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Some amino sugars structurally related to 6-deoxymannojirimycin precursors prepared from methyl 6-deoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranosid-5-ulose and methyl 2,3-*O*-isopropylidene-α-D-*lyxo*-pentodialdo-1,4-furanoside

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Abstract

Methyl (5*S*)-5-*C*-amino-5-cyano-5-deoxy-2,3-*O*-isopropylidene-α-D-lyxofuranoside has been synthesised from methyl 2,3-*O*-isopropylidene-α-D-*lyxo*-pentodialdo-1,4-furanoside, applying the Strecker synthesis. Analogously, methyl (5*S*) and (5*R*)-5-*C*-amino-5-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranosides were prepared from methyl 6-deoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranosid-5-ulose. The 5-*S* configuration was unambigously determined by single-crystal X-ray diffraction analysis of corresponding *N*-acetyl derivatives. Conformations of five-membered rings are discussed. The conversion of *N*-acetylated amino nitriles to *N*-acetylamino acid ethyl ester and amide, respectivelly, is also described.

Keywords: Sugar amino nitriles; Strecker synthesis; Hexuronamide; Hexuronate; X-ray crystallography; Conformation; 6-Deoxymannojirimycin

1. Introduction

Sugar amino nitriles have been recognized as an interesting group of carbohydrate derivatives. They are useful synthetic intermediates because both amino and cyano groups can be transformed to other functionalities or cyclised to several types of heterocycles. Some of them have been used as key intermediates in the chemical synthesis of important antibiotics or their analogs, e.g., Lincosamine,[1] Myriocin,[2] Anhydromyriocin,[3] and Perosamine.[4,5]

Although the α-amino nitrile synthesis involving the C-1 carbonyl group of saccharides is well known,[6] not many of such analogs have been described having the α-amino nitrile grouping C–C linked with a saccharide backbone in an optional position of the pyranose or furanose ring or open chain, excluding anomeric position.[1–5,7–10]

To understand the mechanism of bioactivity of already known, as well as new amino sugar derivatives, there is a growing interest in the use of suitable syntetically prepared model compounds with unambiguously established structure. In the present study, we describe the preparation and some synthetic transformations of sugar amino nitriles starting from 5-aldehydo and 5-ketosugars, readily available from D-mannose. Among described compounds, 6-deoxy derivatives are structurally related to 6-deoxymannojirimycin precursors.[11]

2. Results and discussion

Starting from the known methyl 2,3-*O*-isopropylidene-α-D-*lyxo*-pentodialdo-1,4-furanoside (**1**)[12,13] and applying the Strecker reaction conditions, we have pre-

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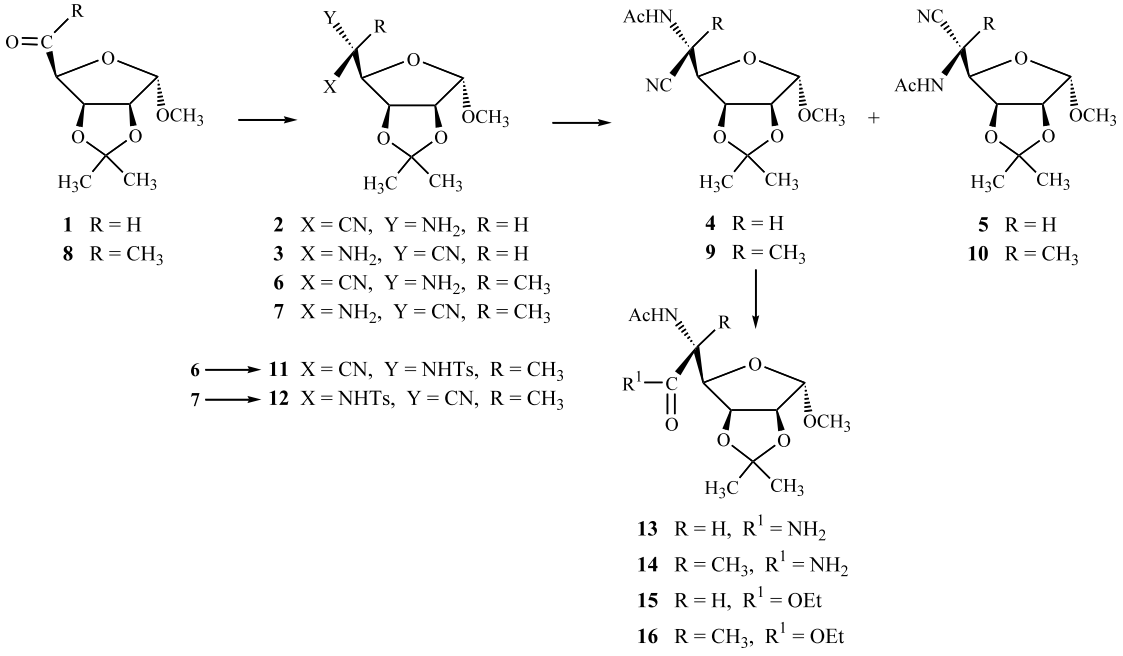
pared methyl (5*S*)-5-*C*-amino-5-cyano-5-deoxy-2,3-*O*-isopropylidene-α-D-lyxofuranoside (**2**) as a major product (Scheme 1). Although the second possible stereoisomer **3** with 5*R* configuration was also detected (about 16% based on the analysis of NMR spectra) in the reaction mixture, its isolation and purification (to prepare an analytical sample) was unsuccessful. But after acetylation of the reaction mixure and using fractional crystallisation, it was possible to isolate in pure form both 5*S* (**4**) and 5*R* (**5**) *N*-acetyl derivatives.

Analogously, methyl (5*S*)-5-*C*-amino-5-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranoside (**6**) (furanose form of *O*-protected 5-*C*-cyano-6-deoxymannojirimycin) and corresponding (5*R*) isomer (**7**) were prepared from the known[14] methyl 6-deoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranosid-5-ulose (**8**). In this case, it was possible to separate and isolate in pure state both stereoisomeric unprotected amino nitriles. To find suitable crystalline compounds for X-ray crystallography, methyl (5*S*)-5-*C*-acetamido-5-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranoside (**9**) (furanose form of *O*- and *N*-protected 5-*C*-cyano-6-deoxymannojirimycin) and methyl (5*R*)-5-*C*-acetamido-5-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranoside (**10**) as well as methyl (5*S*)-5-*C*-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-5-tosylamino-α-D-*lyxo*-hexofuranoside (**11**) and methyl (5*R*)-5-*C*-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-5-tosylamino-α-D-*lyxo*-hexofuranoside (**12**) were also prepared and characterised.

Attempts to prepare unprotected amino acids from *N*-acetylated amino nitriles **4** and **9** by hydrolysis with aq $Ba(OH)_2$ at 80 °C for 6 h were unsuccessful and only corresponding amides—methyl (5*R*)-5-acetamido-5-deoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranosiduronamide (**13**) and methyl (5*R*)-5-*C*-acetamido-5-carbamoyl-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranoside (**14**), respectively, were isolated. In both cases, prolonged hydrolysis at reflux temperature lead to the intensive darkening of the reaction mixture and decomposition of the reaction products. Additionally, reaction of **4** with HCl gas in ether and subsequent treatment with EtOH afforded ethyl [methyl (5*R*)-5-acetamido-5-deoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranosid]uronate (**15**). Application of the same reaction conditions to **9** lead to the formation of methyl (5*R*)-5-*C*-acetamido-5-ethoxycarbonyl-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranoside (**16**).

