Dimethylaminomethylene-α-D-*xylo*-hept-5-ulofuranurononitrile as Building Block in the Synthesis of 'Reversed' *C*-Nucleoside Analogues

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3-*O*-Benzyl-6-deoxy-1,2-*O*-isopropylidene-6-(dimethylaminomethylene)-α-D-*xylo*-hept-5-ulofuranurononitrile (**1**) was reacted with amidinium salts, *S*-methylisothiouronium sulfate, and guanidinium chloride, respectively, in the presence of bases to furnish the 4-(3-*O*-benzyl-1,2-*O*-isopropylidene-α-D-*xylo*-tetrofuranos-4-yl)pyrimidine-5-carbonitriles **2** and the 4-(1,2-*O*-isopropylidene-α-D-*glycero*-tetr-3-enofuranos-4-yl)pyrimidine-5-carbonitriles **3**, respectively. Treatment of **1** with ethyl 5-aminopyrazole-4-carboxylates yielded the ethyl 7-(3-*O*-benzyl-1,2-*O*-isopropylidene-α-D-*xylo*-tetrofuranos-4-yl)-6-cyanopyrazolo[1,5-*a*]pyrimidine-3-carboxylates **4** and the ethyl 7-amino-6-(3-*O*-benzyl-1,2-*O*-isopropylidene-α-D-*xylo*-pentofuranuronoyl)pyrazolo[1,5-*a*]pyrimidine-3-carboxylates **5**, respectively. Reaction of **1** with 2-benzimidazolylacetonitrile in the presence of sodium methanolate afforded 1-amino-2-(3-*O*-benzyl-1,2-*O*-isopropylidene-α-D-*xylo*-pentofuranuronoyl)benzo[4,5]imidazo[1,2-*a*]pyridine-4-carbonitrile (**6**) and 1-amino-2-(3-deoxy-1,2-*O*-isopropylidene-α-D-*glycero*-pent-3-enofuranuronoyl)benzo[4,5]imidazo[1,2-*a*]pyridine-4-carbonitrile (**7**).

Key words: 'Reversed' *C*-Nucleoside Analogues, 5-Aminopyrazoles, Pyrimidines, Pyrazolo[1,5-*a*]pyrimidines, Benzo[4,5]imidazo[1,2-*a*]pyridine

Introduction

'Reversed', 'pseudo' or *iso*-*C*-nucleosides constitute a class of nucleoside analogues in which the nucleobase is linked by a carbon-carbon bond to the sugar moiety through a carbon atom other than C-1. The synthesis of 'reversed' *C*-nucleosides is of growing interest for compounds having anticancer and antiviral activities [1, 2]. Examples of this subclass of nucleosides are relatively rare in the literature but, recently, intensified efforts could be observed on this field [3 – 8]. Like *C*-nucleosides also 'reversed' *C*-nucleosides often show different biological activities frequently connected with their increased hydrolytic and enzymatic stability. Because of their structural analogy with *N*-nucleosides they may serve as enzyme substrates or inhibitors [9 – 11].

Pyrazolo[1,5-*a*]pyrimidine-*C*-nucleosides show activities against various cancer cell lines and were used also for other biological tests [12]. Morelli *et al*. described a route to pyrazole- and pyrimidine-*C*-nucleosides which involved the reaction of β-D-ribofuranosyl enaminoketoesters with benzylhydrazine and acetamidine [13]. Maeba *et al*. synthesized pyrazolo[1,5-*a*]pyrimidine-*C*-nucleosides by cyclization of aminopyrazoles with chain extended monosaccharides having an enaminone function in the prolongated chain [14]. Tronchet and Martin reported the synthesis of a 'reversed' *C*-nucleoside from a monosaccharide with a 2-bromo-2-cyanoethenyl group [15].

In this paper we report the synthesis of 'reversed' pyrimidine-, pyrazolo[1,5-*a*]pyrimidine- and benzo[4,5]imidazo[1,2-*a*]pyridine-*C*-nucleoside analogues from the 'push-pull' functionalized 3-*O*-benzyl-6-deoxy-1,2-*O*-isopropylidene-6-(dimethylaminomethylene)-α-D-*xylo*-hept-5-ulofuranurononitrile (**1**) [16].

Results and Discussion

The α-D-*xylo*-hept-5-ulofuranurononitrile **1** was reacted with acetamidinium chloride in methanol in the

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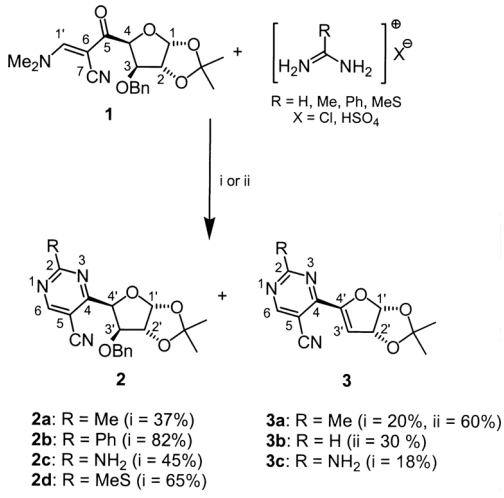


Scheme 1. (i) NaOMe, MeOH, r. t.; (ii) Et_3N, DMF, 80 °C.

presence of sodium methanolate [17]. After stirring for 12 h at room temperature the desired 'reversed' pyrimidine-*C*-nucleoside **2a** was isolated in only 37% yield. As a by-product the 'reversed' enesugar-*C*-nucleoside **3a** was formed in 20% yield as a result of the β-elimination of benzyl alcohol caused by a strong base (NaOMe) (Scheme 1). The required acidification of 4'-H for this elimination is given by the cyano substituted pyrimidine ring. To avoid side product **3a**, the reaction conditions were changed. Unfortunately, in no case better results could be achieved. On the contrary, stirring of α-D-*xylo*-hept-5-ulofuranurononitrile **1** and acetamidine hydrochloride in DMF at 80 °C in the presence of triethylamine [18] gave exclusively the crystalline elimination product **3a** in 60% yield.

In the ^{13}C NMR spectrum of **2a**, downfield signals for carbon atoms of the pyrimidine ring were observed at $\delta = 169.7$ (C-2), 168.0 (C-4), 161.0 (C-6) and 106.2 (C-5), respectively. The not visible carbonyl signal and the presence of resonances for the CN group unequivocally confirmed ring closure with inclusion of the keto and not of the nitrile group. A sharp singlet representing three protons was found in the ^{1}H NMR spectrum at $\delta = 2.70$ corresponding to the 2-methyl group which gave rise to a ^{13}C signal at $\delta = 26.3$. Disappearence of phenyl and CH_2-benzyl signals was observed in the ^{1}H and ^{13}C NMR spectrum of compound **3a**. Due to the formation of the double bond in the furanose ring, the 3'-H signal was shifted downfield to $\delta = 6.49$ compared with the corresponding signal of **2a** at $\delta = 4.34$; 2'-H of **3a** resonated at $\delta = 5.46$ as doublet of a doublet.

