Synthesis of 5,7-Disubstituted-4-β-D-ribofuranosylpyrazolo[4,3-*d*]-pyrimidines and 2,4-Disubstituted-1-β-D-ribofuranosylpyrrolo[3,2-*d*]-pyrimidines as Congeners of Uridine and Cytidine

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The synthesis of the congeners of uridine and cytidine in the pyrazolo[4,3-*d*]pyrimidine and pyrrolo[3,2-*d*]-pyrimidine ring system is described. Glycosylation of the trimethylsilyl (TMS) derivative of pyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,4*H*,6*H*)-dione (**4**) with either 1-bromo- or 1-*O*-acetyl-2,3,5-tri-*O*-benzoyl-D-ribofuranose **5** and **6**, respectively in the presence of a Lewis acid catalyst gave the protected nucleoside **7**, which on debenzoylation afforded the uridine analogue 4-β-D-ribofuranosylpyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,6*H*)-dione (**8**). Thiation of **7** gave **13**, which on deprotection yielded 4-β-D-ribofuranosyl-5-oxopyrazolo[4,3-*d*]pyrimidine-7(1*H*,-6*H*)-thione (**14**). Ammonolysis of **13** gave a low yield of the cytidine analogue **15**. A chlorination of **7**, followed by amination furnished an alternative route to **15**. A similar glycosylation of TMS-**4** with 2,3,5-tri-*O*-benzyl-α-D-arabinofuranosyl chloride (**16**) gave mainly the N4 glycosylated product **17**, which on debenzylation furnished 4-β-D-arabinofuranosylpyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,6*H*)-dione (**18**). 7-Amino-4-β-D-arabinofuranosylpyrazolo[4,3-*d*]pyrimidin-5(1*H*)-one (**23**) was prepared from **17** *via* the pyridinium chloride intermediate **21**. Condensation of the TMS derivative of pyrrolo[3,2-*d*]pyrimidine-2,4(1*H*,3*H*,5*H*)-dione (**24**) with **6**, followed by deprotection of the reaction product gave 1-β-D-ribofuranosylpyrrolo[3,2-*d*]pyrimidine-2,4(3*H*,5*H*)-dione (**26**). Similarly, TMS-**24** was reacted with **16** to give a mixture of the blocked nucleosides **31** and **32**, which on debenzylation afforded a mixture of two isomeric compounds **34** and **35**. 1-β-D-Arabinofuranosylpyrrolo[3,2-*d*]pyrimidine-2,4(3*H*,5*H*)-dione (**34**) was converted to the ara-C analogue **38** *via* the 3-nitrotriazolyl intermediate **36**. The structure of **38** was confirmed by single crystal X-ray diffraction studies.

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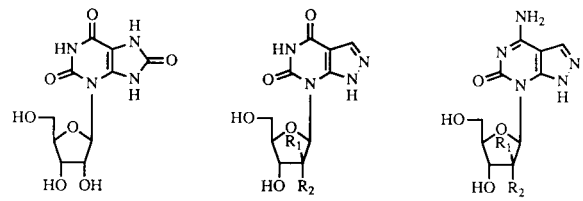
The isolation of 3-β-D-ribofuranosyluric acid (**1**) from bovine erythrocytes [1,2] and the interesting biological properties of synthetic 3-β-D-ribofuranosyladenine (isoadenosine) [3-6] stimulated our interest in 3-glycosylated purine derivatives, which we outlined in an earlier publication [7]. Isoadenosine has been found to inhibit the growth of various tumor cell lines, both *in vitro* and *in vivo*, as well as to show significant activity against adeno III virus in culture [5]. This interest has been further stimulated by the isolation of 7-β-D-ribofuranosylpyrazolo-[3,4-*d*]pyrimidine-4,6(1*H*,5*H*)-dione (oxoallopurinol ribofuranoside, **2a**) from the urine of patients treated with allopurinol [8], and possible involvement of the corresponding 5′-monophosphate in the inhibition of the *de novo* pyrimidine biosynthesis [9]. These observations prompted the synthesis and study of a number of other N3 glycosylated purine analogues in our [7,10] and other [11-15] laboratories.

In continuation of our investigations in this area, we recently reported [16] on the synthesis of several 4,6-disubstituted-7-β-D-ribofuranosyl- and arabinofuranosylpyrazolo[3,4-*d*]pyrimidines as congeners of uridine (**2**) and cytidine (**3**). We now describe the synthesis of 5,7-disubstituted-4-β-D-ribofuranosylpyrazolo[4,3-*d*]pyrimidines and

Figure 1



1 — 3-β-D-Ribofuranosyluric acid

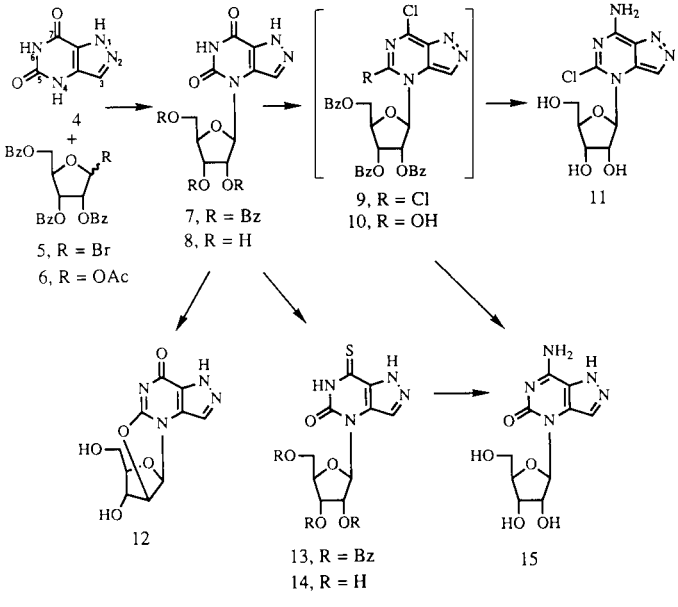
2 — a, R_1 = H; R_2 = OH; b, R_1 = OH; R_2 = H

3

2,4-disubstituted-1-β-D-ribofuranosylpyrrolo[3,2-*d*]pyrimidines which are structurally related to uridine and cytidine. The synthesis of the uridine analogue **8** in the pyrazolo[4,3-*d*]pyrimidine ring system has been accomplished by the trimethylsilyl procedure [17]. The silylation of pyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,4*H*,6*H*)-dione (**4**) [18] was accomplished with 1,1,1,3,3,3-hexamethyldisilazane (HMDS) in the presence of a catalytic amount of ammonium sulfate in anhydrous pyridine. The tristrimethylsilyl derivative thus obtained was condensed with 2,3,5-tri-*O*-benzoyl-D-ribofuranosyl bromide (**5**) [19] in anhydrous acetonitrile at room temperature. A clean reaction was noticed and the reaction product was isolated by flash chromatography over silica gel. Subsequent crystallization of the

pure product from ethyl acetate gave 4-(2,3,5-tri-*O*-benzoyl-β-D-ribofuranosyl)pyrazolo[4,3-*d*]pyrimidine-5,7-(1*H*,6*H*)-dione (**7**) in a 59.5% yield. No other nucleoside product was detected in the reaction mixture by tlc procedures (silica gel using 2% methanol in dichloromethane as the eluent). A similar glycosylation of the trimethylsilyl derivative of **4** with 1-*O*-acetyl-2,3,5-tri-*O*-benzoyl-D-ribofuranose (**6**) in dry acetonitrile in the presence of 1.44 molar equivalents [20] of trimethylsilyl trifluoromethanesulfonate (TMS triflate) at room temperature also gave a 56% yield of **7**. Compound **7** prepared by both the methods was found to be identical in all respects (mixture mp, tlc, ir, uv and ^{1}H nmr). A removal of the protecting benzoyl groups of the glycon moiety of **7** with methanolic ammonia (saturated at 0°) at room temperature furnished the uridine analogue 4-β-D-ribofuranosylpyrazolo[4,3-*d*]-pyrimidine-5,7(1*H*,6*H*)-dione (**8**) in excellent yield.