The configuration at C-5 of the prepared compounds was confirmed by establishing the 5-*S* configuration of methyl (5*S*)-5-*C*-acetamido-5-cyano-5-deoxy-2,3-*O*-isopropylidene-α-D-lyxofuranoside (**4**) and the 5-*S* configuration of methyl (5*S*)-5-*C*-acetamido-5-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranoside (**9**) by X-ray crystallography. Figs. 1 and 2 show molecules and the numbering schemes of compound **4** and **9**, respectively. The H-positions have been put at calculated positions and were during refinement riding on their respective pivot atoms. The relevant crystallographic data for **4** and **9** are given in Table 1. The bond lengths and bond angles are listed in Table 2. A list of selected torsion angles is given in Table 3. The final positional parameters for compound **4** and **9** are summarised in Tables 4 and 5, respectively.



Scheme 1.

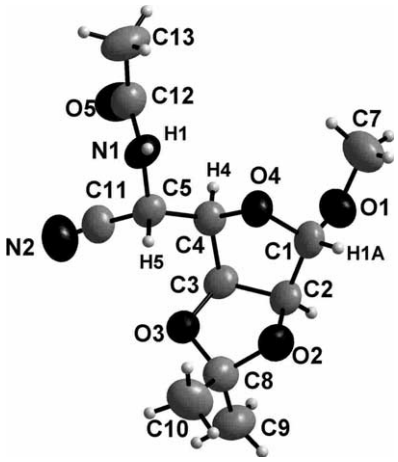


Fig. 1. Thermal ellipsoid plot at 50% probability level and atomic numbering of methyl (5*S*)-5-*C*-acetamido-5-cyano-5-deoxy-2,3-*O*-isopropylidene-α-D-lyxofuranoside (**4**).

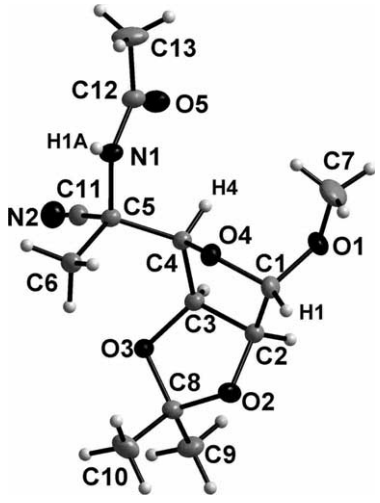


Fig. 2. The geometry of methyl (5*S*)-5-*C*-acetamido-5-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-α-D-*lyxo*-hexofuranoside (**9**) including atom-labelling scheme. Displacement ellipsoids are shown at 50% probability level.

The presence of a 1,3-dioxolane ring fused to a furanose ring at the 2,3-position and the α-glycosidic methyl group imposes some conformational rigidity on **4** and **9**. In the case of **4**, the values of relevant torsion angles O-4–C-1–C-2–C-3 = 28.5(4)°, C-1–C-2–C-3–C-4 = −8.0(4)°, C-2–C-3–C-4–O-4 = −14.7(4)°, C-3–C-4–O-4–C-1 = 33.7(4)°, C-4–O-4–C-1–C-2 = −39.2(4)° and puckering parameters[15] $Q = 0.346(4)$ Å, $\varphi = 13.1(7)°$ indicate that O-4–C-1–C-2–C-3–C-4 furanoside ring adopts the ^{O}E conformation which is significantly deformed to the $^{O}T_{1}$ direction. Analogously, the puckering parameters $Q = 0.333(4)$ Å, $\varphi = 162.0(7)°$ and the relevant dihedral angles O-2–C-2–C-3–O-3 = −10.8(4)°, C-2–C-3–O-3–C-8 = −12.2(4)°, C-3–O-3–C-8–O-2 = 30.4(4)°, O-3–C-8–O-2–C-2 = −37.6(4)°, C-8–O-2–C-2–C-3 = 29.7(4)° are indicative of almost perfect $^{C\text{-}8}T_{O\text{-}2}$ conformation for five-membered 1,3-dioxolane ring (O-2–C-2–C-3–O-3–C-8) with the O-2 atom lying in the *exo* direction with respect to the plane defined by the atoms C-2, C-3, and O-3. For compound **9**, the values of relevant torsion angles O-4–C-1–C-2–C-3 = 25.24(14)°, C-1–C-2–C-3–C-4 = −1.03(13)°, C-2–C-3–C-4–O-4 = −23.21(13)°, C-3–C-4–O-4–C-1 = 40.68(13)°, C-4–O-4–C-1–C-2 = −41.36(13)° and puckering parameters $Q = 0.382(1)$ Å, $\varphi = 1.4(2)°$ indicate that O-4–C-1–C-2–C-3–C-4 furanoside ring adopts almost perfect ^{O}E conformation. On the other hand, the puckering parameters $Q = 0.298(1)$ Å, $\varphi = 152.9(3)°$ and the relevant dihedral angles O-2–C-2–C-3–O-3 = −4.78(15)°, C-2–C-3–O-3–C-8 = −15.62(15)°, C-3–O-3–C-8–O-2 = 30.24(14)°, O-3–C-8–O-2–C-2 = −33.43(14)°, C-8–O-2–C-2–C-3 = 23.44(14)° are indicative of the $^{C\text{-}8}E$ conformation, distorted significantly to the $^{C\text{-}8}T_{O\text{-}2}$ direction for five-membered 1,3-dioxolane ring (O-2–C-2–C-3–O-3–C-8) with O-2, C-2, C-3, O-3 atoms lying almost in a plane and C-8 directed *endo* with respect to this plane.

Analysis of the molecular packing in the unit cell of **4** revealed four principal intermolecular interactions (Table 6). Three of them, [*a*], [*b*] and [*c*], are forming an infinite sheet of molecules in the plane (*a*,*b*) (see Fig. 3(a)), while the fourth, [*d*], weaves these sheets together in direction *c* (Fig. 3(b)). The first-level descriptors based on the graph-set theory[16] include just the above mentioned three C1,1(4) and one C1,1(9) chains, while the second-level comprises: R2,2(14) ring defined by the hydrogen bonds [*a*], and [*b*], R2,2(12) ring defined by the hydrogen bonds [*b*] and [*c*] and R2,2(10) motif defined by the [*a*] and [*c*] hydrogen bonds. Assignment of the H-bond descriptors was based on the graph-set theory.[16] Full set of the first and second-level descriptors has been obtained using the program PLUTO.[17] For convenience, the notation X*a*,*d*(*n*) has also been adopted in this paper, in which (X) is the pattern descriptor, (*a*) is number of acceptors, (*d*) is number of donors and (*n*) is the number of atoms comprising the pattern. For compound **9**, two weak intramolecular hydrogen bonds (C-4–H-4···O-5 and C-6–H-6B···O-3) and only one intermolecular bond (N-1–H-1A···N-2) were observed (Table 7). Molecules of **9** form an infinite chain C1,1(5) by means of a hydrogen bond N-1–H-1A···N-2 in *a*-direction (Fig. 4). Comparing the hydrogen bond with same donor N-1 for **4** (Fig. 3(c)) and for **9**, it is evident that the acceptor for **4** is O-5, while for **9** it is N-2. This is reflected in the change of conformation of these two molecules, especially in change of torsion angles O-4–C-4–C5–N-1, C-3–C-4–C-5–N-1, C-3–C-4–C-5–C-11 and C-4–C-5–N-1–C-12 (see Table 3) reaching 18° in the maximum. Also, a significant change of the bond length C-2–C-3 (see Table 2) can be explained by the internal stress of molecule **4**, when the sheet-like structure is formed.