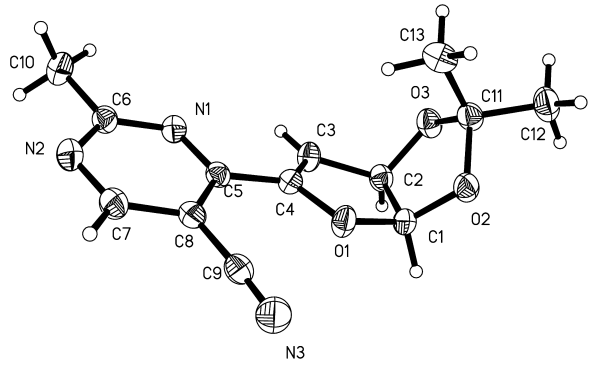


Fig. 1. ORTEP drawing of pyrimidine derivative **3a**.

Compound **3a** was subjected to X-ray crystal structure analysis at 293 K. The relevant crystallographic data are given in the experimental section. An ORTEP drawing of compound **3a** is shown in Fig. 1, which displays the numbering scheme of the atoms. The crystallographic results are in agreement with the proposed structure.

Furthermore, the ulose **1** was reacted with formamidinium acetate in DMF in the presence of triethylamine at 80 °C. After 3 h of stirring the TLC indicated the absence of starting material and the 'reversed' pyrimidine-*C*-nucleoside **3b** was isolated in a yield of 30% as colorless syrup. The structure of compound **3b** was confirmed by IR, NMR and mass spectrometry.

The α-D-*xylo*-hept-5-ulofuranurononitrile **1** was then treated with benzamidinium chloride in methanol in the presence of sodium methanolate (3 h, 20 °C) resulting in the formation of the corresponding pyrimidine **2b** in 82% yield. In accordance with the pyrimidine ring structure of compound **2b** the ^{13}C NMR spectrum showed the expected signals for C-4 ($\delta = 168.5$), C-2 ($\delta = 164.8$), C-6 ($\delta = 161.5$), and C-5 ($\delta = 106.5$) clearly indicating the presence of the heterocyclic ring. In the IR spectrum, a CN band appeared at 2229 cm^{-1}. Furthermore, compound **2b** was subjected to X-ray crystal structure analysis at 293 K. An ORTEP drawing of **2b** is shown in Fig. 2, which also displays the numbering scheme of the atoms.

Guanidines have been reacted with enaminoketones to form different pyrimidine derivatives representing a class of compounds which exhibits *anti*-inflammatory and *anti*-tumor activities [19–23]. Treatment of enaminoketone **1** with guanidinium chloride and sodium methanolate in methanol furnished the desired 'reversed' aminopyrimidine-*C*-nucleoside **2c** in 45% yield. Additionally, beside cyclization the elimina-

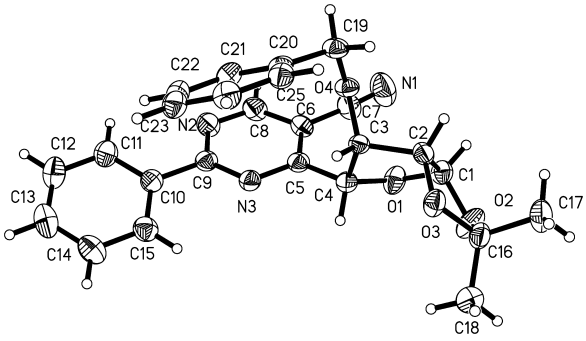
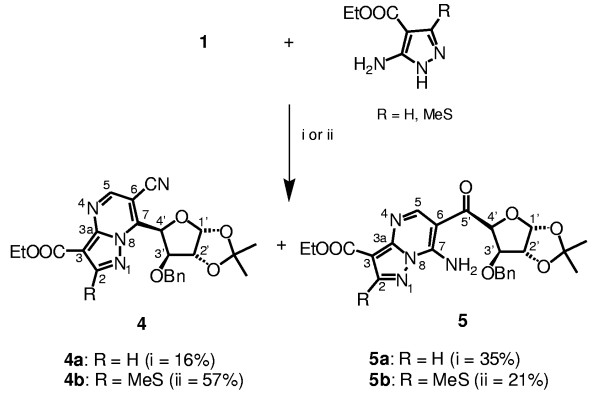


Fig. 2. ORTEP drawing of pyrimidine **2b**.



Scheme 2. (i) LiHMDS, THF, 0 °C; (ii) NaH, THF, 0 – 22 °C.

tion of benzyl alcohol occurred caused by the strong basic reaction conditions. The corresponding 3',4'-unsaturated nucleoside **3c** was isolated in 18% yield.

The reaction of *S*-methylisothiouronium sulfate with the enaminoketone **1** in methanol utilizing sodium methanolate as a base at room temperature yielded the expected 'reversed' pyrimidine-*C*-nucleoside **2d** in 65% yield. The EI-MS spectrum contained the molecular ion peak at *m/z* 399. In the IR spectrum a CN band appeared at 2229 cm^{-1}. The signals for C-2 ($\delta = 175.3$), C-4 ($\delta = 168.0$), C-6 ($\delta = 160.7$), and C-5 ($\delta = 103.6$) in the ^{13}C NMR spectrum were in concordance with the values expected for a pyrimidine structure.

Treatment of **1** with ethyl 5-aminopyrazole-4-carboxylate in the presence of LiHMDS in THF at 0 °C yielded after chromatographic separation ethyl 7-(3-*O*-benzyl-1,2-*O*-isopropylidene-α-D-*xylo*-tetrofuranos-4-yl)pyrazolo[1,5-*a*]pyrimidine-3-carboxylate (**4a**, 16%) and ethyl 7-amino-6-(3-*O*-benzyl-1,2-*O*-isopropylidene-α-D-*xylo*-pentofuranuronoyl)-6-cyanopyrazolo[1,5-*a*]pyrimidine-3-carboxylate (**5a**, 35%), respectively (Scheme 2).

In the ^{1}H NMR and ^{13}C NMR spectra of compound **4a** no signals for the dimethylamino group could be detected. The signal for the keto group was absent from the ^{13}C NMR spectrum. Furthermore, signals for an estercarbonyl and a cyano group appeared at $\delta = 161.6$ and 113.8, respectively. The cyano group was also confirmed by the IR spectrum ($\nu = 2234\ cm^{-1}$). These results proved a heterocyclization through an attack of aminopyrazole at C-1' and C-5 of compound **1**.

The mass spectrum of pyrazolo[1,5-*a*]pyrimidine-3-carboxylate **5a** displayed a molecular ion peak at *m/z* 482. On the other hand, NMR data confirmed the existence of a keto ($\delta = 192.6$) and an estercarbonyl group ($\delta = 162.2$), but no signals of cyano and dimethylamino group were present. Evidently, the cyclization had proceeded under participation of the nitrile group. Absorption of the resulting amino function appeared in the IR spectrum at $\nu = 3283$ and $\nu = 3387\ cm^{-1}$.

Similarly, **1** was reacted with ethyl 5-amino-3-methylsulfanylpyrazole-4-carboxylate in the presence of NaH in THF at 0 – 22 °C. After column chromatography the compounds **4b** (57%) and **5b** (21%) were isolated. The absence of a carbonyl signal in the ^{13}C NMR spectrum of **4b** indicated cyclization with involvement of the carbonyl group. In contrast to compound **4b**, in the ^{13}C NMR spectrum of the pyrazolo[1,5-*a*]pyrimidine-3-carboxylate **5b** a carbonyl signal appeared at $\delta = 192.2$ (IR: $\nu = 1589\ cm^{-1}$), but no nitrile group could be identified in the ^{13}C NMR and IR spectra.