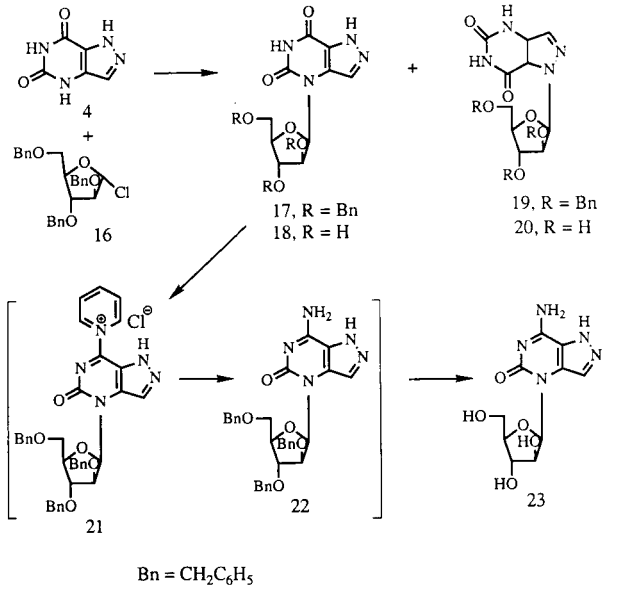
Scheme 1



The synthesis of the cytidine analogue 7-amino-4-β-D-ribofuranosylpyrazolo[4,3-*d*]pyrimidin-5(1*H*)-one (**15**) was accomplished by transformation of the hydroxyl function at C7 of **7**. Treatment of **7** with phosphorus pentasulfide in dioxane at reflux temperature proceeded smoothly to afford 4-(2,3,5-tri-*O*-benzoyl-β-D-ribofuranosyl)-5-oxopyrazolo[4,3-*d*]pyrimidine-7(1*H*,6*H*)-thione (**13**), which was isolated by silica gel column chromatography in a 82% yield. Deprotection of **13** with methanolic ammonia at room temperature furnished a 86% yield of 3-β-D-ribofuranosyl-5-oxopyrazolo[4,3-*d*]pyrimidine-7(1*H*,6*H*)-thione (**14**). The direct nucleophilic displacement of the thio function of **13** by ammonia at elevated temperature resulted in a low yield of the desired cytidine analogue **15**. This prompted us to investigate an alternate route to **15** *via* the chloro intermediate **9**. Thus, treatment of **7** with phosphorus oxychloride in the presence of tetraethylammonium chloride and *N*,*N*-diethylaniline at reflux temperature gave presumably a mixture of 5,7-dichloro- **9** and 7-chloro-5-hydroxy- **10** derivatives. Without further characterization, compounds **9** and **10**, were subjected to ammonolysis. Compounds 7-amino-5-chloro-4-β-D-ribofuranosylpyrazolo[4,3-*d*]pyrimidine (**11**) and the cytidine analogue **15** were isolated in rather low yields and fully characterized (see experimental).

The preparation of 4-β-D-arabinofuranosylpyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,6*H*)-dione (**18**) was envisioned to be possible *via* the ring opening of the 2′,5-anhydronucleoside **12**. The preparation of crystalline 4-β-D-ribofuranosyl-2′,5-*O*-anhydropyrazolo[4,3-*d*]pyrimidin-7(1*H*)-one (**12**) was accomplished in a 77% yield by the treatment of **8** with diphenyl carbonate in hexamethylphosphoramide at 150° for 20 minutes. Our attempts to open the anhydro linkage under various alkaline conditions were unsuccessful. However, the formation of the anhydro nucleoside **12** established the site of glycosylation in **8** as N4 and ruled out the possibility for the glycosidic linkage either at N1 or N2. Although the possibility of the attachment of the sugar moiety at N6 can not be ruled out, our previous studies [16] indicated that *N*-glycosylation between two carbonyls generally does not take place under the glycosylation reaction conditions presently employed.

Scheme 2

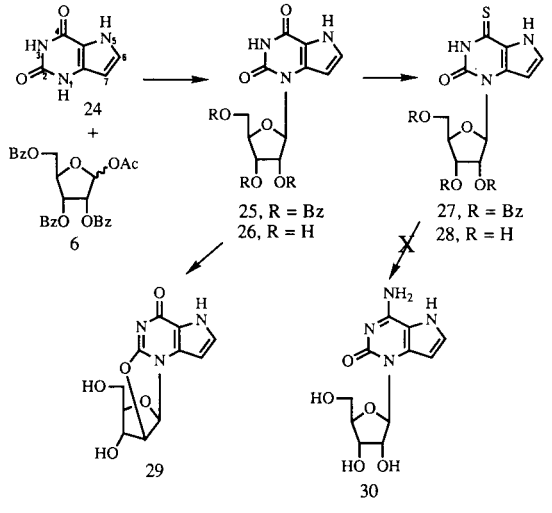


In an effort to prepare the desired **18**, a direct glycosylation of **4** with the protected α-halogenose (**16**) was considered. 2,3,5-Tri-*O*-benzyl-α-D-arabinofuranosyl chloride (**16**) was prepared as reported [21] and reacted with the tristrimethylsilyl derivative of **4** in 1,2-dichloroethane in the presence of 1.44 molar equivalents of tin(IV) chloride at room temperature. A complex reaction mixture was ob-

tained from which 4-(2,3,5-tri-*O*-benzyl-β-D-arabinofuranosyl)pyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,6*H*)-dione (**17**) was isolated as a colorless glass in a 29% yield. A small amount (6.9%) of crystalline 1-(2,3,5-tri-*O*-benzyl-β-D-arabinofuranosyl)pyrazolo[4,3-*d*]pyrimidine-5,7(4*H*,6*H*)-dione (**19**) was also isolated. Debenzylation of **17** with palladium hydroxide in ethanol in the presence of cyclohexene (as hydrogen source) at reflux temperature gave the desired 4-β-D-arabinofuranosylpyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,6*H*)-dione (**18**). The ultraviolet absorption spectrum of **18** was essentially identical to that of compound **8**, thereby proving the site of glycosylation in **18** as N4. A similar debenzylation of **19** with palladium hydroxide gave 1-β-D-arabinofuranosylpyrazolo[4,3-*d*]pyrimidine-5,7(4*H*,6*H*)-dione (**20**). Although the site of glycosylation in **20** is presumed to be N1, the anomeric configuration of both **18** and **20** was assigned as β on the basis of $J_{1',2'}$ coupling constants (5.26 Hz and 4.4 Hz, respectively) observed for the anomeric proton in the ^1H nmr spectra, which are within the region of 3.5-8.0 Hz, expected for a vicinal, *cis* arrangement of the $C_{1'}$ and $C_{2'}$ protons [22].