3. Experimental

General methods.—^{1}H and ^{13}C NMR spectra (in $CDCl_3$ unless specified other, internal standard Me_4Si) were recorded on a Bruker Avance DPX 300 instrument operating at 300.13 and 75.46 MHz working frequencies, respectively. For the assignments of signals, 1D NOESY and C–H heterocorrelated experiments were used. The quaternary carbon atoms were identified on the basis of a semiselective INEPT experiment and a 1D INADEQUATE pulse sequence technique. The EI and CI (using pyridine as a reactive agent; only one peak, characteristic of the molecular weight of compound, is registered by this method[18]) mass spectra (70 eV) were obtained on a Finnigan MAT SSQ 710 instrument. Specific rotations were determined on a Perkin–Elmer 241 polarimeter (10 cm cell). Microanalyses were performed on a Fisons EA 1108 analyser. Melting points were determined with a Boetius PHMK 05 microscope. All reactions were monitored by TLC on Silica Gel plates (E. Merck) using the following solvents: 6:1 $CHCl_3$–Me_2CO (eluent A), 5:1 $CHCl_3$–Me_2CO (eluent B), EtAc (eluent C), 5:1 $CHCl_3$–MeOH (eluent D). Visualisation was affected with iodine vapour or H_2SO_4. Column chromatography was performed as flash chromatography on Silica Gel 60 (E. Merck, 230–400 mesh).

X-ray techniques.—Crystal and experimental data for compounds **4** and **9** are summarised in Table 1. Preliminary orientation matrices were obtained from the first frames using Siemens SMART software.[19] Final cell parameters were obtained by refinement using Siemens SAINT software.[19] The data were empirically corrected for absorption and other effects using SADABS program[20] based on the method of Blessing.[21] The structures were solved by direct methods and refined by full-matrix least-squares on all F^2 data using Bruker SHELXTL.[22] The non-H atoms were refined anisotropically. Hydrogen atoms were constrained to the idealgeometry using an appropriate riding model. Molecular graphics were obtained using the program DIAMOND.[23]

Table 1
Crystallographic and experimental data for compounds **4** and **9** [a]

	4	**9**
Empirical formula	$C_{12}H_{18}N_2O_5$	$C_{13}H_{20}N_2O_5$
Formula weight	270.28	284.31
Temperature, T (K)	297(2)	163(2)
Wavelength, λ (Å)	0.71073	0.71073
Crystal system	orthorhombic	orthorhombic
Space group	$P2_12_12_1$	$P2_12_12_1$
Unit cell dimensions		
a (Å)	5.04370(10)	5.82590(10)
b (Å)	15.3015(3)	10.6964(2)
c (Å)	18.0028(4)	23.2667(4)
Unit-cell volume V (Å^3)	1389.39(5)	1449.89(4)
Formula per unit cell, Z	4	4
D_{calcd} (g/cm^3)	1.292	1.302
Radiation	Mo K_α	Mo K_α
Absorption coefficient, μ (mm^{-1})	0.101	0.100
F(000)	576	608
Crystal size (mm)	1.00 (max)	0.85 (max)
	0.05 (min)	0.08 (min)
Diffractometer	Siemens SMART CCD	Siemens SMART CCD
θ Range (°)	1.75–25.37	1.75–32.93
Range of h	$-6 \rightarrow 6$	$-8 \rightarrow 8$
Range of k	$-18 \rightarrow 18$	$-16 \rightarrow 15$
Range of l	$-21 \rightarrow 21$	$-34 \rightarrow 34$
Reflections	13213	21396
Independent reflections	2536 ($R_{int} = 0.0856$)	5173 ($R_{int} = 0.0471$)
Refinement method	full-matrix least-squares on F^2	full-matrix least-squares on F^2
Data/parameters	2536/194	5173/216
Goodness-of-fit (all)	0.996	1.019
Final R indices [$I>2\sigma(I)$]	$R_1 = 0.0608$, $wR_2 = 0.1432$	$R_1 = 0.0465$, $wR_2 = 0.0963$
R indices (all data)	$R_1 = 0.1222$, $wR_2 = 0.1762$	$R_1 = 0.0679$, $wR_2 = 0.1072$
Largest difference peak and hole (e/Å^3)	0.127 and -0.149	0.280 and -0.206

[a] Standard deviations in parentheses.

Table 2
Bond lengths (Å) and bond angles (°) for compounds **4** and **9** [a]

	4	**9**
Bond lengths		
O-5–C-12	1.227(6)	1.224(2)
O-1–C-1	1.394(5)	1.4091(18)
O-1–C-7	1.424(6)	1.437(2)
O-2–C-8	1.435(5)	1.4344(17)
O-2–C-2	1.425(5)	1.4266(16)
O-4–C-4	1.438(5)	1.4379(17)
O-4–C-1	1.416(5)	1.4225(17)
O-3–C-8	1.425(5)	1.4342(16)
O-3–C-3	1.420(5)	1.4249(16)
N-2–C-11	1.143(6)	1.144(2)
N-1–C-12	1.343(5)	1.3649(18)
N-1–C-5	1.448(5)	1.4609(18)
C-10–C-8	1.506(7)	1.509(2)
C-9–C-8	1.511(6)	1.513(2)
C-11–C-5	1.479(7)	1.492(2)
C-2–C-1	1.506(6)	1.524(2)
C-2–C-3	1.529(6)	1.5526(19)
C-3–C-4	1.530(6)	1.5344(19)
C-5–C-4	1.531(5)	1.5535(18)
C-13–C-12	1.492(7)	1.507(2)
C-5–C-6	—	1.5363(19)
Bond angles		
C-1–O-1–C-7	113.6(4)	112.68(13)
C-8–O-2–C-2	106.4(3)	107.63(10)
C-4–O-4–C-1	106.4(3)	105.18(11)
C-8–O-3–C-3	108.5(3)	108.55(10)
C-12–N-1–C-5	123.7(4)	123.72(13)
N-2–C-11–C-5	175.8(5)	178.14(15)
O-3–C-8–O-2	103.3(3)	104.26(10)
O-3–C-8–C-10	107.5(4)	108.52(12)
O-2–C-8–C-10	110.9(4)	109.40(13)
O-3–C-8–C-9	111.7(4)	110.08(12)
O-2–C-8–C-9	110.3(4)	111.59(12)
C-10–C-8–C-9	112.8(4)	112.69(13)
O-2–C-2–C-1	110.6(4)	109.26(13)
O-2–C-2–C-3	103.5(3)	104.23(10)
C-1–C-2–C-3	104.4(3)	104.09(11)
O-3–C-3–C-4	112.7(3)	112.87(11)
O-3–C-3–C-2	105.0(3)	104.57(10)
C-4–C-3–C-2	104.0(3)	103.12(11)
N-1–C-5–C-11	111.5(3)	109.35(11)
N-1–C-5–C-4	113.3(3)	109.48(11)
C-11–C-5–C-4	109.3(3)	106.83(11)
O-1–C-1–O-4	112.4(4)	111.84(11)
O-1–C-1–C-2	105.8(4)	106.71(12)
O-4–C-1–C-2	105.2(3)	105.09(11)
O-4–C-4–C-3	105.7(3)	105.14(10)
O-4–C-4–C-5	106.0(3)	107.87(11)
C-3–C-4–C-5	114.7(3)	119.22(11)
O-5–C-12–N-1	121.3(5)	121.75(14)
O-5–C-12–C-13	122.8(5)	123.13(14)
N-1–C-12–C-13	115.9(4)	115.11(14)
N-1–C-5–C-6	—	107.81(11)
C-11–C-5–C-6	—	109.18(11)
C-6–C-5–C-4	—	114.13(11)

[a] Standard deviations in parentheses.

