1H, dd, $J=12.1$, 5.4 Hz, H-5), 3.92 (1H, dd, $J=12.1$ 9.8 Hz, H-5′); ^{13}C NMR: δ 111.4 (CN, $^{3}J_{\text{H-2,CN}}=3.5$ Hz), 105.1 (SCN), 84.8 (C-1), 70.1, 68.2, 66.5 (C-2 to C-4), 63.0 (C-5).

4.8. 2,6-Anhydro-3,4,5,7-tetra-*O*-benzoyl-D-*arabino*-hex-2-enononitrile 20

Yield 5%; mp 108–110°C (from EtOH); $[\alpha]_D=+60$ (c 1.03, $CHCl_3$); ^{1}H NMR: δ 6.27 (1H, d, $J=4.2$ Hz, H-4), 5.91 (1H t, $J=4.8$, 4.8 Hz, H-5), 5.01 (1H, ddd, $J=6.8$, 4.8, 4.2 Hz, H-6), 4.91 (1H, dd, $J=12.2$, 4.2 Hz, H-7), 4.73 (1H, dd, $J=12.2$, 6.8 Hz, H-7′); ^{13}C NMR: δ 110.4 (CN), 125.5 (C-2), 137.9 (C-3), 75.7, 67.2, 65.8 (C-4 to C-6), 60.5 (C-7). Anal. calcd for $C_{35}H_{25}N_2O_9$ (603.58): C, 69.65; H, 4.17; N, 2.32. Found: C, 69.87; H, 3.92; N, 2.44%.

4.9. Reaction of 2,3,4,6-tetra-*O*-benzoyl-α-D-glucopyranosyl bromide 13 with thiocyanate ion[14,21]

Benzobromoglucose (**13**, 1 g, 3 mmol) was dissolved in dry acetone, then potassium thiocyanate (0.705 g, ~9 mmol) and 18-crown-6 (0.072 g, 0.2 mmol) were added. The mixture was stirred at room temp. and monitored by ^{1}H NMR. Work-up of the reaction mixture after 9 h and chromatography of the crude product (eluent: ethyl acetate–hexane 1:2) gave the products below.

4.10. 2,3,4,6-Tetra-*O*-benzoyl-β-D-glucopyranosylthiocyanate 16

Yield 22%, colourless syrup; $[\alpha]_D=+16$ (c 1.01, $CHCl_3$), lit.[21] $[\alpha]_D$ +46 (c 0.80, $CHCl_3$); ^{1}H NMR (the spectrum obtained is different from the reported one[21]): δ 6.00 (1H, pseudo t, $J=9.9$, 9.5 Hz, H-2), 5.77 (1H, t, $J=9.5$ Hz, H-4), 5.67 (1H, t, $J=9.5$ Hz, H-3), 5.27 (1H, d, $J=9.9$ Hz, H-1), 4.66 (1H, dd, $J=12.6$, 2.6 Hz, H-6), 4.52 (1H, dd, $J=12.6$, 5.3 Hz, H-6′), 4.33 (1H, ddd, $J=9.5$, 6.3, 2.6 Hz, H-5); ^{13}C NMR (corresponds to the reported spectrum[21]): δ 108.4 (SCN), 83.9 (C-1), 73.2, 71.2, 68.6, 62.6 (C-2 to C-5), 60.3 (C-6).

4.11. 2,3,4,6-Tetra-*O*-benzoyl-α-D-glucopyranosylthiocyanate 19

Could not be completely purified. Yield 17% for a mixture of **19**+**23**; ^{1}H NMR: δ 6.49 (1H, d, $J=5.5$ Hz, H-1), 5.82 (1H, dd, $J=9.6$, 5.5 Hz, H-2), 5.62 (1H, t, $J=9.6$ Hz, H-4), 5.56 (1H, t, $J=9.6$ Hz, H-3), 4.71 (1H, ddd, $J=9.6$, 6.3, 3.1 Hz, H-5), 4.58 (1H, dd, $J=12.6$, 3.1 Hz, H-6), 4.48 (1H, dd, $J=12.6$, 6.3 Hz, H-6′); ^{13}C NMR ($CDCl_3$): δ 108.3 (SCN), 86.1 (C-1), 71.4, 70.5, 69.9, 68.0 (C-2 to C-5), 62.2 (C-6).

4.12. 2,3,4,6-Tetra-*O*-benzoyl-β-D-glucopyranosylisothiocyanate 23

Yield 33%; mp 149–151°C, lit.[10] mp 147–148°C; ^{1}H NMR: δ 5.94 (1H, t, $J=9.5$, 8.8 Hz, H-2), 5.75 (1H, t, $J=9.5$ Hz, H-3), 5.66 (1H, t, $J=9.5$ Hz, H-4), 5.36 (1H, d, $J=8.8$ Hz, H-1), 4.68 (1H, dd, $J=12.2$, 2.0 Hz, H-6 or H-6′), 4.45 (1H, dd, $J=12.2$, 4.7 Hz, H-6 or H-6′), 4.24 (1H, ddd, $J=9.5$, 4.7, 2.0 Hz, H-5); ^{13}C NMR: δ 144.6 (NCS), 83.8 (C-1), 74.4, 72.6, 72.3, 68.8 (C-2 to C-5), 62.5 (C-6).

4.13. X-Ray crystallography of 3

Colourless block crystals (0.45×0.25×0.16 mm) of $C_{16}H_{18}N_2O_9S$, $M=414.38$, monoclinic, $a=11.094(2)$ Å, $b=7.9141(10)$ Å, $c=22.678(3)$ Å, $\beta=97.34(1)°$, $V=1974.4(5)$ Å^3, $Z=4$, space group: $P2_1$, $\rho_{\text{calcd}}=1.394$ g/cm^3. Data were collected at 293(1) K, Enraf Nonius MACH3 diffractometer, Mo Kα radiation $\lambda=0.71073$ Å, ω–2θ motion, $\theta_{\max}=26°$, 4161 measured, 2112

reflections were unique with $I>2\sigma(I)$, decay: 3%. The structure was solved using the SIR-92 software[26] and refined on F^2 using the SHELX-97[27] program, publication material was prepared with the WINGX-97 suite,[28] $R(F)=0.081$ and $wR(F^2)=0.1767$ for 4161 reflections, 505 parameters. Residual electron density: 0.286/−0.285 e/Å^3.

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