The synthesis of 7-amino-4-β-D-arabinofuranosylpyrazolo[4,3-*d*]pyrimidin-5(1*H*)-one (**23**) was accomplished by manipulation of the functional groups in **17**. Thus, pyridine assisted phosphorylation [23] of **17** with phosphorus oxychloride gave the reactive intermediate 4-(2,3,5-tri-*O*-benzyl-β-D-arabinofuranosyl)-5(1*H*)-oxopyrazolo[4,3-*d*]pyrimidin-7-yl-pyridinium chloride (**21**), which on sequential treatment with methanolic ammonia and palladium hydroxide/cyclohexene furnished **23** as an amorphous solid in an overall yield of 63%. The ultraviolet absorption spectrum of **23** (in *p*H 1, 7 and 11) was essentially similar to that of **15**, lending support to the assigned structure of **23**.

Scheme 3



The preparation of the uridine and cytidine analogues in the pyrrolo[3,2-*d*]pyrimidine (9-deazapurine) ring system was next considered by the direct glycosylation procedure. Pyrrolo[3,2-*d*]pyrimidine-2,4(1*H*,3*H*,5*H*)-dione (**24**) served as the starting material and was prepared as reported by Imai [24]. Silylation of **24** with excess of HMDS in pyridine in the presence of catalytic amount of ammonium sulfate gave the corresponding tristrimethylsilyl (TMS) derivative. Glycosylation of the TMS derivative of **24** with **6** in 1,2-dichloroethane in the presence of TMS triflate afforded a nucleoside product, which was isolated as a glass in a 82% yield by silica gel column chromatography and identified as 1-(2,3,5-tri-*O*-benzoyl-β-D-ribofuranosyl)pyrrolo[3,2-*d*]pyrimidine-2,4(3*H*,5*H*)-dione (**25**).

Conventional debenzoylation of **25** with methanolic ammonia at room temperature furnished the uridine analogue 1-β-D-ribofuranosylpyrrolo[3,2-*d*]pyrimidine-2,4-(3*H*,5*H*)-dione (**26**) in good yield. Treatment of **26** with diphenyl carbonate and sodium hydrogen carbonate in hexamethylphosphoramide at 150° gave the 2,2'-anhydronucleoside **29**. The formation of **29** established the site of glycosylation in **26** as N1. As in the case of **12**, our attempts to ring open the anhydro linkage of **29** under a variety of alkaline conditions were unsuccessful. The structure of **26** was unequivocally established by single crystal X-ray diffraction studies [25].

The synthesis of the cytidine analogue 4-amino-1-β-D-ribofuranosylpyrrolo[3,2-*d*]pyrimidin-2(5*H*)-one (**30**) was attempted *via* the corresponding 4-thio derivative **27**. Treatment of **25** with phosphorus pentasulfide in dioxane at reflux temperature gave 1-(2,3,5-tri-*O*-benzoyl-β-D-ribofuranosyl)-2-oxopyrrolo[3,2-*d*]pyrimidine-4(3*H*,5*H*)-thione (**27**). Debenzoylation of **27** with methanolic ammonia at room temperature afforded crystalline 1-(β-D-ribofuranosyl)-2-oxopyrrolo[3,2-*d*]pyrimidine-4(3*H*,5*H*)-thione (**28**). However, our attempt to synthesize the cytidine analogue **30** by the direct nucleophilic displacement of the thio function of **28** by ammonia at elevated temperature was not successful.

The synthesis of the pyrrolo[3,2-*d*]pyrimidine arabinosides was achieved by the direct glycosylation of the TMS derivative of **24** with the protected α-halogenose **16** in the presence of tin(IV) chloride. The reaction product formed was found to be a mixture of two positional isomers **31** and **32** and the separation of these isomers by column chromatography was rather difficult. Therefore, the mixture was subjected to debenzylation using palladium hydroxide/cyclohexene to obtain the free nucleosides. Resolution of these two isomers was achieved by preparative liquid chromatography using 40% methanol in water as the eluent. The major product (42%) which has identical ultraviolet absorption characteristics to that of **26** was assigned as N1 glycosylated product **34** and the structure of the minor

product (15%) was presumed to be 5-β-D-arabinofuranosylpyrrolo[3,2-*d*]pyrimidine-2,4(1*H*,3*H*)-dione (**35**). The β anomeric configuration for **34** and **35** was assigned on the basis of ^{1}H nmr studies [22].

The preparation of the ara-C analogue 4-amino-1-β-D-arabinofuranosylpyrrolo[3,2-*d*]pyrimidine-2(5*H*)-one (**38**) was carried out *via* the 3-nitrotriazolyl intermediate **36**. Acetylation of **34** with acetic anhydride in pyridine at room temperature gave the corresponding 2',3',5'-tri-*O*-acetyl derivative **33** in excellent yield. Treatment of **33** with 3-nitrotriazole and diphenylchlorophosphate in anhydrous pyridine, and purification of the reaction product on a silica gel column afforded a 41% yield of 1-(2,3,5-tri-*O*-acetyl-β-D-arabinofuranosyl)-4-(3-nitrotriazol-1-yl)pyrrolo-[3,2-*d*]pyrimidin-2(5*H*)-one (**36**). When a methanolic solution of **36** was treated with 30% ammonium hydroxide at room temperature, a free nucleoside was obtained which was identified as 4-methoxy-1-β-D-arabinofuranosylpyrrolo[3,2-*d*]pyrimidin-2(5*H*)-one (**37**). However, the desired cytidine analogue **38** was obtained by the treatment of **36** with ammonium hydroxide in dioxane at room temperature. The crystalline product was isolated in 60% yield and the structure was established by single crystal X-ray diffraction studies.

Single Crystal X-ray Diffraction Analysis of Compound **38**.

A colorless needle-shaped crystal (from ethanol:water) of compound **38** having approximate dimensions of 0.30 x 0.10 x 0.03 mm was mounted on a glass fiber. All measurements were made on a Rigaku AFC5R diffractometer with graphite monochromated CuKα radiation and a 12 KW rotating anode generator. A summary of crystal and experimental data, as well as intensity measurements is given in Table 1.

Cell constants and an orientation matrix for data collection, obtained from a least-squares refinement using the setting angles of 24 carefully centered reflections in the range $20.73 < 2\theta < 52.70°$ corresponded to a monoclinic cell with dimensions:

$a = 9.575(2)$ Å
$b = 6.942(1)$ Å $\quad \beta = 116.44\,(1)°$
$c = 10.658(2)$ Å
$V = 634.2(2)$ Å^3

The data were collected at a temperature of $23 \pm 1°$ using the ω-2θ scan technique to a maximum 2θ value of 120.1°. Omega scans of several intense reflections, made prior to data collection, had an average width at half-height of 0.40° with the take-off angle of 6.0°. Scans of $[1.37 + 0.30 \tan\theta]°$ were made at a speed of 16.0°/min (in omega). The weak reflections $[I < 10.0\sigma(I)]$ were rescanned (maximum of 3 rescans) and the counts were accumulated to assure good counting statistics. Stationary background counts were recorded on each side of the reflection. The ratio of peak counting time to background counting time was 2:1. The diameter of the incident beam collimator was 0.5 mm and the crystal to detector distance was 400.0 mm.