Table 3
Selected torsion angles (°) for compounds **4** and **9** [a]

	4	**9**
C-1–C-2–C-3–C-4	−8.0(4)	−1.03(13)
O-4–C-1–C-2–C-3	28.5(4)	25.24(14)
C-2–C-3–C-4–O-4	−14.7(4)	−23.21(13)
C-1–O-4–C-4–C-3	33.7(4)	40.68(13)
C-4–O-4–C-1–C-2	−39.2(4)	−41.36(13)
O-2–C-2–C-3–O-3	−10.8(4)	−4.78(15)
C-8–O-3–C-3–C-2	−12.2(4)	−15.62(15)
C-3–O-3–C-8–O-2	30.4(4)	30.24(14)
C-2–O-2–C-8–O-3	−37.6(4)	−33.43(14)
C-8–O-2–C-2–C-3	29.7(4)	23.44(14)
O-4–C-1–O-1–C-7	66.2(5)	59.59(17)
C-7–O-1–C-1–C-2	−179.6(4)	173.99(13)
O-4–C-4–C-5–N-1	59.0(4)	71.99(13)
C-3–C-4–C-5–N-1	175.1(4)	−168.35 (12)
C-3–C-4–C-5–C-11	−59.8(5)	−50.05(15)
C-4–C-5–N-1–C-12	76.3(5)	65.02(17)
C-5–N-1–C-12–C-13	−177.8(4)	−179.64(14)
C-3–C-4–C-5–C-6	—	70.72(16)
H-4–C-4–C-5–H-5	−179	—
H-4–C-4–C-5–C-6	—	−166

[a] Standard deviations in parentheses.

*Methyl (5*S*)-5-*C*-amino-5-cyano-5-deoxy-2,3-*O*-isopropylidene-α-*D*-lyxofuranoside* (**2**).—Dry ammonia gas was introduced to a magnetically stirred mixture of methyl 2,3-*O*-isopropylidene-α-D-*lyxo*-pentodialdo-1,4-furanoside (**1**) (8.09 g, 40 mmol), NaCN (3.93 g, 80 mmol), and NH_4Cl (4.28 g; 80 mmol) in dry MeOH (500 mL). The mixture was stirred at 40 °C for 4 days. The solvent was distilled off under reduced pressure and the residue was dissolved in water (100 mL). Extraction with $CHCl_3$ (3×100 mL), washing of the combined extracts with satd aq $NaHCO_3$ solution (100 mL), water (100 mL), drying over Na_2SO_4, filtration and evaporation of the solvent in vacuo afforded the crude reaction product (5.16 g). From this, pure **2** (3.46 g, 38%) was separated by crystallisation using ether–hexane as a solvent, leaving an unseparable mixture of **2** and **3** (ca. 1:1) in the mother liquor. Analytical sample of **2** (colourless needles, R_f 0.36, eluent A) was obtained by two recrystallisation from ether–hexane; mp 106–108 °C; $[\alpha]_D$ +53° (*c* 1, MeOH); NMR: ^1H (300 MHz, $CDCl_3$): δ 4.99 (s, 1 H, H-1), 4.82 (dd, 1 H, $J_{2,3}$ 5.9, $J_{3,4}$ 3.7 Hz, H-3), 4.60 (d, 1 H, H-2), 4.15 (d, 1 H, $J_{4,5}$ 7.7 Hz, H-5), 4.07 (dd, 1 H, H-4), 3.35 (s, 3 H, OCH_3), 1.83 (bs, 2 H, NH_2), 1.54 and 1.32 (2 s, each 3 H, Me_2C); ^{13}C (75.5 MHz, $CDCl_3$): δ 119.7 (CN), 113.4 (CMe_2), 107.3 (C-1), 84.6 (C-2), 79.7 (C-4), 79.0 (C-3), 54.9 (OCH_3), 43.4 (C-5), 25.3 and 24.4 [$(CH_3)_2C$]; EIMS (70 eV): *m*/*z* 213 $[M-Me]^+$, 197, 173 (100%), 125, 115, 113, 96, 87, 85, 71, 59, 43, 42. CIMS: *m*/*z* 308 $[M+80]^+$. Anal. Calcd for $C_{10}H_{16}N_2O_4$: C, 52.60; H, 7.07; N, 12.30. Found: C, 52.49; H, 7.14; N, 12.39.

Table 4
Atomic coordinates ($\times 10^4$) and equivalent isotropic displacement parameters ($Å^2 \times 10^3$) for compound **4** [a]

Atom	x	y	z	U_{eq}
O-1	8607(7)	9419(2)	10756(2)	76(1)
O-2	6161(6)	8225(2)	9209(2)	68(1)
O-3	9067(6)	8827(2)	8417(2)	59(1)
O-4	6781(6)	10066(2)	9699(1)	60(1)
O-5	11803(7)	12015(2)	8979(2)	85(1)
N-1	7747(8)	11493(2)	8731(2)	58(1)
H-1	6089	11614	8689	110(20)
N-2	12725(10)	10531(3)	7693(2)	87(1)
C-1	6892(11)	9313(3)	10155(2)	62(1)
H-1A	5118	9142	10322	75(15)
C-2	8112(9)	8614(3)	9676(2)	58(1)
H-2	9102	8181	9966	37(9)
C-3	9876(8)	9115(2)	9132(2)	53(1)
H-3	11760	8996	9220	56(11)
C-4	9196(8)	10075(3)	9275(2)	54(1)
H-4	10615	10355	9561	52(11)
C-5	8599(9)	10608(3)	8575(2)	53(1)
H-5	7147	10315	8312	34(9)
C-7	7744(17)	10059(4)	11276(3)	100(2)
H-7A	7910	10630	11061	140(30)
H-7B	8817	10025	11716	170(30)
H-7C	5924	9953	11404	120(30)
C-8	7414(9)	8079(3)	8504(2)	63(1)
C-9	9013(12)	7244(3)	8524(3)	83(2)
H-9A	9871	7159	8053	93(18)
H-9B	7858	6759	8623	110(20)
H-9C	10328	7282	8908	120(20)
C-10	5407(11)	8092(4)	7885(3)	90(2)
H-10A	4303	8600	7934	110(20)
H-10B	4329	7576	7911	80(16)
H-10C	6309	8108	7416	180(40)
C-11	10941(10)	10595(3)	8081(2)	62(1)
C-12	9402(11)	12136(3)	8939(3)	67(1)
C-13	8141(12)	12997(3)	9103(4)	92(2)
H-13A	8874	13231	9553	120(20)
H-13B	6264	12919	9161	93(17)
H-13C	8475	13393	8700	160(30)

[a] Standard deviations in parentheses.

Table 5
Atomic coordinates ($\times 10^4$) and equivalent isotropic displacement parameters ($Å^2 \times 10^3$) for compound **9** [a]