Finally, the crystalline compound **4b** was subjected to X-ray crystal structure analysis at 293 K. The ORTEP drawing (Fig. 3) clearly demonstrates that cyclization had occurred by an attack of N-1 of the 5-amino-3-methylsulfanylpyrazole-4-carboxylate on the carbonyl function and of the 5-amino group on the C-1' of the 'push-pull' functionalized α-D-*xylo*-hept-5-ulofuranurononitrile **1**. Therefore, it can be assumed that the ethyl 5-aminopyrazole-4-carboxylate reacted in the same way with compound **1** to yield **4a**. Furthermore, it is very probable that the direction of cyclization to furnish **5a**, **b** ocurred in a similar way under substitution of the dimethylamino group by the amino group of the aminopyrazole and subsequent ring closure through its N-1 and the cyano group of **1**.

To synthesize another 'reversed' C-nucleoside derivative having an anellated heterocyclic system, the α-D-*xylo*-hept-5-ulofuranurononitrile **1** and (2-benzimidazolyl)acetonitrile [24] were reacted in refluxing

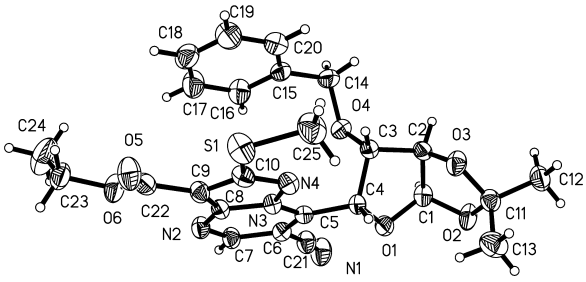
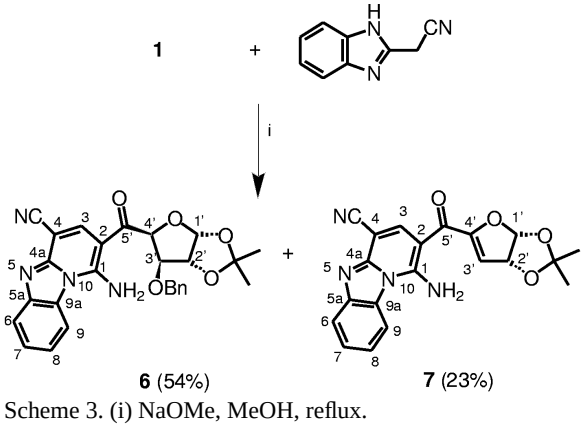


Fig. 3. ORTEP drawing of ethyl pyrazolo[1,5-*a*]pyrimidine-3-carboxylate **4b**.



Scheme 3. (i) NaOMe, MeOH, reflux.

methanol with sodium methanolate as base. After the completion of the reaction 1-amino-2-(3-*O*-benzyl-1,2-*O*-isopropylidene-α-D-*xylo*-pentofuranuronoyl) benzo[4,5]imidazo[1,2-*a*]pyridine-4-carbonitrile (**6**) and 1-amino-2-(3-desoxy-1,2-*O*-isopropylidene-α-D-*glycero*-pent-3-enofuranuronoyl)benzo[4,5]imidazo[1,2-*a*]pyridine-4-carbonitrile (**7**) were isolated by column chromatography (Scheme 3). Both compounds resulted from the cyclization at the nitrile group caused possibly by the bulkiness of the nucleophile.

The structures **6** and **7** were proven by IR, NMR and mass spectroscopy. So, the EI-MS spectrum of compound **6** supplied the molecular peak at *m/z* 484 and the IR spectrum showed the expected NH_2 bands ($\nu = 3439\ cm^{-1}$ and $\nu = 3333\ cm^{-1}$) as well as a nitrile band at $\nu = 2224\ cm^{-1}$ and a carbonyl band at $\nu = 1581\ cm^{-1}$, respectively. Also the appearance of a cyano signal at $\delta = 115.6$ and a carbonyl signal at $\delta = 191.4$ in the ^{13}C NMR spectrum confirmed the cyclization involving the nitrile group of compound **1**. The spectroscopic data of compound **7** clearly indicated the elimination of benzyl alcohol from the furanose ring. Due to the formation of the double bond in the furanose ring, the 3'-H signal was shifted downfield to $\delta = 6.00$ and the signal for 2'-H at $\delta = 5.52$ appearing as doublet of a doublet in the ^1H NMR spectrum.

Experimental Section

General procedures

Melting points were determined with a Boëtius melting point apparatus and are corrected. Optical rotations were measured with a Gyromat-HP (Dr. Kernchen Ltd.) polarimeter. IR spectra were recorded with a Nicolet 205 FT-IR spectrometer. ^1H and ^{13}C NMR spectra were recorded with Bruker spectrometers AC 250 (250.1 MHz and 62.9 MHz, respectively) and ARX 300 (300.1 MHz and 75.5 MHz, respectively), with $CDCl_3$ (compounds **3c** and **7** with [D_6]-DMSO) as solvent. The calibration of spectra was carried out on solvent signals ($CDCl_3$: $\delta(^1H) = 7.25$; $\delta(^{13}C) = 77.0$; [D_6]-DMSO: $\delta(^1H) = 2.50$; $\delta(^{13}C) = 39.7$). Mass spectra were obtained with an AMD 402/3 spectrometer (AMD Intectra GmbH). Elemental analyses were performed with a Leco CHNS-932 analyzer. Column chromatography was carried out on silica gel 60 (63 – 200 μm, Merck). Thin-layer chromatography (TLC) was performed on silica gel 60 GF_{254} foils (Merck) with detection by UV light and by charring with sulphuric acid. Solvents and liquid reagents were purified and dried according to recommended procedures.

*4-(3-O-Benzyl-1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-2-methylpyrimidine-5-carbonitrile (***2a***)*

Acetamidinium chloride (75.8 mg, 0.8 mmol) was added to a solution of sodium (18 mg, 0.8 mmol) in methanol (1 ml). The mixture was stirred for 20 min and then added under stirring to a solution of **1** (100 mg, 0.26 mmol) in methanol (2 ml) and stirring was continued for 12 h at room temperature. After completion of the reaction (TLC control) the solvent was evaporated *in vacuo* and the residue purified by column chromatography (toluene/EtOAc 8:2) to obtain **2a** as a colorless syrup. Yield 36.5 mg (37%). – $R_f = 0.51$ (toluene/EtOAc 8:2). – $[\alpha]_D^{22} = -71.8$ (*c* 0.5, $CHCl_3$). – IR (capillary): ν (cm^{-1}) = 2232 (CN). – ^1H NMR (250.1 MHz, $CDCl_3$): $\delta = 1.37$, 1.52 (2s, 6H, CMe_2), 2.70 (s, 3H, 2-Me), 4.22 (d, 1H, $J_{CH(a),CH(b)} = 12.5$ Hz, CH*H*Ph), 4.34 (d, 1H, $J_{3',4'} = 3.9$ Hz, 3'-H), 4.53 (d, 1H, $J_{CH(a),CH(b)} = 12.5$ Hz, C*H*HPh), 4.73 (d, 1H, $J_{1',2'} = 3.5$ Hz, 2'-H), 5.39 (d, 1H, $J_{3',4'} = 3.9$ Hz, 4'-H), 6.28 (d, 1H, $J_{1',2'} = 3.5$ Hz, 1'-H), 6.85 – 6.90 (m, 2H, Ph), 7.17 – 7.22 (m, 3H, Ph), 8.80 (s, 1H, 6-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 26.3$ (2-Me), 26.5, 27.2 ($C(CH_3)_2$), 72.2 (CH_2Ph), 82.7, 83.3, 83.6 (C-2', C-3', C-4'), 106.2 (C-5), 106.3 (C-1'), 113.0 (CMe_2), 114.7 (CN), 127.4, 128.0, 128.3 (Ph), 136.5 (*i*-Ph), 161.0 (C-6), 168.0 (C-4), 169.7 (C-2). – MS (EI): *m/z* (%) = 367 $[M]^+$. – $C_{20}H_{21}N_3O_4$ (367.40): calcd. C 65.38, H 5.76, N 11.44; found C 65.21, H 5.81, N 11.39.