Table 1
Crystal and Experimental Data for Compound **38**

A. Crystal data	
Empirical formula	$C_{11}H_{14}N_4O_5 \cdot H_2O$
Formula weight	300.27
Crystal color, habit	colorless, needle
Crystal dimensions (mm)	0.3 x 0.10 x 0.03
Crystal system	monoclinic
Number of reflections used for unit cell determinatiom (2θ range)	24 (20.7-52.7°)
Omega scale peak width at half-height	0.40
Lattice parameters:	a = 9.573(2)Å b = 6.942(1)Å c = 10.658(2)Å β = 116.44(1)° v = 634.2(2)Å^3
Space group	$P2_1$ (#4)
Z value	2
D_{calc}	1.572g/cm^3
F_{000}	316 (electrons)
μ(CuKα)	10.59 cm^{-1}
B. Intensity Measurements	
Diffractometer	Rigaku AFC5R
Radiation	CuKα (λ=1.54178Å)
Temperature	23°
Attenuators	Zr foil (factors: 3.6, 12.3, 44.7)
Take-off angle	6.0°
Detector aperture	6.0 mm horizontal 6.0mm vertical
Crystal to detector distance	40 cm
Scan type	ω-2θ
Scan rate	16.0°/min (in omega) (3 rescans)
Scan width	(1.37 + 0.30 tanθ)°
2θ max	120.1°
No. of reflections measured	Total: 1101 Unique: 1035 (R_{int} = .045)
Corrections	Lorentz-polarization Secondary extintion (coefficient: 0.90561E-05)

Of the 1101 reflections which were collected, 1035 were unique ($R_{int} = 0.045$). The intensities of three representative reflections which were measured after every 150 reflections remained constant throughout data collection indicating crystal and electronic stability (no decay correction was applied).

The linear absorption coefficient for CuKα is 10.6 cm^{-1}. Azimuthal scans of several reflections indicated no need for an absorption correction. The data were corrected for Lorentz and polarization effects. A correction for secondary extinction was applied (coefficient = 0.90561E-05).

Structure Solution and Refinement.

The structure was solved by direct methods [26]. The

Table 2

Torsion Angles (°) Compound **38**

(1)	(2)	(3)	(4)	angle	(1)	(2)	(3)	(4)	angle
O(5')	C(5')	C(4')	O(4')	-72(1)	N(3)	C(4)	C(4a)	N(5)	176(1)
O(5')	C(5')	C(4')	C(3')	44(1)	N(3)	C(4)	C(4a)	C(7a)	-9(2)
O(3')	C(3')	C(4')	O(4')	-158.6 (8)	N(4)	C(4)	N(2)	C(2)	-179(1)
O(3')	C(3')	C(4')	C(5')	83(1)	N(4)	C(4)	C(4a)	N(5)	-1(2)
O(3')	C(3')	C(2')	O(2')	-71(1)	N(4)	C(4)	C(4a)	C(7a)	173(1)
O(3')	C(3')	C(2')	C(1')	166.4(9)	N(5)	C(4a)	C(7a)	C(7)	1(2)
O(2')	C(2')	C(3')	C(4')	165.9(9)	N(5)	C(6)	C(7)	C(7a)	1(2)
O(2')	C(2')	C(1')	O(4')	-164.3(8)	C(5')	C(4')	O(4')	C(1')	134.2(9)
O(2')	C(2')	C(1')	N(1)	73(1)	C(5')	C(4')	C(3')	C(2')	-152.4(9)
O(4')	C(4')	C(3')	C(2')	-34.1(9)	C(4')	O(4')	C(1')	C(2')	16.9(9)
O(4')	C(1')	N(1)	C(2)	119(1)	C(4')	C(3')	C(2')	C(1')	42.9(9)
O(4')	C(1')	N(1)	C(7a)	-62(1)	C(3')	C(4')	O(4')	C(1')	11(9)
O(4')	C(1')	C(2')	C(3')	-37.3(9)	C(2')	C(1')	N(1)	C(2)	-120(1)
O(5)	C(2)	N(1)	C(1')	-4(2)	C(2')	C(1')	N(1)	C(7a)	59(1)
O(5)	C(2)	N(1)	C(7a)	177(1)	C(1')	N(1)	C(7a)	C(4a)	-175(1)
O(5)	C(2)	N(3)	C(4)	180(1)	C(1')	N(1)	C(7a)	C(7)	5(2)
N(1)	C(1')	O(4')	C(4')	143.2(8)	C(2)	N(1)	C(7a)	C(4a)	4(2)
N(1)	C(1')	C(2')	C(3')	-159.6(8)	C(2)	N(1)	C(7a)	C(7)	-175(2)
N(1)	C(2)	N(3)	C(4)	6(2)	C(2)	N(3)	C(4)	C(4a)	4(2)
N(1)	C(7a)	C(4a)	N(5)	-179(1)	C(4)	C(4a)	N(5)	C(6)	175(2)
N(1)	C(7a)	C(4a)	C(4)	6(2)	C(4)	C(4a)	C(7a)	C(7)	-175(1)
N(1)	C(7a)	C(7)	C(6)	179(1)	C(4a)	N(5)	C(6)	C(7)	0(2)
N(3)	C(2)	N(1)	C(1')	170(1)	C(4a)	C(7a)	C(7)	C(6)	-1(2)
N(3)	C(2)	N(1)	C(7a)	-9(2)	C(6)	N(5)	C(4a)	C(7a)	0(2)

non-hydrogen atoms were refined either anisotropically or isotropically. The hydrogen atoms were either located from difference Fourier maps or included in the structure factor calculation in idealized positions (d_{C-H} = 0.95 Å), and were assigned isotropic thermal parameters which were 20% greater than the $B_{equivalent}$ value of the atom to which they were bonded. The final cycle of full-matrix least-squares refinement [27] was based on 601 observed reflections [$I > 30.00\sigma(I)$] and 135 variable parameters and converged (largest parameter shift was 0.00 times its esd) with unweighted and weighted agreement factors of:

$$R = \Sigma \parallel Fo \mid - \mid Fc \parallel / \Sigma \mid Fo \mid = 0.051$$

$$R_w = [(\Sigma w(\mid Fo \mid - \mid Fc \mid)^2 / \Sigma w Fo^2)]^{1/2} = 0.059$$

The standard deviation of an observation of unit weight [28] was 1.74. The weighting scheme was based on counting statistics and included a factor (p = 0.03) to down-weight the intense reflections. Plots of $\Sigma w(\mid Fo \mid - \mid Fc \mid)^2$ versus $\mid Fo \mid$, reflection order in data collection, sin θ/λ, and various classes of indices showed no unusual