Atom	x	y	z	U_{eq}
O-1	9994(2)	4460(1)	10077(1)	29(1)
O-2	8386(2)	7279(1)	9366(1)	24(1)
O-3	7262(2)	6291(1)	8553(1)	22(1)
O-4	11399(2)	5043(1)	9171(1)	21(1)
O-5	9547(2)	1700(1)	8531(1)	29(1)
C-1	10426(3)	5461(1)	9698(1)	22(1)
H-1	11389(18)	6086(11)	9877(3)	18(4)
C-2	8099(3)	6006(1)	9535(1)	20(1)
H-2	6980(20)	5903(2)	9827(6)	27(5)
C-3	7460(2)	5320(1)	8969(1)	18(1)
H-3	6060(30)	4852(9)	9007(1)	21(4)
C-4	9535(2)	4467(1)	8864(1)	18(1)
H-4	9229(6)	3686(13)	9037(3)	15(4)
C-5	10347(2)	4226(1)	8238(1)	18(1)
C-6	11476(3)	5362(1)	7949(1)	21(1)
H-6A	12849(18)	5609(7)	8169(4)	29(5)
H-6B	10380(13)	6063(8)	7941(4)	32(5)
H-6C	11924(18)	5143(4)	7554(4)	27(5)
C-7	12035(4)	3774(2)	10220(1)	47(1)
H-7A	12575(17)	3344(13)	9890(5)	46(6)
H-7B	11696(8)	3187(13)	10515(6)	74(8)
H-7C	13182(19)	4336(8)	10351(6)	71(9)
C-8	7099(3)	7465(1)	8848(1)	20(1)
C-9	4612(3)	7768(1)	8973(1)	26(1)
H-9A	3766(11)	7828(10)	8613(4)	38(5)
H-9B	4520(3)	8562(10)	9176(5)	31(5)
H-9C	3950(10)	7111(9)	9210(5)	40(5)
C-10	8256(3)	8454(1)	8487(1)	30(1)
H-10A	9840(20)	8224(6)	8424(5)	45(6)
H-10B	8189(19)	9249(10)	8684(3)	41(6)
H-10C	7478(16)	8521(8)	8120(5)	52(7)
C-11	8275(3)	3854(1)	7902(1)	20(1)
C-12	11481(3)	2001(1)	8379(1)	24(1)
C-13	13454(4)	1092(2)	8348(1)	40(1)
H-13A	13550(20)	666(15)	8677(7)	145(16)
H-13B	14760(20)	1510(7)	8290(8)	72(8)
H-13C	13224(17)	559(15)	8058(7)	105(11)
N-1	12008(2)	3203(1)	8233(1)	21(1)
H-1A	13360(40)	3363(4)	8134(3)	30(5)
N-2	6681(3)	3601(1)	7639(1)	28(1)

[a] Standard deviations in parentheses.

Methyl (5S)-5-C-acetamido-5-cyano-5-deoxy-2,3-O-isopropylidene-α-D-lyxofuranoside (**4**).—Pyridine (15 mL) and Ac_2O (5 mL) were added to **2** (2.28 g, 10 mmol) and the solution was stirred for 18 h at rt followed by concentration and co-evaporation with toluene at reduced pressure. The product (R_f 0.56, eluent B) was crystallised from ether–hexane to give colourless needles of **4** (2.32 g, 86%); mp 162–163 °C; $[\alpha]_D$ +83° (*c* 1, MeOH); NMR: ^{1}H (300 MHz, $CDCl_3$): δ 6.27 (d, 1 H, $J_{5,NH}$ 8.4 Hz, NH), 5.39 (dd, 1 H, $J_{4,5}$ 7.1 Hz, H-5), 5.03 (s, 1 H, H-1), 4.76 (dd, 1 H, $J_{2,3}$ 5.9, $J_{3,4}$ 3.9 Hz, H-3), 4.61 (d, 1 H, H-2), 4.20 (dd, 1 H, H-4), 3.35 (s, 3 H, OCH_3), 2.08 (s, 3 H, CH_3CO), 1.56 and 1.33 (2 s, each 3 H, Me_2C); ^{13}C (75.5 MHz, $CDCl_3$): δ 169.5 (CO), 116.7 (CN), 113.8 (CMe_2), 107.3 (C-1), 84.4 (C-2), 78.9 (C-3), 76.8 (C-4), 55.0 (OCH_3), 40.0 (C-5), 25.0 and 24.3 [$(CH_3)_2C$], 22.8 (CH_3CO); EIMS (70 eV): m/z 271 $[M+1]^+$, 255 $[M-Me]^+$, 239 $[M-OMe]^+$, 173, 152, 121, 110, 85, 59, 43 (100%). CIMS: m/z 350 $[M+80]^+$. Anal. Calcd for $C_{12}H_{18}N_2O_5$: C, 53.30; H, 6.71; N, 10.40. Found: C, 53.19; H, 6.80; N, 10.37.

Table 6
Hydrogen bond geometry in compound **4** [a]

Notation	X–H···Y	Symmetry code	X–H (Å)	H···Y (Å)	X···Y (Å)	X–H···Y (°)
a	N-1–H-1···O-5	$x-1, y, z$	0.86	2.31	3.134(5)	161.5
b	C-3–H-3···O-2	$x+1, y, z$	0.98	2.51	3.452(5)	160.3
c	C-5–H-5···N-2	$x-1, y, z$	0.98	2.52	3.363(7)	144.7
d	C-7–H-7B···N-2	$-x+5/2, -y+2, z+1/2$	0.96	2.62	3.541(8)	161.2

[a] Standard deviations in parentheses.

*Methyl (5*R*)-5-*C*-acetamido-5-cyano-5-deoxy-2,3-*O*-isopropylidene-α-*D*-lyxofuranoside* (**5**).—A mixture of **2** and **3** (1.70 g) obtained by the evaporation of solvent from the mother liquor (see preparation of **2**) was acetylated as above. Fractional crystallisation of the crude reaction product from ether–hexane gave a mixture of **4** and **5** (1.13 g, 56%) and pure **5** (0.54 g, 27%) as colourless needles (R_f 0.48, eluent B); mp 224–226 °C; $[\alpha]_D$ +44° (*c* 1, MeOH); NMR: ^{1}H (300 MHz, $CDCl_3$): δ 6.60 (d, 1 H, $J_{5,NH}$ 8.7 Hz, NH), 5.37 (dd, 1 H, $J_{4,5}$ 4.7 Hz, H-5), 4.99 (s, 1 H, H-1), 4.89 (dd, 1 H, $J_{2,3}$ 5.9, $J_{3,4}$ 3.7 Hz, H-3), 4.60 (d, 1 H, H-2), 4.18 (dd, 1 H, H-4), 3.35 (s, 3 H, OCH_3), 2.05 (s, 3 H, CH_3CO), 1.56 and 1.34 (2 s, each 3 H, Me_2C); ^{13}C (75.5 MHz, $CDCl_3$): δ 169.3 (CO), 116.4 (CN), 113.6 (CMe_2), 107.4 (C-1), 84.7 (C-2), 79.9 (C-3), 77.0 (C-4), 55.2 (OCH_3), 40.3 (C-5), 25.4 and 24.1 [$(CH_3)_2C$], 23.0 (CH_3CO); EIMS (70 eV): *m*/*z* 271 $[M+1]^+$, 255 $[M-Me]^+$, 239 $[M-OMe]^+$, 173, 152, 121, 110, 85, 59, 43 (100%). CIMS: *m*/*z* 350 $[M+80]^+$. Anal. Calcd for $C_{12}H_{18}N_2O_5$: C, 53.30; H, 6.71; N, 10.40. Found: C, 53.16; H, 6.77; N, 10.35.

*Methyl (5*S*)-5-*C*-amino-5-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-α-*D*-lyxo-hexofuranoside* (**6**).—Starting from 5-ulose **8** (4.32 g, 20 mmol), and application of the same reaction procedure as described for the preparation of **2** afforded **6** (1.74 g, 36%) as colourless needles (R_f 0.44, eluent C); mp 88–90 °C; $[\alpha]_D$ +57° (*c* 1, MeOH); NMR: ^{1}H (300 MHz, $CDCl_3$): δ 4.97 (s, 1 H, H-1), 4.72 (dd, 1 H, $J_{2,3}$ 6.0, $J_{3,4}$ 3.9 Hz, H-3), 4.52 (d, 1 H, H-2), 3.64 (d, 1 H, H-4), 3.27 (s, 3 H, OCH_3), 1.98 (bs, 2 H, NH_2), 1.60 (s, 3 H, H-6), 1.52 and 1.25 (2 s, each 3 H, Me_2C); ^{13}C (75.5 MHz, $CDCl_3$): δ 122.9 (CN), 113.4 (CMe_2), 106.7 (C-1), 84.3 (C-2), 83.6 (C-4), 78.7 (C-3), 54.5 (OCH_3), 50.6 (C-5), 27.2 and 24.4 [$(CH_3)_2C$], 24.1 (C-6). Anal. Calcd for $C_{11}H_{18}N_2O_4$: C, 54.50; H, 7.49; N, 11.60. Found: C, 54.61; H, 7.58; N, 11.54.