*4-(1,2-O-Isopropylidene-α-D-glycero-tetr-3-enofuranos-4-yl)-2-methylpyrimidine-5-carbonitrile (***3a***)*

Acetamidinium chloride (75.8 mg, 0.8 mmol) was added to the solution of **1** (100 mg, 0.26 mmol) and triethylamine (0.11 ml, 0.8 mmol) in DMF (2 ml). The resulting mixture was stirred for 5 h at 80 °C. After completion of the reaction (TLC control) the solvent was evaporated *in vacuo* and the residue purified by column chromatography (toluene/EtOAc 8:2) to furnish the crystalline compound **3a**. Yield 42 mg (60%); colorless crystals. – M. p. 186 °C. – $R_f = 0.48$ (toluene/EtOAc 8:2). – $[\alpha]_D^{21} = -65.9$ (c 1.0, $CHCl_3$). – IR (capillary): ν (cm^{-1}) = 2186 (CN). – ^1H NMR (250.1 MHz, $CDCl_3$): $\delta = 1.43$, 1.45 (2s, 6H, CMe_2), 2.79 (s, 3H, 2-Me), 5.46 (dd, 1H, $J_{1',2'} = 5.5$ Hz, $J_{2',3'} = 2.8$ Hz, 2'-H), 6.30 (d, 1H, $J_{1',2'} = 5.5$ Hz, 1'-H), 6.49 (d, 1H, $J_{2',3'} = 2.8$ Hz, 3'-H), 8.90 (s, 1H, 6-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 26.5$, 27.6 ($C(CH_3)_2$), 28.0 (2-Me), 82.7 (C-2'), 102.3 (C-5), 106.7 (C-1'), 109.2 (C-3'), 113.1 ($C(CH_3)_2$), 114.7 (CN), 156.0 (C-4'), 154.3 (C-4), 162.0 (C-6), 170.7 (C-2). – MS (EI): *m/z* (%) = 259 $[M]^+$. – $C_{13}H_{13}N_3O_3$ (259.26): calcd. C 60.23, H 5.05, N 16.21; found C 60.08, H 5.07, N 15.83.

*4-(1,2-O-Isopropylidene-α-D-glycero-tetr-3-enofuranos-4-yl)pyrimidine-5-carbonitrile (***3b***)*

Formamidinium acetate (83.2 mg, 0.8 mmol) was added to the solution of **1** (100 mg, 0.26 mmol) and triethylamine (0.11 ml, 0.8 mmol) in DMF (2 ml). The resulting mixture was stirred for 3 h at 80 °C. After completion of the reaction (TLC control) the solvent was evaporated in vacuum and the residue purified by column chromatography (toluene/EtOAc 8:2) to furnish the crystalline compound **3b**. Yield 20 mg (30%, colorless syrup). – $R_f = 0.49$ (toluene/ethyl acetate 8:2). – $[\alpha]_D^{21} = -165.9$ (c 1.0, $CHCl_3$). – IR (capillary): ν (cm^{-1}) = 2180 (CN). – ^1H NMR (250.1 MHz, $CDCl_3$): $\delta = 1.45$, 1.47 (2s, 6H, CMe_2), 5.48 (dd, 1H, $J_{1',2'} = 5.5$ Hz, $J_{2',3'} = 2.8$ Hz, 2'-H), 6.33 (d, 1H, $J_{1',2'} = 5.5$ Hz, 1'-H), 6.55 (d, 1H, $J_{2',3'} = 2.8$ Hz, 3'-H), 9.03 (s, 1H, 6-H), 9.31 (s, 1H, 2-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 27.7$, 28.0 ($C(CH_3)_2$), 82.7 (C-2'), 105.4 (C-5), 106.9 (C-1'), 109.9 (C-3'), 113.3 ($C(CH_3)_2$), 114.1 (CN), 154.2 (C-4), 156.1 (C-4'), 160.0, 162.0 (C-2, C-6). – MS(EI): m/z (%) = 245 $[M]^+$. – $C_{12}H_{11}N_3O_3$ (245.24): calcd. C 58.77, H 4.52, N 17.13; found C 58.58, H 5.07, N 16.83.

4-(3-O-Benzyl-1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-2-phenylpyrimidine-5-carbonitrile (**2b**)

Benzamidinium chloride (81 mg, 0.52 mmol) was added to a solution of sodium (12 mg, 0.52 mmol) in methanol (1 ml). The mixture was stirred for 20 min and then added under stirring to a solution of **1** (100 mg, 0.26 mmol) in methanol (2 ml). After stirring of the resulting mixture for 3 h at r. t. the precipitate was filtered and recrystallized from ethyl acetate. Yield: 95 mg (82%, colorless crystals). – M.p. 182 °C. – $R_f = 0.48$ (toluene/ethyl acetate 9:1). – $[\alpha]_D^{22} = -180.9$ (c 0.2, $CHCl_3$). – IR (capillary): ν (cm^{-1}) = 2229 (CN). – ^1H NMR (250.1 MHz, $CDCl_3$): $\delta = 1.40$, 1.57 (2s, 6H, CMe_2), 4.24 (d, 1H, $J_{CH(a),CH(b)} = 12.4$ Hz, CH*H*Ph), 4.41 (d, 1H, $J_{3',4'} = 4.0$ Hz, 3'-H), 4.53 (d, 1H, $J_{CH(a),CH(b)} = 12.4$ Hz, C*H*HPh), 4.76 (d, 1H, $J_{1',2'} = 3.5$ Hz, 2'-H), 5.52 (d, 1H, $J_{3',4'} = 4.0$ Hz, 4'-H), 6.33 (d, 1H, $J_{1',2'} = 3.5$ Hz, 1'-H), 6.83 – 6.90 (m, 2H, CH_2*Ph*), 7.08 – 7.03 (m, 3H, CH_2*Ph*), 7.46 – 7.58 (m, 3H, 2-Ph), 8.39 – 8.44 (m, 2H, 2-Ph), 8.94 (s, 1H, 6-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 26.5$, 27.3 ($C(CH_3)_2$), 72.2 (CH_2Ph), 82.7, 83.3, 84.0 (C-2', C-3', C-4'), 106.3 (C-1'), 106.5 (C-5), 113.0 ($C(CH_3)_2$), 115.1 (CN), 127.2, 128.3, 128.7, 129.1 (*o*-, *m*-2-Ph, *o*-, *m*-CH_2Ph), 127.8 (*p*-CH_2Ph), 132.2 (*p*-2-Ph), 135.6 (*i*-2-Ph), 136.4 (*i*-CH_2Ph), 161.5 (C-6), 164.8 (C-2), 168.5 (C-4). – MS(EI): m/z (%) = 429 $[M]^+$. – $C_{25}H_{23}N_3O_4$ (429.47): calcd. C 69.92, H 5.40, N 9.78; found C 69.78, H 5.51, N 9.54.