Table 3

Positional Parameters and B(eq) for Compound **38**

Atom	x	y	z	B(eq)
O(5')	-0.2731(8)	0.9341	-0.3429(7)	3.6(3)
O(3')	-0.1535(8)	0.478(2)	-0.4478(7)	3.3(3)
O(2')	0.0568(7)	0.352(2)	-0.1367(7)	3.1(3)
O(4')	0.0688(8)	0.857(2)	-0.2114(8)	2.9(3)
O(5)	0.2194(7)	0.733(2)	0.1632(6)	3.3(3)
O(6)	0.4227(9)	0.857(2)	0.4641(9)	5.9(4)
N(1)	0.2759(7)	0.708(2)	-0.0214(7)	2.1(3)
N(3)	0.4745(8)	0.701(2)	0.2141(7)	2.4(3)
N(4)	0.7352(9)	0.664(2)	0.2690(8)	2.9(4)
N(5)	0.6348(8)	0.702(2)	-0.0425(8)	3.0(3)
C(5')	-0.174(1)	0.936(2)	-0.407(1)	3.0(2)
C(4')	-0.046(1)	0.793(2)	-0.352(1)	2.3(2)
C(3')	-0.090(1)	0.592(2)	-0.327(1)	2.1(2)
C(2')	0.061(1)	0.518(2)	-0.210(1)	2.4(2)
C(1')	0.111(1)	0.696(2)	-0.1193(9)	2.0(2)
C(2)	0.321(1)	0.720(2)	0.122(1)	2.3(2)
C(4)	0.586(1)	0.686(2)	0.171(1)	2.2(2)
C(4a)	0.543(1)	0.701(2)	0.030(1)	2.3(2)
C(6)	0.538(1)	0.704(3)	-0.180(1)	2.9(2)
C(7)	0.385(1)	0.704(2)	-0.202(1)	2.7(2)
C(7a)	0.389(1)	0.704(2)	-0.0705(9)	2.2(2)
H(O5')	-0.2297	1.0866	-0.3084	4.2
H(O3')	-0.2622	0.5500	-0.5263	3.4
H(O2')	-0.0280	0.3378	-0.1278	3.3
H(N4Ha)	0.7346	0.6229	0.3539	2.5
H(N4Hb)	0.8371	0.6314	0.2387	2.8
H(N5)	0.7524	0.7465	-0.0092	3.4
H(C5'Hb)	-0.2355	0.9106	-0.5042	3.6
H(C5'Ha)	-0.1296	1.0606	-0.3956	3.6
H(C4')	0.0031	0.7864	-0.4124	2.8
H(C3')	-0.1654	0.6037	-0.2914	2.5
H(C2')	0.1326	0.4971	-0.2479	2.9
H(C1')	0.0524	0.7020	-0.0670	2.5
H(C6)	0.5704	0.7050	-0.2525	3.5
H(C7)	0.2951	0.7039	-0.2893	3.2
H(15)	0.5316	0.8404	0.5408	6.4
H(16)	0.4332	0.9603	0.4295	5.6

Table 4

Intramolecular Distances (Å) Involving the Hydrogen Atoms in **38**

atom	atom	distance	atom	atom	distance
O(5')	H(O5')	1.137	C(5')	H(C5'Hb)	0.950
O(3')	H(O3')	1.123	C(5')	H(C5'Ha)	0.950
O(2')	H(O2')	0.865	C(4')	H(C4')	0.950
O(6)	H(15)	1.005	C(3')	H(C3')	0.950
O(6)	H(16)	0.833	C(2')	H(C2')	0.950
N(4)	H(N4Ha)	0.950	C(1')	H(C1')	0.950
N(4)	H(N4Hb)	1.177	C(6)	H(C6)	0.950
N(5)	H(N5)	1.065	C(7)	H(C7)	0.950

Itramolecular Distances (Å) Involving the Nonhydrogen atoms in **38**

atom	atom	distance	atom	atom	distance
O(5')	C(5')	1.39(1)	N(4)	C(4)	1.35(1)
O(3')	C(3')	1.41(1)	N(5)	C(4a)	1.41(1)
O(2')	C(2')	1.40(1)	N(5)	C(6)	1.34(1)
O(4')	C(4')	1.48(1)	C(5')	C(4')	1.48(2)
O(4')	C(1')	1.42(1)	C(4')	C(3')	1.52(1)
O(5)	C(2)	1.24(1)	C(3')	C(2')	1.52(1)
N(1)	C(1')	1.46(1)	C(2')	C(1')	1.51(2)
N(1)	C(2)	1.39(1)	C(4)	C(4a)	1.37(1)
N(1)	C(7a)	1.40(1)	C(4a)	C(7a)	1.38(1)
N(3)	C(2)	1.36(1)	C(6)	C(7)	1.37(1)
N(3)	C(4)	1.34(1)	C(7)	C(7a)	1.38(1)

Estimated standard deviations are given in parentheses.

Table 5

Intramolecular Bond Angles (°) Involving the Hydrogen Atoms in **38**

atom	atom	atom	angle	atom	atom	atom	angle
C(5')	O(5')	H(05')	85.47	C(5')	C(4')	H(C4')	109.70
C(3')	O(3')	H(03')	107.89	C(3')	C(4')	H(C4')	109.71
C(2')	O(2')	H(02')	114.64	O(3)	C(3')	H(C3')	108.57
H(15)	O(6)	H(16)	100.01	C(4')	C(3')	H(C3')	108.56
C(4)	N(4)	H(N4Ha)	108.34	C(2')	C(3')	H(C3')	108.57
C(4)	N(4)	H(N4Hb)	122.09	O(2')	C(2')	H(C2')	108.29
H(N4Ha)	N(4)	H(N4Hb)	124.20	C(3')	C(2')	H(C2')	108.30
C(4a)	N(5)	H(N5)	129.99	C(1')	C(2')	H(C2')	108.29
C(6)	N(5)	H(N5)	118.29	O(4')	C(1')	H(C1')	108.12
O(5')	C(5')	H(C5'Hb)	108.04	N(1)	C(1')	H(C1')	108.12
O(5')	C(5')	H(C5'Ha)	108.04	C(2')	C(1')	H(C1')	108.12
C(4')	C(5')	H(C5'Hb)	108.02	N(5)	C(6)	H(C6)	124.85
C(4')	C(5')	H(C5'Ha)	108.02	C(7)	C(6)	H(C6)	124.85
H(C5'Hb)	C(5')	H(C5'Ha)	109.46	C(6)	C(7)	H(C7)	126.75
O(4')	C(4')	H(C4')	109.70	C(7a)	C(7)	H(14)	126.75

Intramolecular Bond Angles (°) Involving the Nonhydrogen Atoms in **38**

atom	atom	atom	angle	atom	atom	atom	angle
C(3')	O(4')	C(1')	108.7(8)	O(4')	C(1')	C(2')	106.7(7)
C(1')	N(1)	C(2)	119.8(7)	N(1)	C(1')	C(2')	116.0(9)
C(1')	N(1)	C(7a)	120.4(7)	O(5)	C(2)	N(1)	119.1(8)
C(2)	N(1)	C(7a)	119.8(7)	O(5)	C(2)	N(3)	121.0(8)
C(2)	N(3)	C(4)	121.7(8)	N(1)	C(2)	N(3)	119.7(8)
C(4a)	N(5)	C(6)	107.8(7)	N(3)	C(4)	N(4)	118.3(8)
O(5')	C(5')	C(4')	115.0(1)	N(3)	C(4)	C(4a)	118.4(8)
O(4')	C(4')	C(5')	108.3(9)	N(4)	C(4)	C(4a)	123.2(8)
O(4')	C(4')	C(3')	103.5(9)	N(5)	C(4a)	C(4)	130.5(8)
C(5')	C(4')	C(3')	115.6(9)	N(5)	C(4a)	C(7a)	106.4(7)
O(3')	C(3')	C(4')	113.4(9)	C(4)	C(4a)	C(7a)	122.9(9)
O(3')	C(3')	C(2')	114.9(9)	N(5)	C(6)	C(7)	110.3(8)
C(4')	C(3')	C(2')	102.5(9)	C(6)	C(7)	C(7a)	106.5(8)
O(2')	C(2')	C(3')	118.9(9)	N(1)	C(7a)	C(4a)	116.4(8)
O(2')	C(2')	C(1')	113.1(9)	N(1)	C(7a)	C(7)	134.6(8)
C(3')	C(2')	C(1')	99.3(9)	C(4a)	C(7a)	C(7)	109.0(8)
O(4')	C(1')	N(1)	109.5(9)				

Estimated standard deviations are given in parentheses.