*Methyl (5*S*)-5-*C*-amino-5-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-α-*D*-lyxo-hexofuranoside* (**7**).—A mixture of **6** and **7** obtained by the evaporation of solvent from the mother liquor (see preparation of **6** and **2**) was separated on a column of silica gel (eluent C) affording **7** (678 mg, 14%) as a colourless oil (R_f 0.31, eluent C);

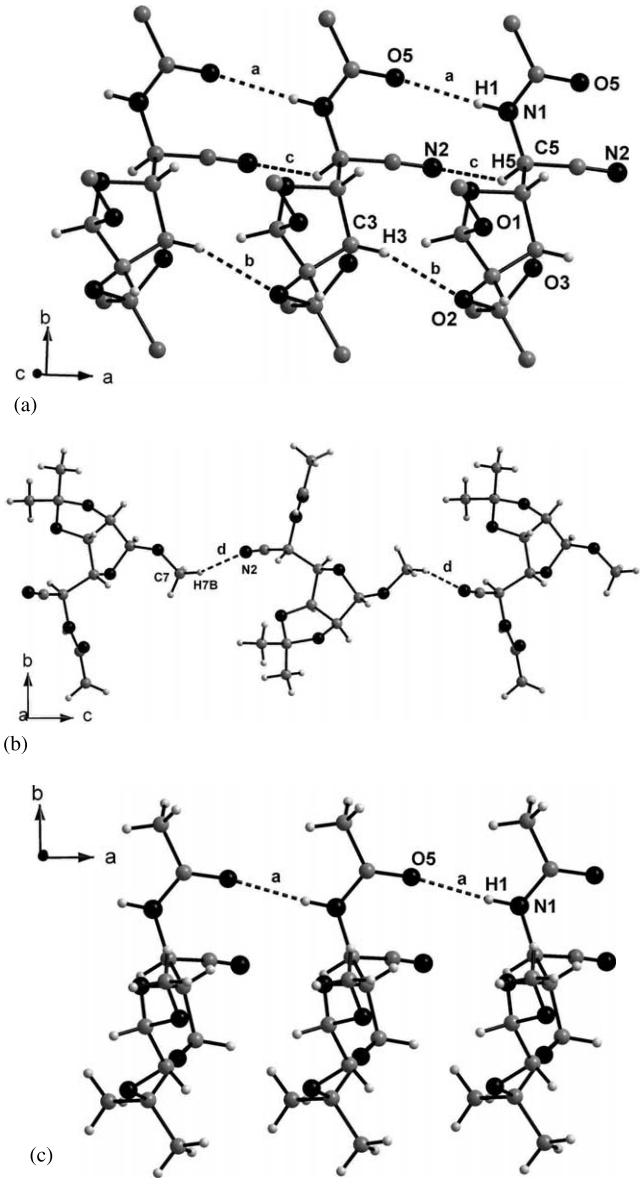


Fig. 3. (a) The sheet formed by hydrogen bonds in compound **4**. Methyl hydrogen atoms are omitted for clarity. Codes of hydrogen bonds refer to those in Table 6. (b) Infinite chain perpendicular to the sheets shown in Fig. 3(a) in compound **4**. (c) Hydrogen bond chain with N-1-atom as a donor for compound **4**.

Table 7
Hydrogen bond geometry in compound **9** [a]

X–H···Y	Symmetry code	X–H (Å)	H···Y (Å)	X···Y (Å)	X–H···Y (°)
N-1–H-1A···N-2	$x+1, y, z$	0.84	2.26	3.0829(19)	164.6
C-4–H-4···O-5		0.95	2.43	3.0591(17)	123.5
C-6–H-6B···O-3		0.98	2.32	2.9976(18)	125.1

[a] Standard deviations in parentheses.

$[\alpha]_D$ + 75° (*c* 1, MeOH); NMR: ^{1}H (300 MHz, $CDCl_3$): δ 5.03 (s, 1 H, H-1), 4.79 (dd, 1 H, $J_{2,3}$ 6.0, $J_{3,4}$ 3.7 Hz, H-3), 4.59 (d, 1 H, H-2), 3.79 (d, 1 H, H-4), 3.34 (s, 3 H, OCH_3), 2.22 (bs, 2 H, NH_2), 1.59 (s, 3 H, H-6), 1.56 and 1.31 (2 s, each 3 H, Me_2C); ^{13}C (75.5 MHz, $CDCl_3$): δ 122.9 (CN), 113.5 (CMe_2), 106.8 (C-1), 84.7 (C-2), 83.5 (C-4), 78.7 (C-3), 54.6 (OCH_3), 50.3 (C-5), 24.7 and 24.2 [$(CH_3)_2C$], 23.9 (C-6). Anal. Calcd for $C_{11}H_{18}N_2O_4$: C, 54.50; H, 7.49; N, 11.60. Found: C, 54.64; H, 7.55; N, 11.52.

*Methyl (5*S*)-5-*C*-acetamido-5-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-α-*D*-lyxo-hexofuranoside* (**9**).—Starting from **6** (2.42 g, 10 mmol), and application of the same reaction procedure as described for the preparation of **4** afforded crude product (R_f 0.32, eluent A) which was crystallised from ether–hexane to give colourless needles of **9** (2.50 g, 88%); mp 179–181 °C; $[\alpha]_D$ + 91° (*c* 1, MeOH); NMR: ^{1}H (300 MHz, $CDCl_3$): δ 6.90 (bs, 1 H, NH), 5.00 (s, 1 H, H-1), 4.85 (dd, 1 H, $J_{2,3}$ 5.8, $J_{3,4}$ 3.2 Hz, H-3), 4.61 (d, 1 H, H-2), 4.24 (d, 1 H, H-4), 3.37 (s, 3 H, OCH_3), 2.01 (s, 3 H, CH_3CO), 1.87 (s, 3 H, H-6), 1.54 and 1.33 (2 s, each 3 H, Me_2C); ^{13}C (75.5 MHz, $CDCl_3$): δ 169.1 (CO), 118.7 (CN), 113.2 (CMe_2), 106.6 (C-1), 84.6 (C-2), 80.0 (C-4), 78.9 (C-3), 54.8 (OCH_3), 50.8 (C-5), 25.4 and 23.8 [$(CH_3)_2C$], 23.3 (CH_3CO), 21.8 (C-6). Anal. Calcd for $C_{13}H_{20}N_2O_5$: C, 54.90; H, 7.09; N, 9.85. Found: C, 54.78; H, 7.13; N, 9.89.

*Methyl (5*R*)-5-*C*-acetamido-5-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-α-*D*-lyxo-hexofuranoside* (**10**).—Starting from **7** (1.21 g, 5 mmol), and application of the same reaction procedure as described for the preparation of **4** afforded crude product (R_f 0.41, eluent A) which was crystallised from ether–hexane to give colourless needles of **10** (1.18 g, 83%); mp 144–145 °C; $[\alpha]_D$ + 50° (*c* 1, MeOH); NMR: ^{1}H (300 MHz, $CDCl_3$): δ 6.64 (bs, 1 H, NH), 5.00 (s, 1 H, H-1), 4.89 (dd, 1 H, $J_{2,3}$ 5.8, $J_{3,4}$ 3.3 Hz, H-3), 4.60 (d, 1 H, H-2), 4.16 (d, 1 H, H-4), 3.36 (s, 3 H, OCH_3), 2.02 (s, 3 H, CH_3CO), 1.92 (s, 3 H, H-6), 1.54 and 1.33 (2 s, each 3 H, Me_2C); ^{13}C (75.5 MHz, $CDCl_3$): δ 169.5 (CO), 118.3 (CN), 113.2 (CMe_2), 107.0 (C-1), 84.5 (C-2), 80.2 (C-4), 79.3 (C-3), 54.9 (OCH_3), 50.8 (C-5), 25.3 and 23.9 [$(CH_3)_2C$], 23.4 (CH_3CO), 22.4 (C-6). Anal. Calcd for $C_{13}H_{20}N_2O_5$: C, 54.90; H, 7.09; N, 9.85. Found: C, 54.99; H, 7.14; N, 9.82.