2-Amino-4-(3-O-benzyl-1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)pyrimidine-5-carbonitrile (**2c**) *and 2-amino-4-(1,2-O-isopropylidene-α-D-glycero-tetr-3-enofuranos-4-yl) pyrimidine-5-carbonitrile* (**3c**)

Guanidinium chloride (37.8 mg, 0.4 mmol) was added to a solution of sodium (9.5 mg, 0.4 mmol) in methanol (1 ml). The mixture was stirred for 20 min and then added under stirring to a solution of **1** (100 mg, 0.26 mmol) in methanol (2 ml) and stirring was continued for 2 h at r. t. After completion of the reaction (TLC control) the solvent was evaporated *in vacuo* and the residue purified by column chromatography (toluene/EtOAc 7:3) to obtain **2c** and **3c**.

2c: Yield 44 mg (45%, colorless syrup). – $R_f = 0.55$ (toluene/EtOAc 7:3). – $[\alpha]_D^{22} = -86.6$ (c 1.0, $CHCl_3$). – IR (capillary): ν (cm^{-1}) = 2221 (CN), 3324, 3200 (NH_2). – ^1H NMR (250.1 MHz, $CDCl_3$): $\delta = 1.35$, 1.51 (2s, 6H, CMe_2), 4.30 (d, 1H, $J_{CH(a),CH(b)} = 12.2$ Hz, CH*H*Ph), 4.37 (d, 1H, $J_{3',4'} = 3.7$ Hz, 3'-H), 4.56 (d, 1H, $J_{CH(a),CH(b)} = 12.2$ Hz, C*H*HPh), 4.69 (d, 1H, $J_{1',2'} = 3.7$ Hz, 2'-H), 5.27 (d, 1H, $J_{3',4'} = 3.7$ Hz, 4'-H), 5.88 (br s, 2H, NH_2), 6.21 (d, 1H, $J_{1',2'} = 3.7$ Hz, 1'-*H*), 6.98 – 7.02 (m, 2H, Ph), 7.21 – 7.26 (m, 3H, Ph), 8.40 (s, 1H, 6-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 26.5$, 27.1 ($C(CH_3)_2$), 72.3 (CH_2Ph), 82.4 (C-4'), 82.7 (C-2'), 83.2 (C-3'), 96.9 (C-5), 105.9 (C-1'), 112.8 ($C(CH_3)_2$), 115.7 (CN), 127.6, 128.0, 128.5 (Ph), 136.7 (*i*-Ph), 162.3, 169.5 (C-2, C-4), 162.6 (C-6). – MS(EI): m/z (%) = 368 $[M]^+$. – $C_{19}H_{20}N_4O_4$ (368.39): calcd. C 61.95, H 5.47, N 15.21; found C 61.87, H 5.51, N 15.39.

3c: Yield 13 mg (18%, yellow amorphous solid). – $R_f = 0.51$ (toluene/EtOAc 7:3). – $[\alpha]_D^{22} = -15.9$ (c 1.0, MeOH).

– ^{1}H NMR (250.1 MHz, [D$_6$]-DMSO): $\delta = 1.37$, 1.39 (2s, 6H, CMe$_2$), 5.50 (dd, 1H, $J_{1',2'} = 5.5$ Hz, $J_{2',3'} = 2.6$ Hz, 2'-H), 6.19 (d, 1H, $J_{2',3'} = 2.6$ Hz, 3'-H), 6.33 (d, 1H, $J_{1',2'} = 5.5$ Hz, 1'-H), 7.90 (2br s, 2H, NH$_2$), 8.69 (s, 1H, 6-H). – ^{13}C NMR (62.9 MHz, [D$_6$]-DMSO): $\delta = 27.7$, 28.1 (C(*C*H$_3$)$_2$), 82.6 (C-2'), 91.8 (C-5), 106.3 (C-1'), 107.4 (C-3'), 112.1 (*C*(CH$_3$)$_2$), 116.9 (CN), 154.7 (C-4), 157.4 (C-4'), 163.2 (C-2), 164.5 (C-6). – MS(EI): $m/z\,(\%) = 260$ [M]$^+$. – C$_{12}$H$_{12}$N$_4$O$_3$ (260.251): calcd. C 55.38, H 4.65, N 21.53; found C 55.45, H 4.81, N 21.01.

4-(3-O-Benzyl-1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-2-methylsulfanyl-pyrimidine-5-carbonitrile (**2d**)

S-Methylisothiouronium sulfate (222 mg, 0.8 mmol) was added to a solution of sodium (18 mg, 0.8 mmol) in methanol (1 ml). The mixture was stirred for 20 min and then added under stirring to a solution of **1** (100 mg, 0.26 mmol) in methanol (2 ml). The resulting mixture was stirred for 5 h at r.t. After completion of the reaction (TLC control) the solvent was evaporated *in vacuo* and the residue purified by column chromatography (toluene/EtOAc 8:2) to obtain **2d**. Yield: 70 mg (65%, colorless syrup). – $R_f = 0.51$ (toluene/EtOAc 8:2). – $[\alpha]^{22}_{D} = -181.5$ (*c* 1.0, CHCl$_3$). – IR (capillary): ν (cm^{-1}) = 2229 (CN). – ^{1}H NMR (250.1 MHz, CDCl$_3$): $\delta = 1.36$, 1.51 (2s, 6H, CMe$_2$), 2.47 (s, 3H, SMe), 4.24 (d, 1H, $J_{CH(a),CH(b)} = 12.5$ Hz, CH*H*Ph), 4.30 (d, 1H, $J_{3',4'} = 4.0$ Hz, 3'-H), 4.55 (d, 1H, $J_{CH(a),CH(b)} = 12.5$ Hz, C*H*HPh), 4.71 (d, 1H, $J_{1',2'} = 3.5$ Hz, 2'-H), 5.32 (d, 1H, $J_{3',4'} = 4.0$ Hz, 4'-H), 6.26 (d, 1H, $J_{1',2'} = 3.5$ Hz, 1'-H), 6.90 – 6.95 (m, 2H, Ph), 7.20 – 7.25 (m, 3H, Ph), 8.63 (s, 1H, 6-H). – ^{13}C NMR (62.9 MHz, CDCl$_3$): $\delta = 14.3$ (SMe), 26.5, 27.2 (C(*C*H$_3$)$_2$), 72.2 (*C*H$_2$Ph), 82.6, 83.2, 83.6 (C-2', C-3', C-4'), 103.6 (C-5), 106.3 (C-1'), 113.0 (*C*(CH$_3$)$_2$), 115.0 (CN), 127.4, 128.0, 128.4 (Ph), 136.5 (*i*-Ph), 160.7 (C-6), 168.0 (C-4), 175.3 (C-2). – MS(EI): $m/z\,(\%) = 399$ [M]$^+$. – C$_{20}$H$_{21}$N$_3$O$_4$S (399.46): calcd. C 60.14, H 5.30, N 10.52, S 8.03; found C 60.21, H 5.41, N 10.49, S 8.05.