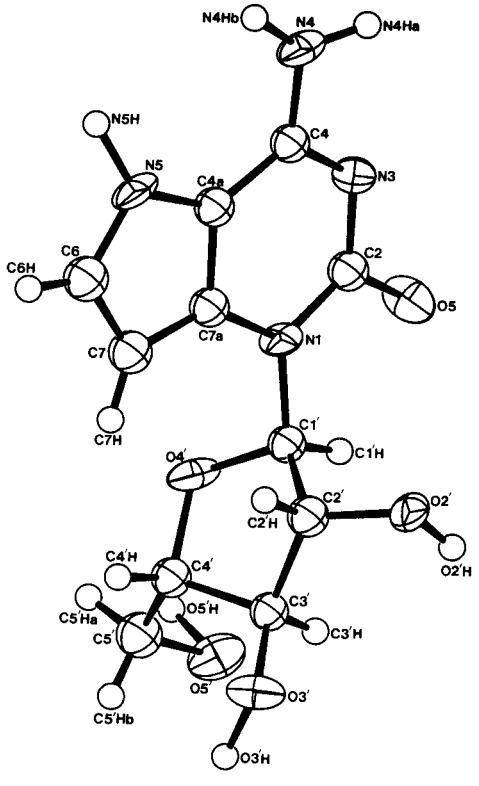
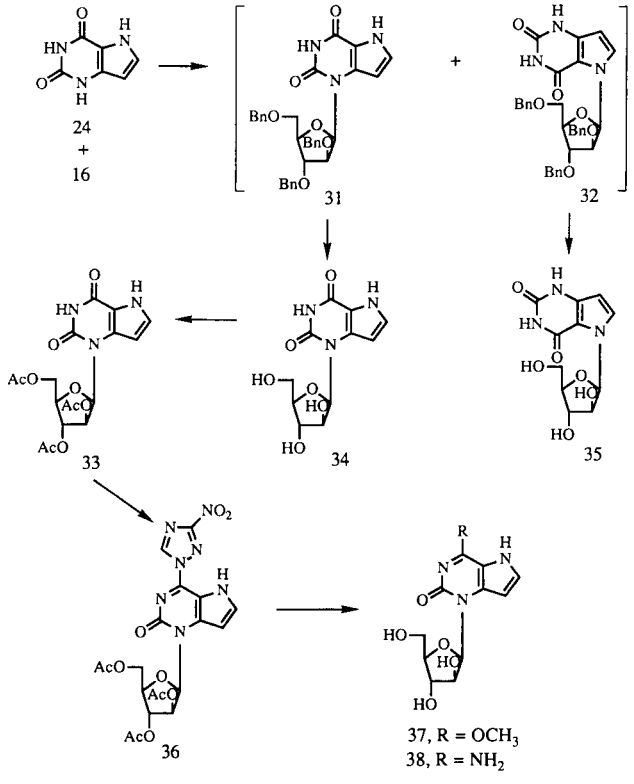


Figure 2. Perspective drawing of **38** showing atom labeling.

Scheme 4



trends. The maximum and minimum peaks on the final difference Fourier map corresponded to 0.27 and -0.22 $e^-/Å^3$, respectively.

Neutral atom scattering factors were taken from Cromer and Waber [29]. Anomalous dispersion effects were included in Fcalc [30]; the values for Δf' and Δf'' were those of Cromer [31]. All calculations were performed using the TEXSAN [32] crystallographic software package of Molecular Structure Corporation, The Woodlands, Texas 77381.

Figure 2 illustrates the molecular conformation of compound **38**. Selected torsion angles (Table 2) and positional parameters (Table 3) for compound **38** are also given. Intramolecular distances (Table 4) and bond angles (Table 5) involving the hydrogen atoms in **38** are also listed. The structural determination confirms that compound **38** is an N1-glycosylated product with the β-anomeric configuration.

EXPERIMENTAL

Melting points (uncorrected) were determined in a Thomas-Hoover capillary melting-point apparatus. Elemental analyses were performed by Robertson Laboratory, Madison, NJ. The presence of solvent as indicated by elemental analysis was verified by ^{1}H nmr spectroscopy. Thin layer chromatography (tlc) was performed on plates of silica gel 60F-254 (EM Reagents). Silica gel (E. Merck; 230-400 mesh) was used for flash column chromatography. All solvents used were reagent grade. Detection of nucleoside components in tlc was by uv light, and with 10% sulfuric acid in methanol spray followed by heating. Evaporations were conducted under diminished pressure with the bath temperature below 30°. Infrared (ir) spectra were recorded in potassium bromide with a Perkin-Elmer 1420 spectrophotometer and ultraviolet spectra (uv) were recorded on a Beckman DU-50 spectrophotometer. Nuclear magnetic resonance (^{1}H nmr) spectra were recorded at 300 MHz with an IBM NR/300 spectrometer. The chemical shift values are expressed in δ values (parts per million) relative to tetramethylsilane as the internal standard (key: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet and br = broad).

4-(2,3,5-Tri-*O*-benzoyl-β-D-ribofuranosyl)pyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,6*H*)-dione (**7**). Method A.

A mixture of dry pyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,4*H*,6*H*)-dione [18] (**4**, 10.64 g, 70 mmoles), ammonium sulfate (0.2 g), 1,1,1-3,3,3-hexamethyldisilazane (HMDS, 70 ml) and anhydrous pyridine (10 ml) was heated under reflux for 15 hours. Excess HMDS and pyridine were removed by distillation and the residue was subjected to a high vacuum for 2 hours. A solution of 2,3,5-tri-*O*-benzoyl-D-ribofuranosyl bromide [19] (**5**), [prepared from 1-*O*-acetyl-2,3,5-tri-*O*-benzoyl-β-D-ribofuranose (38.85 g, 73.95 mmoles)] in anhydrous acetonitrile (200 ml) was added with stirring to the above silyl derivative. The mixture was stirred at room temperature for 18 hours, filtered and the filtrate evaporated to dryness. The residue was dissolved in dichloromethane (800 ml) and washed successively with 5% aqueous sodium bicarbonate (2 x 200 ml), water (2 x 200 ml) and saturated aqueous sodium chloride solution (100 ml). After drying over sodium sulfate the sol-

vent was evaporated to dryness. The solid thus obtained was purified by flash chromatography over a silica gel column (6 x 60 cm) using 5% methanol in chloroform as the eluent. Evaporation of the homogeneous fractions and crystallization of the residue from ethyl acetate yielded 24.82 g (59.5%) of **7**, mp 250-251°; ir: ν max 1715 (C=O), 3100-3400 (NH) cm^{-1}; uv (*p*H 1): λ max 277 nm (ϵ 7,600), 234 (21,200); (*p*H 7): λ max 277 nm (ϵ 10,000), 234 (26,100); (*p*H 11): λ max 274 nm (ϵ 7,000), 230 (35,000); ^1H nmr (DMSO-d_6): δ 4.72-4.76 (m, 3 H, $C_{4'}H$ and $C_{5'}CH_2$), 6.02 (m, 2 H, $C_{2'}H$ and $C_{3'}H$), 6.34 (d, 1 H, J = 3.8 Hz, $C_{1'}H$), 7.49-7.68 (m, 16 H, 3 OBz and C_3H), 11.50 (br s, 1 H, N_6H) and 14.10 (br s, 1 H, N_1H).

Anal. Calcd. for $C_{31}H_{23}N_4O_9$: C, 62.41; H, 4.06; N, 9.39. Found: C, 62.22; H, 4.30; N, 9.15.

Method B.