*Methyl (5*S*)-5-*C*-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-5-tosylamino-α-*D*-lyxo-hexofuranoside* (**11**).—A mixture of **6** (705 mg, 2.5 mmol), pyridine (5 mL) and tosyl chloride (515 mg, 2.7 mmol) was stirred overnight at rt followed by pouring onto crushed ice (100 mL). The product was extracted with EtAc (3 × 30 mL), the combined extracts were washed with water, dried (Na_2SO_4) and the solvent was evaporated under reduced pressure to give the crude product (R_f 0.29, eluent C). Recrystallisation from EtAc–hexane afforded colourless needles of **11** (833 mg, 84%); mp 134–136 °C; $[\alpha]_D$ + 31° (*c* 1, MeOH); NMR: ^{1}H (300 MHz, $CDCl_3$): δ 7.82 (d, 2 H, $J_{2',3'} = J_{5',6'}$ 8.1 Hz H-2′,6′), 7.34 (d, 2 H, H-3′,5′), 5.81 (bs, 1 H, NH), 5.01 (s, 1 H, H-1), 4.84 (dd, 1 H, $J_{2,3}$ 6.0, $J_{3,4}$ 3.9 Hz, H-3), 4.60 (d, 1 H, H-2), 4.00 (d, 1 H, H-4), 3.31 (s, 3 H, OCH_3), 2.44 (s, 3 H, $CH_3C_6H_4$), 1.81 (s, 3 H, H-6), 1.57 and 1.33 (2 s, each 3 H, Me_2C); ^{13}C (75.5 MHz, $CDCl_3$): δ 144.1 (C-4′), 137.5 (C-1′), 129.7 (C-3′, C-5′), 127.4 (C-2′, C-6′), 118.0 (CN), 114.1 (CMe_2), 106.8 (C-1), 84.4 (C-2), 82.7 (C-4), 78.5 (C-3), 54.9 (OCH_3), 53.8 (C-5), 24.5 and 24.0 [$(CH_3)_2C$], 23.5 (C-6), 21.6 ($CH_3C_6H_4$). Anal. Calcd for $C_{18}H_{24}N_2O_6S$: C, 54.50; H, 6.10; N, 7.07; S, 8.09. Found: C, 54.42; H, 6.14; N, 7.02; S, 8.03.

*Methyl (5*R*)-5-*C*-cyano-5,6-dideoxy-2,3-*O*-isopropylidene-5-tosylamino-α-*D*-lyxo-hexofuranoside* (**12**).—Starting from **7** (705 mg, 2.5 mmol), and application of the same reaction procedure as described for the preparation of **11** afforded crude product (R_f 0.32, eluent C) which was purified by chromatography on a short

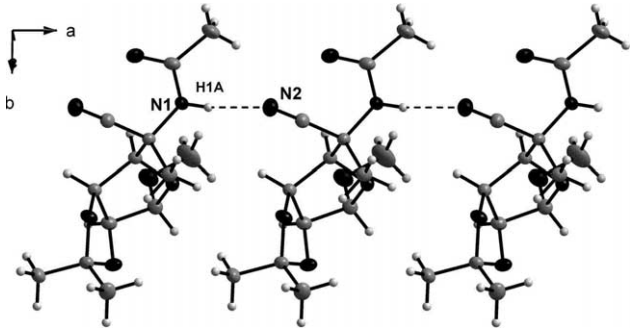


Fig. 4. The only intermolecular hydrogen bond for compound **9** with N-1-atoms as a donor.

column of silica gel with eluent C to give **12** (793 mg, 80%) as a colourless oil; $[\alpha]_D$ +19° (*c* 1, MeOH); NMR: ^{1}H (300 MHz, $CDCl_3$): δ 7.82 (d, 2 H, $J_{2',3'} = J_{5',6'}$ 8.1 Hz H-2′,6′), 7.34 (d, 2 H, H-3′,5′), 6.08 (bs, 1 H, NH), 5.00 (s, 1 H, H-1), 4.84 (dd, 1 H, $J_{2,3}$ 5.9, $J_{3,4}$ 3.6 Hz, H-3), 4.59 (d, 1 H, H-2), 3.94 (d, 1 H, H-4), 3.34 (s, 3 H, OCH_3), 2.44 (s, 3 H, $CH_3C_6H_4$), 1.81 (s, 3 H, H-6), 1.53 and 1.30 (2 s, each 3 H, Me_2C); ^{13}C (75.5 MHz, $CDCl_3$): δ 144.0 (C-4′), 137.2 (C-1′), 129.6 (C-3′, C-5′), 127.5 (C-2′, C-6′), 117.6 (CN), 113.8 (CMe_2), 106.9 (C-1), 84.6 (C-2), 82.2 (C-4), 79.0 (C-3), 55.1 (OCH_3), 53.4 (C-5), 24.8 and 24.0 [$(CH_3)_2C$], 21.7 (C-6), 21.5 ($CH_3C_6H_4$). Anal. Calcd for $C_{18}H_{24}N_2O_6S$: C, 54.50; H, 6.10; N, 7.07; S, 8.09. Found: C, 54.59; H, 6.13; N, 7.03; S, 8.04.

*Methyl (5*R*)-5-acetamido-5-deoxy-2,3*-O-*isopropylidene-α-*D-lyxo-*hexofuranosiduronamide* (**13**).—A mixture of *N*-acetylated amino nitrile **4** (1.35 g, 5 mmol), barium hydroxide octahydrate (4.73 g, 15 mmol), EtOH (25 mL), and water (50 mL) was heated at 80 °C for 6 h. Carbon dioxide gas was then passed to the hot reaction mixture. The separated barium carbonate was removed by filtration and washed with hot EtOH. Carbon dioxide gas was again passed to the hot solution and after cooling to rt, another portion of barium carbonate was separated. Filtration, evaporation of the solvents and decolourising with charcoal in MeOH gave a clear solution. Methanol was evaporated under diminished pressure and the residual solid was purified on a short column of silica gel (eluent D). Fractions with R_f 0.69 (eluent D) were collected and evaporated to afford **13** (331 mg, 23%); mp 186–188 °C; $[\alpha]_D$ +58° (*c* 1, MeOH); NMR: ^{1}H (300 MHz, $CDCl_3$): δ 6.91 (d, 1 H, $J_{5,NH}$ 8.2 Hz, NH), 5.74 (bs, 2 H, NH_2), 4.89 (s, 1 H, H-1), 4.74 (dd, 1 H, $J_{2,3}$ 5.9, $J_{3,4}$ 3.6 Hz, H-3), 4.63 (dd, 1 H, $J_{4,5}$ 7.1 Hz, H-5), 4.52 (d, 1 H, H-2), 4.11 (dd, 1 H, H-4), 3.26 (s, 3 H, OCH_3), 2.02 (s, 3 H, CH_3CO), 1.39 and 1.23 (2 s, each 3 H, Me_2C); ^{13}C (75.5 MHz, $CDCl_3$): δ 172.6 (CO), 169.6 (CO), 111.9 (CMe_2), 106.1 (C-1), 84.3 (C-2), 79.6 (C-3), 77.2 (C-4), 54.0 (OCH_3), 51.7 (C-5), 25.7 and 24.2 [$(CH_3)_2C$]; EIMS (70 eV): *m*/*z* 289 $[M+1]^+$, 272 $[M-Me]^+$, 257 $[M-OMe]^+$, 244, 173, 152, 121, 110, 85, 59, 43 (100%). Anal. Calcd for $C_{12}H_{20}N_2O_6$: C, 50.00; H, 6.99; N, 9.72. Found: C, 50.13; H, 7.04; N, 9.68.