Ethyl 7-(3-O-benzyl-1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-6-cyano-pyrazolo[1,5-a]pyrimidine-3-carboxylate (**4a**) *and ethyl 7-amino-6-(3-O-benzyl-1,2-O-isopropylidene-α-D-xylo-pentofuranuronoyl)pyrazolo[1,5-a]pyrimidine-3-carboxylate* (**5a**)

To a vigorously stirred solution of **1** (100 mg, 0.26 mmol) and ethyl 5-amino-1*H*-pyrazole-4-carboxylate (61.5 mg, 0.4 mmol) in anhyd THF (5 ml) LiHMDS (0.7 ml, 0.8 mmol) was added at 0 °C. The resulting mixture was stirred for 4.5 h at 0 °C. After completion of the reaction (TLC control) the resulting solution was diluted with water (25 ml) and extracted with chloroform (3 × 25 ml). The combined organic layers were dried over Na$_2$SO$_4$, filtered, evaporated under reduced pressure and the residue obtained was purified by column chromatography (toluene/EtOAc 7:3) to furnish **4a** and **5a**.

4a: Yield 20 mg (16%, colorless syrup). – $R_f = 0.55$ (toluene/EtOAc 9:1). – $[\alpha]^{22}_{D} = -161.4$ (*c* 1.0, CHCl$_3$). – IR (capillary): ν (cm^{-1}) = 1618 (COOEt), 2234 (CN). – ^{1}H NMR (250.1 MHz, CDCl$_3$): $\delta = 1.41$, 1.57 (2s, 6H, CMe$_2$), 1.44 (t, 3H, $J_{CH2,CH3} = 7.0$ Hz, CH$_2$C*H*$_3$), 4.07 (d, 1H, $J_{CH(a),CH(b)} = 12.3$ Hz, CH*H*Ph), 4.44 (d, 1H, $J_{CH(a),CH(b)} = 12.3$ Hz, C*H*HPh), 4.47 (q, 2H, C*H*$_2$CH$_3$), 4.68 (d, 1H, $J_{3',4'} = 4.0$ Hz, 3'-H), 4.75 (d, 1H, $J_{1',2'} = 3.3$ Hz, 2'-H), 6.17 (d, 1H, $J_{3',4'} = 4.0$ Hz, 4'-H), 6.33 (d, 1H, $J_{1',2'} = 3.3$ Hz, 1'-H), 6.61 – 6.66 (m, 2H, Ph), 7.00 – 7.14 (m, 3H, Ph), 8.40 (s, 1H, 2-H), 8.80 (s, 1H, 5-H). – ^{13}C NMR (62.9 MHz, CDCl$_3$): $\delta = 14.5$ (CH$_2$*C*H$_3$), 26.5, 27.4 (C(*C*H$_3$)$_2$), 60.9 (*C*H$_2$CH$_3$), 72.4 (*C*H$_2$Ph), 78.4 (C-4'), 81.4 (C-3'), 82.6 (C-2'), 97.1 (C-6), 105.0 (C-3), 106.2 (C-1'), 113.6 (*C*(CH$_3$)$_2$), 113.8 (CN), 127.3, 128.1, 128.4 (Ph), 135.8 (*i*-Ph), 146.7 (C-7), 149.1 (C-2), 151.8 (C-3a), 153.2 (C-5), 161.6 (COO). – MS (EI): $m/z\,(\%) = 464$ [M]$^+$. – C$_{24}$H$_{24}$N$_4$O$_6$ (464.47): calcd. C 62.06, H 5.21, N 12.06; found C 62.12, H 5.23, N 11.97.

5a: Yield 45 mg (35%, yellow syrup). – $R_f = 0.54$ (toluene/EtOAc 7:3). – $[\alpha]^{22}_{D} = -37.4$ (*c* 1.0, CHCl$_3$). – IR (capillary): ν (cm^{-1}) = 1589 (COOEt), 1675 (CO), 3283, 3387 (NH$_2$). – ^{1}H NMR (250.1 MHz, CDCl$_3$): $\delta = 1.35$, 1.51 (2s, 6H, CMe$_2$), 1.40 (t, 3H, $J_{CH2,CH3} = 7.1$ Hz, CH$_2$C*H*$_3$), 4.24 (d, 1H, $J_{CH(a),CH(b)} = 12.3$ Hz, CH*H*Ph), 4.36 (d, 1H, $J_{3',4'} = 3.8$ Hz, 3'-H), 4.43 (q, 2H, $J_{CH2,CH3} = 7.1$ Hz, C*H*$_2$CH$_3$), 4.56 (d, 1H, $J_{CH(a),CH(b)} = 12.3$ Hz, C*H*HPh), 4.66 (d, 1H, $J_{1',2'} = 3.6$ Hz, 2'-H), 5.39 (d, 1H, $J_{3',4'} = 3.8$ Hz, 4'-H), 6.17 (d, 1H, $J_{1',2'} = 3.6$ Hz, 1'-H), 6.89 – 7.00 (m, 5H, Ph), 7.36 (br, 1H, NH$_2$), 8.49 (s, 1H, 2-H), 8.96 (s, 1H, 5-H), 9.45 (br, 1H, NH$_2$). – ^{13}C NMR (62.9 MHz, CDCl$_3$): $\delta = 14.5$ (CH$_2$*C*H$_3$), 26.3, 26.9 (C(*C*H$_3$)$_2$), 60.5 (*C*H$_2$CH$_3$), 72.1 (*C*H$_2$Ph), 82.1 (C-4'), 83.3 (C-2'), 83.3 (C-3'), 100.2, 104.3 (C-3, C-6), 105.5 (C-1'), 112.5 (*C*(CH$_3$)$_2$), 127.8, 127.8, 128.0 (Ph), 136.1 (*i*-Ph), 147.6, 149.0 (C-3a, C-7), 148.2 (C-2), 152.8 (C-5), 162.2 (COO), 192.6 (CO). – MS (EI): $m/z\,(\%) = 482$ [M]$^+$. – C$_{24}$H$_{26}$N$_4$O$_7$ (482.47): calcd. C 59.75, H 5.43, N 11.61; found C 59.82, H 5.51, N 11.47.

Ethyl 7-(3-O-benzyl-1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-6-cyano-2-methylsulfanylpyrazolo[1,5-a]pyrimidine-3-carboxylate (**4b**) *and ethyl 7-amino-6-(3-O-benzyl-1,2-O-isopropylidene-α-D-xylo-pentofuranuronoyl)-2-methylsulfanylpyrazolo[1,5-a]pyrimidine-3-carboxylate* (**5b**)

To a vigorously stirred solution of **1** (100 mg, 0.26 mmol) and ethyl 5-amino-3-methylsulfanyl-1*H*-pyrazole-4-carboxylate (106 mg, 0.53 mmol) in anhyd THF (5 ml) NaH (22.7 mg, 0.57 mmol, 60% in mineral oil) was added at 0 °C. The resulting mixture was stirred for 2 h at 0 °C. After completion of the reaction (TLC control) the resulting solution was diluted with water (25 ml) and extracted with

chloroform (3 × 25 ml). Then the combined organic layers were dried over Na_2SO_4, filtered and evaporated under reduced pressure. The residue obtained was purified by column chromatography (toluene/EtOAc 7:3) to furnish **4b** and **5b**.