A mixture of dry pyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,4*H*,6*H*)-dione [17] (**4**, 10.64 g, 70 mmoles), ammonium sulfate (175 mg), 1,1,-1,3,3,3-hexamethyldisilazane (HMDS, 107 ml) and anhydrous pyridine (10 ml) was heated under reflux for 18 hours. Excess HMDS and pyridine were removed by distillation and the residue was subjected to a high vacuum for 2 hours. The dry residue was dissolved in anhydrous acetonitrile (200 ml) and 1-*O*-acetyl-2,3,5-tri-*O*-benzoyl-D-ribofuranose (**6**, 38.85 g, 77 mmoles) was added. The mixture was cooled to 0° and trimethylsilyl trifluoromethanesulfonate [TMS triflate, 17.89 ml, 1.44 equivalent] was added dropwise with stirring. The solution was gradually warmed to room temperature and stirred overnight. Methanol (30 ml) was added and after stirring for 30 minutes at room temperature, the solvents were evaporated. The residue was dissolved in dichloromethane (800 ml), and washed successively with 5% aqueous sodium bicarbonate (2 x 200 ml), water (2 x 200 ml), saturated aqueous sodium chloride solution (100 ml) and dried over anhydrous sodium sulfate. After evaporation of the solvent, the solid thus obtained was crystallized from ethyl acetate to yield 23.2 g (56%) of the title compound, mp 250-251°. This product was found to be identical in all respects (mixture mp, tlc, ir, uv and ^1H nmr) to that obtained by Method A.

4-β-D-Ribofuranosylpyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,6*H*)-dione (**8**).

A solution of **7** (0.7 g, 1.175 mmoles) in methanolic ammonia (30 ml, saturated at 0°) was stirred at room temperature for 19 hours in a pressure bottle. After the evaporation of methanol, the solid obtained was purified by flash chromatography over a silica gel column (3 x 25 cm) using ethyl acetate:*n*-propanol:water (4:1:2, upper phase) as eluent. Homogeneous fractions were pooled and evaporated. The solid thus obtained was crystallized from ethanol to yield 287 mg (86%) of **8**, mp 174-176°; ir: ν max 1680 (C=O), 3100-3450 (OH, NH) cm^{-1}; uv (*p*H 1): λ max 285 nm (ϵ 3,800); (*p*H 7): λ max 282 nm (ϵ 4,200); (*p*H 11): λ max 285 nm (ϵ 4,200), 248 (6,100); ^1H nmr (DMSO-d_6): δ 3.63 (m, 2 H, $C_{5'}CH_2$), 3.83 (m, 1 H, $C_{4'}H$), 4.04 (dd, 1 H, $C_{3'}H$), 4.25 (t, 1 H, $C_{2'}H$), 5.07-5.22 (br s, 3 H, 3 OH), 5.99 (d, 1 H, J = 7.5 Hz, $C_{1'}H$), 8.20 (s, 1 H, C_3H), 11.37 (br s, 1 H, N_6H) and 13.94 (br s, 1 H, N_1H).

Anal. Calcd. for $C_{10}H_{12}N_4O_6$: C, 42.25; H, 4.25; N, 19.71. Found: C, 41.89; H, 4.16; N, 19.55.

7-Amino-5-chloro-4-β-D-ribofuranosylpyrazolo[4,3-*d*]pyrimidine (**11**) and 7-Amino-4-β-D-ribofuranosylpyrazolo[4,3-*d*]pyrimidin-5-(1*H*)-one (**15**).

A mixture of **7** (1.19 g, 2 mmoles), tetraethylammonium chloride hydrate (1.32 g, 8 mmoles), *N*,*N*-diethylaniline (0.64 ml, 4.04 mmoles) and freshly distilled phosphorus oxychloride (15 ml) was heated under a nitrogen atmosphere in a round bottom flask placed in an oil bath at 100° for 40 minutes. The reaction mixture was allowed to cool to room temperature and excess phosphorus oxychloride was evaporated. The residue was dissolved in chloroform (50 ml) and poured onto crushed ice (50 g) and stirred vigorously for 1 hour. The aqueous phase was separated and extracted with chloroform (3 x 50 ml). The combined organic extracts were washed successively with cold 1*N* hydrochloric acid (1 x 40 ml), cold saturated aqueous sodium bicarbonate (2 x 40 ml), cold water (2 x 40 ml), then dried over anhydrous sodium sulfate and evaporated. The residue thus obtained was flash chromatographed on a silica gel column (3 x 25 cm) using 2% methanol in dichloromethane as the eluent.

A mixture of compounds **9** (0.4 g, 31.14%) and **10** (0.25 g, 20.4%) were isolated and immediately subjected to ammonolysis without full characterization. A solution of **9** in methanolic ammonia (25 ml, saturated at 0°) was left at 4° for 2 days in a pressure bottle. Methanol was evaporated and the residue was purified on a flash silica gel column (3 x 25 cm) using ethylacetate:-methanol:acetone:water (7:1:1:1) as eluent. The homogeneous fractions were pooled and evaporated to give a solid which was crystallized from aqueous ethanol to yield 0.14 g (23%) of **11** as colorless needles, mp 261°; ir: ν max 800 (C-Cl), 3150-3500 (OH, NH_2) cm^{-1}; uv (*p*H 1): λ max 305 nm (ϵ 5,300); (*p*H 7): λ max 295 nm (ϵ 6,400), 251 (12,500); (*p*H 11): λ max 298 nm (ϵ 6,000), 265 (11,000); ^1H nmr (DMSO-d_6): δ 3.52 (m, 2 H, $C_{5'}CH_2$), 3.76 (m, 1 H, $C_{4'}H$), 4.03 (t, 1 H, C_3H), 4.24 (dd, 1 H, $C_{2'}H$), 4.97 (d, 1 H, J = 3.3 Hz, $C_{3'}OH$), 5.02 (d, 1 H, J = 6.9 Hz, $C_{2'}OH$), 5.13 (t, 1 H, $C_{5'}OH$), 6.04 (d, 1 H, J = 6.0 Hz, $C_{1'}H$), 7.78 (br s, 2 H, NH_2) and 8.04 (s, 1 H, C_3H).

Anal. Calcd. for $C_{10}H_{12}ClN_5O_4$: C, 39.81; H, 4.00; N, 23.31. Found: C, 39.71; H, 3.84; N, 23.44.

A solution of **10** in methanolic ammonia (20 ml, saturated at 0°) was stirred at room temperature for 24 hours in a pressure bottle. Methanol was evaporated and the residue was triturated with ethanol (3 x 10 ml). The ethanol insoluable solid was crystallized from aqueous ethanol to yield 0.11 g (19%) of **15**, mp 252-253°; ir: ν max 1720 (C=O), 3140-3500 (OH, NH, NH_2) cm^{-1}; uv (*p*H 1): λ max 304 nm (ϵ 8,700); (*p*H 7): λ max 296 nm (ϵ 9,300), 250 (20,100); (*p*H 11): λ max 299 nm (ϵ 9,600), 266 (17,600); ^1H nmr (DMSO-d_6): δ 3.68 (m, 2 H, $C_{5'}CH_2$), 3.79 (m, 1 H, $C_{4'}H$), 4.05 (m, 1 H, $C_{3'}H$), 4.27 (t, 1 H, $C_{2'}H$), 5.05 (br s, 2 H, 2' and 3'OH), 5.17 (br s, 1 H, C5'OH), 6.07 (d, 1 H, J = 7.1 Hz, $C_{1'}H$), 7.80 (br s, 2 H, NH_2), 8.07 (s, 1 H, C_3H) and 13.30 (br s, 1 H, NH).

Anal. Calcd. for $C_{10}H_{13}N_5O_5 \cdot 1/4H_2O$: C, 41.73; H, 4.69; N, 24.34. Found: C, 41.97; H, 4.46; N, 24.06.

4-β-D-Ribofuranosyl-2',5-*O*-anhydropyrazolo[4,3-*d*]pyrimidin-7(1*H*)-one (**12**).