*Methyl (5*R*)-5-*C*-acetamido-5-carbamoyl-5,6-dideoxy-2,3*-O-*isopropylidene-α-*D-lyxo-*hexofuranoside* (**14**).—Starting from **9** (1.42 g, 5 mmol), and application of the same reaction procedure as described for the preparation of **13** afforded **14** (408 mg, 27%) as colourless needles (R_f 0.75, eluent D); mp 165–167 °C; $[\alpha]_D$ +63° (*c* 1, MeOH); NMR: ^{1}H (300 MHz, $CDCl_3$): δ 7.29 (bs, 1 H, NH), 6.94 and 5.60 (2 bs, each 1 H, NH_2), 4.99 (d, 1 H, $J_{3,4}$ 3.3 Hz, H-4), 4.97 (s, 1 H, H-1), 4.70 (dd, 1 H, $J_{2,3}$ 5.9 Hz, H-3), 4.53 (d, 1 H, H-2), 3.34 (s, 3 H, OCH_3), 2.03 (s, 3 H, CH_3CO), 1.77 (s, 3 H, H-6), 1.45 and 1.27 (2 s, each 3 H, Me_2C); ^{13}C (75.5 MHz, $CDCl_3$): δ 175.3 (NHCO), 169.7 ($CONH_2$), 112.4 (CMe_2), 106.5 (C-1), 84.2 (C-2), 80.3 (C-4), 78.8 (C-3), 58.8 (C-5), 54.6 (OCH_3), 24.6 and 23.6 [$(CH_3)_2C$], 24.2 (CH_3CO), 22.4 (C-6); EIMS (70 eV): *m*/*z* 303 $[M+1]^+$, 286 $[M-Me]^+$, 271 $[M-OMe]^+$, 258, 243, 216, 173, 140, 113, 100, 85, 59, 43 (100%). Anal. Calcd for $C_{13}H_{22}N_2O_6$: C, 51.60; H, 7.33; N, 9.27. Found: C, 51.66; H, 7.37; N, 9.22.

*Ethyl [methyl (5*R*)-5-acetamido-5-deoxy-2,3*-O-*isopropylidene-α-*D-lyxo-*hexofuranosid]uronate* (**15**).—To a solution of acetylated amino nitrile **4** (1.35 g, 5 mmol) in dry $CHCl_3$ (10 mL) and dry EtOH (0.6 mL) was added HCl in dry $CHCl_3$ (7.5% w/w, 5 mL) and the mixture was stirred at rt for 2 h. The solvents were evaporated under reduced pressure and water (20 mL) was added to the residue followed by extraction with EtOAc (3 × 20 mL). Drying of the combined extracts ($MgSO_4$), filtration, evaporation of the solvents and chromatography on a column of silica gel (eluent D, R_f 0.80) afforded **15** (333 mg, 21%) as colourless oil; $[\alpha]_D$ +52° (*c* 1, MeOH); NMR: ^{1}H (300 MHz, $CDCl_3$): δ 7.06 (d, 1 H, $J_{5,NH}$ 8.4 Hz, NH), 5.02 (dd, 1 H, $J_{4,5}$ 6.5 Hz, H-5), 4.84 (s, 1 H, H-1), 4.70 (dd, 1 H, $J_{2,3}$ 5.9, $J_{3,4}$ 3.4 Hz, H-3), 4.48 (d, 1 H, H-2), 4.25 (dd, 1 H, H-4), 4.17 (q, 2 H, OCH_2), 3.24 (s, 3 H, OCH_3), 1.96 (s, 3 H, CH_3CO), 1.44 and 1.23 (2 s, each 3 H, Me_2C), 1.22 (t, 3 H, CH_3); ^{13}C (75.5 MHz, $CDCl_3$): δ 169.8 (CO_{amide}), 169.4 (CO_{ester}), 112.4 (CMe_2), 106.4 (C-1), 84.4 (C-2), 79.7 (C-3), 76.1 (C-4), 61.1 (OCH_2), 54.3 (OCH_3), 51.5 (C-5), 25.5 and 23.9 [$(CH_3)_2C$], 22.6 (CH_3CO), 13.7 (CH_3); EIMS (70 eV): *m*/*z* 318 $[M+1]^+$, 302 $[M-Me]^+$, 286 $[M-OMe]^+$, 272, 244 (100%), 199, 173, 170, 132, 115, 85, 84, 59, 43. Anal. Calcd for $C_{14}H_{23}NO_7$: C, 53.00; H, 7.31; N, 4.41. Found: C, 53.11; H, 7.39; N, 4.44.

*Methyl (5*R*)-5-*C*-acetamido-5-ethoxycarbonyl-5,6-dideoxy-2,3*-O-*isopropylidene-α-*D-lyxo-*hexofuranoside* (**16**).—Starting from **9** (1.42 g, 5 mmol), and application of the same reaction procedure as described for the preparation of **15** afforded **16** (380 mg, 23%) as colourless needles (R_f 0.51, eluent A); mp 112–113 °C; $[\alpha]_D$ +120° (*c* 0.2, MeOH); NMR: ^{1}H (300 MHz, $CDCl_3$): δ 6.84 (bs, 1 H, NH), 4.97 (s, 1 H, H-1), 4.85 (dd, 1 H, $J_{2,3}$ 5.8, $J_{3,4}$ 3.1 Hz, H-3), 4.54 (d, 1 H, H-2), 4.26 (q, 2 H, OCH_2), 4.04 (dd, 1 H, H-4), 3.27 (s, 3 H, OCH_3), 1.99 (s, 3 H, CH_3CO), 1.73 (s, 3 H, H-6), 1.52 and 1.32 (2 s, each 3 H, Me_2C), 1.29 (t, 3 H, CH_3); ^{13}C (75.5 MHz, $CDCl_3$): δ 171.6 (CO_{amide}), 169.2 (CO_{ester}), 112.8 (CMe_2), 106.7 (C-1), 84.5 (C-2), 80.2 (C-4), 80.0 (C-3), 61.8 (OCH_2), 59.9 (C-5), 54.7 (OCH_3), 25.8 and 23.9 [$(CH_3)_2C$], 23.6 (CH_3CO), 19.6 (C-6), 14.2 (CH_3); EIMS (70 eV): *m*/*z* 332 $[M+1]^+$, 316 $[M-Me]^+$, 300 $[M-OMe]^+$, 286, 272, 258 (100%), 226, 216, 181, 164, 119, 89, 75. Anal. Calcd for $C_{15}H_{25}NO_7$: C, 54.40; H, 7.60; N, 4.23. Found: C, 54.31; H, 7.68; N, 4.19.

4. Supplementary material

Crystallographic data for the structural analysis for compounds **4** and **9** has been deposited with the Cambridge Crystallographic Data Centre, CCDC nos. 172672 and 172673, respectively. Copies of this information may be obtained free of charge from The Director, CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (Fax: + 44-1223-336033; e-mail: deposit@ccdc.cam.ac.uk or www: http://www.ccdc.cam.ac.uk).

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