4b: Yield 78 mg (57%, colorless crystals). – $R_f = 0.49$ (toluene/EtOAc 9:1). – $[\alpha]_D^{24} = -383.8$ (*c* 1.0, $CHCl_3$). – IR (capillary): ν (cm^{-1}) = 1689 (COOEt), 2229 (CN). – ^{1}H NMR (250.1 MHz, $CDCl_3$): $\delta = 1.38$, 1.52 (2s, 6H, CMe_2), 1.42 (t, 3H, $J_{CH2,CH3} = 7.0$ Hz, CH_2CH_3), 2.28 (s, 3H, SMe), 4.08 (d, 1H, $J_{CH(a),CH(b)} = 12.3$ Hz, CH*H*Ph), 4.45 (q, 2H, $J_{CH2,CH3} = 7.0$ Hz, CH_2CH_3), 4.45 (d, 2H, $J_{CH(a),CH(b)} = 12.3$ Hz, C*H*HPh), 4.54 (d, 1H, $J_{3',4'} = 4.0$ Hz, 3'-H), 4.74 (d, 1H, $J_{1',2'} = 3.3$ Hz, 2'-H), 6.01 (d, 1H, $J_{3',4'} = 4.0$ Hz, 4'-H), 6.29 (d, 1H, $J_{1',2'} = 3.3$ Hz, 1'-H), 6.55 – 6.61 (m, 2H, Ph), 6.97 – 7.14 (m, 3H, Ph), 8.70 (s, 1H, 5-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 13.2$ (SMe), 14.4 (CH_2CH_3), 26.4, 27.3 ($C(CH_3)_2$), 60.8 (CH_2CH_3), 71.9 (CH_2Ph), 78.2 (C-4'), 80.0 (C-3'), 82.2 (C-2'), 95.6 (C-6), 101.5 (C-3), 106.1 (C-1'), 113.4 ($C(CH_3)_2$), 114.0 (CN), 127.4, 128.1, 128.2 (Ph), 135.5 (*i*-Ph), 148.0, 149.6 (C-3a, C-7), 153.1 (C-5), 161.9 (C-2), 162.6 (COO). – MS (EI): m/z (%) = 510 $[M]^+$. – $C_{25}H_{26}N_4O_6S$ (510.56): calcd. C 58.81, H 5.13, N 10.97, S 6.28; found C 59.12, H 5.23, N 10.77, S 7.09.

5b: Yield 30 mg (21%, yellow syrup). – $R_f = 0.53$ (toluene/EtOAc 7:3). – $[\alpha]_D^{23} = -4.7$ (*c* 1.0, $CHCl_3$). – IR (capillary): ν (cm^{-1}) = 1580 (CO), 1671 (COOEt), 3293, 3440 (NH_2). – ^{1}H NMR (250.1 MHz, $CDCl_3$): $\delta = 1.34$, 1.50 (2s, 6H, CMe_2), 1.42 (t, 3H, $J_{CH2,CH3} = 7.1$ Hz, CH_2CH_3), 2.60 (s, 3H, SMe), 4.24 (d, 1H, $J_{CH(a),CH(b)} = 12.3$ Hz, CH*H*Ph), 4.34 (d, 1H, $J_{3',4'} = 3.8$ Hz, 3'-H), 4.45 (q, 2H, $J_{CH2,CH3} = 7.1$ Hz, CH_2CH_3), 4.55 (d, 1H, $J_{CH(a),CH(b)} = 12.3$ Hz, C*H*HPh), 4.66 (d, 1H, $J_{1',2'} = 3.6$ Hz, 2'-H), 5.38 (d, 1H, $J_{3',4'} = 3.8$ Hz, 4'-H), 6.16 (d, 1H, $J_{1',2'} = 3.6$ Hz, 1'-H), 6.89 – 7.00 (m, 5H, Ph), 7.12 (br, 1H, NH_2), 8.86 (s, 1H, 5-H), 9.34 (br, 1H, NH_2). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 13.3$ (SMe), 14.5 (CH_2CH_3), 26.1, 26.7 ($C(CH_3)_2$), 60.4 (CH_2CH_3), 71.9 (CH_2Ph), 82.0 (C-4'), 83.0, 83.1 (C-2', C-3'), 100.0, 101.4 (C-3, C-6), 105.3 (C-1'), 112.3 ($C(CH_3)_2$), 127.7, 127.9, 128.0 (Ph), 136.0 (*i*-Ph), 147.3, 148.7 (C-3a, C-7), 152.6 (C-5), 160.8 (C-2), 162.5 (COO), 192.2 (CO). – MS (EI): m/z (%) = 528 $[M]^+$, – $C_{25}H_{28}N_4O_7S$ (528.58): HRMS calcd. 528.16785; found 528.16715.

1-Amino-2-(3-O-benzyl-1,2-O-isopropylidene-α-D-xylo-pentofuranuronoyl)benzo[4,5]imidazo[1,2-a]pyridine-4-carbonitrile (**6**) *and 1-amino-2-(1,2-O-isopropylidene-α-D-glycero-pent-3-eno-furanuronoyl)benzo[4,5]imidazo[1,2-a]pyridine-4-carbonitrile* (**7**)

A mixture of compound **1** (100 mg, 0.26 mmol), (2-benzimidazolyl)acetonitrile (63 mg, 0.4 mmol), sodium methanolate (22 mg, 0.4 mmol) and dry methanol (5 ml) was refluxed for 5 h. After completion of the reaction (TLC control) the solvent was evaporated *in vacuo* and the residue purified by column chromatography (toluene/EtOAc 8:2) to obtain **6** and **7**.

6: Yield 70 mg (54%, colorless syrup). – $R_f = 0.41$ (toluene/EtOAc 7:3). – $[\alpha]_D^{22} = +16.7$ (*c* 1.0, $CHCl_3$). – IR (capillary): ν (cm^{-1}) = 2224 (CN), 3439, 3433 (NH_2). – ^{1}H NMR (250.1 MHz, $CDCl_3$): $\delta = 1.40$, 1.59 (2s, 6H, CMe), 4.25 (d, 1H, $J_{CH(a),CH(b)}$ = 12.2 Hz, CH*H*Ph), 4.36 (d, 1H, $J_{3',4'} = 3.6$ Hz, 3'-H), 4.62 (d, 1H, $J_{CH(a),CH(b)} = 12.2$ Hz, C*H*HPh), 4.73 (d, 1H, $J_{1',2'} = 3.6$ Hz, 2'-H), 5.35 (d, 1H, $J_{3',4'} = 3.6$ Hz, 4'-H), 6.22 (d, 1H, $J_{1',2'} = 3.6$ Hz, 1'-H), 6.85 – 7.03 (m, 5H, Ph), 7.16 (m, 1H), 8.02 (m, 1H) (6-H, 9-H), 7.47 (dt, 1H), 7.62 (t, 1H) (7-H, 8-H), 8.04 (s, 1H, 3-H), 8.86 (br, 2H, NH_2). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 26.3$, 27.0 ($C(CH_3)_2$), 72.0 (CH_2Ph), 81.2 , 82.5, 83.1 (C-2', C-3', C-4'), 87.7 (C-4), 98.9 (C-2), 105.4 (C-1'), 112.7 ($C(CH_3)_2$), 113.1, 121.1 (C-6, C-9), 123.0, 127.1 (C-7, C-8), 115.6 (CN), 128.7 (C-9a), 128.0, 128.1, 128.2 (Ph), 135.8 (*i*-Ph), 138.1 (C-3), 145.2, 146.4, 152.5 (C-1, C-4a, C-5a), 191.4 (CO). – MS (EI): m/z (%) = 484 $[M]^+$. – $C_{27}H_{24}N_4O_5$ (484.51): calcd. C 66.93, H 4.99, N 11.56; found C 66.72, H 5.18, N 11.23.

7: Yield 23 mg (23%, colorless syrup). – $R_f = 0.50$ (ethyl acetate). – $[\alpha]_D^{25} = -28.8$ (*c* 1.0, $CHCl_3$). – ^{1}H NMR (250.1 MHz, $[D_6]$-DMSO): $\delta = 1.43$, 1.44 (2s, 6H, CMe_2), 5.52 (dd, 1H, $J_{1',2'} = 5.3$ Hz, $J_{2',3'} = 2.8$ Hz, 2'-H), 6.00 (d, 1H, $J_{2',3'} = 2.8$ Hz, 3'-H), 6.40 (d, 1H, $J_{1',2'} = 5.3$ Hz, 1'-H), 7.46 (m, 1H), 7.60 (t, 1H) (7-H, 8-H), 7.87 (dd, 1H), 8.50 (d, 1H) (6-H, 9-H), 8.58 (s, 1H, 3-H), 9.84 (NH_2). – ^{13}C NMR (62.9 MHz, $[D_6]$-DMSO): $\delta = 27.7$, 28.1 ($C(CH_3)_2$), 82.6 (C-2'), 85.7 (C-4), 99.6 (C-2), 106.8 (C-1'), 109.0 (C-3'), 112.1 ($C(CH_3)_2$), 115.0, 119.7 (C-6, C-9), 122.7, 126.8 (C-7, C-8), 116.6 (CN), 129.2 (C-9a), 141.6 (C-3), 144.7, 146.9, 153.4, 155.5 (C-1, C-4a, C-5a, C-4'), 182.8 (CO). – MS (EI): m/z (%) = 376 $[M]^+$. – $C_{20}H_{16}N_4O_4$ (376.37): calcd. C 63.83,H 4.28, N 14.89; found C 63.72, H 4.18, N 14.63.

X-ray crystal structure determinations

The data collections for **3a** and **2b** were performed on a Bruker X8Apex CCD diffractometer system with Mo-K_α radiation and a graphite monochromator with ϕ and ω-scans after checking the crystal quality by collecting reflections from 60 frames and determining a reasonable reduced cell. The data collection for **4b** was done on a Bruker P4 four circle diffractometer also with Mo-K_α radiation and a graphite monochromator in routine ω-scan after determining a reasonable reduced cell from 45 reflections. The structures were solved by direct methods (Bruker SHELXTL) and refined by the full matrix least-squares method of the Bruker SHELXTL software package. All non-hydrogen atoms were

refined anisotropically with the hydrogen atoms introduced into theoretical positions and refined according to the riding model. CCDC 267356, 267357 and 267358 contains the supplementary crystallographic data for compounds **3a**, **2b** and **4b**. These data can be obtained free of charge *via* www.ccdc.cam.ac.uk/conts/retrieving.html (or from the CCDC, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033; e-mail: deposit@ccdc.cam.ac.uk)

*X-ray structure determination of **3a***: Temperature 173(2) K; monoclinic space group $P2_1$; unit cell dimensions $a = 9.5224(3)$ Å, $b = 6.7378(2)$ Å, $c = 9.9150(3)$ Å, $\alpha = 90°$, $\beta = 103.707(1)°$, $\gamma = 90°$; volume 618.03(3) Å^3; $z = 2$; density (calculated) 1.393 Mg/m^3; absorption coefficient 0.102 mm-1; $F(000)$ = 272; crystal size $0.67 \times 0.44 \times 0.30$ mm^3; Θ range for data collection 3.40 to 25.00°; index ranges $-11 \leq h \leq 11$, $-8 \leq k \leq 8$, $-11 \leq l \leq 11$; reflections collected 13407; independent reflections 2147 [R(int) = 0.0207]; completeness to $\Theta = 25.00°$ 99.0%; absorption correction multiscan (min max transitions 0.9702 0.9351); data/restraints/parameters 2147 / 1 / 173; goodness-of-fit on $F^2 = 1.072$; final R indices $[I > 2\sigma(I)]$ $R1 = 0.0237$, $wR2 = 0.0627$; R indices (all data) $R1 = 0.0239$, $wR2 = 0.0627$; absolute structure parameter 0.1(8); largest diff. peak and hole 0.142 and -0.175 e/Å^3. The weighting scheme was calculated according to $w^{-1} = \sigma^2({F_o}^2) + (0.0633P)^2 + 0.1228P$ with $P = ({F_o}^2 + 2F_c^2)/3$.

*X-ray structure determination of **2b***: Temperature 293(2) K; monoclinic space group $P2_1$; unit cell dimensions $a = 11.568(5)$ Å, $b = 7.315(2)$ Å, $c = 13.485(5)$ Å, $\alpha = 90°$, $\beta = 101.810(10)°$, $\gamma = 90°$; volume 1116.9(7) Å^3; $z = 2$; density (calculated) 1.277 Mg/m^3; absorption coefficient 0.088 mm^{-1}; $F(000) = 452$; crystal size $0.6 \times 0.4 \times 0.3$ mm^3; Θ range for data collection 1.80 to 22.99°; index ranges $-12 \leq h \leq 12$, $-8 \leq k \leq 8$, $-14 \leq l \leq 14$; reflections collected 3538; independent reflections 3090 [R(int) = 0.0283]; completeness to $\Theta = 22.99°$ 99.7%; absorption correction none; data/restraints/parameters 3090 / 1 / 290; goodness-of-fit on $F^2 = 1.065$; final R indices $[I > 2\sigma(I)]R1 = 0.0362$, $wR2 = 0.0872$; R indices (all data) $R1 = 0.0419$, $wR2 = 0.0909$; absolute structure parameter $-0.5(12)$; extinction coefficient 0.031(4); largest diff. peak and hole 0.106 and -0.102 e/Å^3. The weighting scheme was calculated according to $w^{-1} = \sigma^2({F_o}^2) + (0.0633P)^2 + 0.1228P$ with $P = ({F_o}^2 + 2{F_c}^2)/3$.

*X-ray structure determination of **4b***: Temperature 293(2) K; monoclinic space group $P2_1$; unit cell dimensions $a = 7.493(2)$ Å, $b = 15.414(3)$ Å, $c = 11.296(2)$ Å, $\alpha = 90°$, $\beta = 99.63(2)°$, $\gamma = 90°$; volume 1286.3(5) Å^3; $z = 2$; density (calculated) 1.318 Mg/m^3; absorption coefficient 0.172 mm^{-1}; $F(000) = 536$; crystal size $0.6 \times 0.3 \times 0.06$ mm^3; Θ range for data collection 1.83 to 22.00°; index ranges $-7 \leq h \leq 7$, $-16 \leq k \leq 16$, $-11 \leq l \leq 11$; reflections collected 3564; independent reflections 3148[R(int) = 0.0329]; completeness to $\Theta = 22.00°$ 100.0%; refinement method full-matrix least-squares on F^2; data/restraints/parameters 3148 / 1 / 326; goodness-of-fit on $F^2 = 1.010$; final R indices $[I > 2\sigma(I)]R1 = 0.0411$, $wR2 = 0.0878$; R indices (all data) $R1 = 0.0646$, $wR2 = 0.1022$; absolute structure parameter 0.15(12); extinction coefficient 0.0102(11); largest diff. peak and hole 0.153 and -0.152 e/Å^3. The weighting scheme was calculated according to $w^{-1} = \sigma^2({F_o}^2) + (0.0633P)^2 + 0.1228P$ with $P = ({F_o}^2 + 2{F_c}^2)/3$.

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