To a solution of **8** (0.57 g, 2 mmoles) and diphenyl carbonate (0.53 g, 2.5 mmoles) in hexamethylphosphoramide (3 ml) was added sodium hydrogen carbonate (26 mg) and the reaction mixture was heated at 150° for 20 minutes. The reaction mixture was cooled to room temperature and then poured into water (20 ml). The aqueous layer was washed with chloroform (3 x 10 ml) and evaporated to dryness. The residue was crystallized from aqueous methanol to afford 0.41 g (77%) of **12**, mp 268-269°; ir: ν max 1660 (C=O), 3200-3400 (OH, NH) cm^{-1}; uv (*p*H 1): λ max 277 nm

(ε 5,800); (*p*H 7): λ max 276 nm (ε 6,300); (*p*H 11): λ max 259 nm (ε 6,700); ^{1}H nmr (DMSO-d_6): δ 3.11-3.33 (m, 2 H, $C_{5'}CH_2$), 4.10 (m, 1 H, $C_{4'}H$), 4.43 (s, 1 H, $C_{3'}H$), 4.91 (br, 1 H, $C_{3'}OH$), 5.28 (d, 1 H, $C_{2'}H$), 5.95 (br, 1 H, $C_{5'}OH$), 6.55 (d, 1 H, J = 6.0 Hz, $C_{1'}H$), 7.93 (s, 1 H, C_3H) and 14.10 (br s, 1 H, N_1H).

Anal. Calcd. for $C_{10}H_{10}N_4O_5 \cdot 1/4H_2O$: C, 44.36; H, 3.90; N, 20.69. Found: C, 44.33; H, 3.78; N, 20.42.

4-(2,3,5-Tri-*O*-benzoyl-β-D-ribofuranosyl)-5-oxopyrazolo[4,3-*d*]pyrimidine-7(1*H*,6*H*)-thione (**13**).

To a suspension of **7** (0.5 g, 0.83 mmole) in dry dioxane (20 ml) was added purified phosphorus pentasulfide (0.44 g, 0.98 mmole) and the reaction mixture was heated under reflux for 3 hours with the exclusion of moisture. The solvent was evaporated and the residual syrup poured on crushed ice (50 g) with vigorous stirring. After stirring for 1 hour, chloroform (40 ml) was added and the organic layer was separated, washed successively with water (3 x 40 ml), saturated aqueous sodium chloride (40 ml), dried over anhydrous sodium sulfate and evaporated to dryness. The residue was purified by flash chromatography over a silica gel column (3 x 25 cm) using 3% methanol in dichloromethane as the eluent, to afford 0.42 g (82%) of **13** as a pale yellow foam, mp 125-127°; ir: ν max 1120 (C=S), 1720 (C=O), 3200 (NH) cm^{-1}; uv (*p*H 1): λ max 344 nm (ε 11,000), 236 (22,200); (*p*H 7): λ max 345 nm (ε 12,500), 234 (25,700); (*p*H 11): λ max 333 nm (ε 12,800), 230 (33,000); ^{1}H nmr (DMSO-d_6): δ 4.72-4.76 (m, 3 H, $C_{4'}H$ and $C_{5'}CH_2$), 6.03 (m, 2 H, $C_{2'}H$ and $C_{3'}H$), 6.36 (d, 1 H, J = 3.3 Hz, $C_{1'}H$), 7.48-7.86 (m, 16 H, C_3H, 3 OBz), 12.86 (br s, 1 H, N_6H) and 14.17 (br s, 1 H, N*H*).

Anal. Calcd. for $C_{31}H_{23}N_4O_8S$: C, 60.87; H, 3.79; N, 9.16. Found: C, 60.67; H, 3.86; N, 8.89.

4-β-D-Ribofuranosyl-5-oxopyrazolo[4,3-*d*]pyrimidine-7(1*H*,6*H*)-thione (**14**).

A solution of **13** (0.4 g, 0.65 mmole) in methanolic ammonia (20 ml, saturated at 0°) was stirred overnight at room temperature. Methanol was evaporated and the residue was purified by flash chromatography over a silica gel column using ethylacetate:*n*-propanol:water (4:1:2, upper phase) as eluent. Evaporation of homogeneous fractions gave a solid which was crystallized from methanol to yield 0.17 g (86%) of **14**, mp 140-142°; ir: ν max 1120 (C=S), 1680 (C=O), 3000-3400 (OH, NH) cm^{-1}; uv (*p*H 1): λ max 342 nm (ε 9,900), 260 (5,300); (*p*H 7): λ max 340 nm (ε 10,600), 259 (5,400); (*p*H 11): λ max 335 nm (ε 9,700); ^{1}H nmr (DMSO-d_6): δ 5.08 (d, 1 H, $C_{3'}OH$), 5.24 (d, 1 H, $C_{2'}OH$), 5.28 (t, 1 H, $C_{5'}OH$), 6.00 (d, 1 H, J = 7.5 Hz, $C_{1'}H$), 8.24 (s, 1 H, C_8H), 12.8 (br, 2 H, 2 N*H*), and other sugar protons.

Anal. Calcd. for $C_{10}H_{12}N_4O_5S \cdot 1/2EtOH$: C, 40.86; H, 4.64; N, 17.33; S, 9.91. Found: C, 40.81; H, 4.42; N, 17.06; S, 10.02.

4-(2,3,5-Tri-*O*-benzyl-β-D-arabinofuranosyl)pyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,6*H*)-dione (**17**) and 1-(2,3,5-Tri-*O*-benzyl-β-D-arabinofuranosyl)pyrazolo[4,3-*d*]pyrimidine-5,7(4*H*,6*H*)-dione (**19**).

A mixture of dry **4** (8 g, 52.6 mmoles), ammonium sulfate (150 mg), HMDS (60 ml) and anhydrous pyridine (20 ml) was heated under reflux overnight. Excess HMDS and pyridine were removed by distillation and the residue was subjected to a high vacuum for 2 hours. A solution of 2,3,5-tri-*O*-benzyl-α-D-arabinofuranosyl chloride [21] (**16**) [prepared from 2,3,5-tri-*O*-benzyl-1-*O*-(p-nitrobenzoyl)-D-arabinose (32 g, 56.18 mmoles)], in anhydrous 1,2-dichloroethane (200 ml) was added with stirring to the above silyl derivative. The mixture was cooled to 0° and tin(IV) chloride (1.4 ml) was added dropwise under a argon atmosphere. The reaction mixture was allowed to warm gradually to room temperature and stirred for an additional 12 hours. The solvent was evaporated and the residue dissolved in ethyl acetate (250 ml) which was washed with saturated aqueous sodium hydrogen carbonate solution (100 ml). The emulsion thus formed was filtered through a Celite pad, the organic layer was separated, dried over anhydrous sodium sulfate and evaporated to dryness. The residual gum thus obtained was purified by flash chromatography over a silica gel column (3.5 x 40 cm) using 0-5% methanol in dichloromethane gradient as the eluent. The following two nucleosides were isolated in the order listed: 1-(2,3,5-Tri-*O*-benzyl-β-D-arabinofuranosyl)pyrazolo[4,3-*d*]pyrimidine-5,7(4*H*,6*H*)-dione (**19**). Crystallized from a mixture of dichloromethane:cyclohexane to yield 2 g (6.9%) as colorless needles, mp 106-107°; ir: ν max 1680, 1715 (C=O), 3000-3300 (NH) cm^{-1}; uv (methanol): λ max 282 nm (ε 6,500), 286 (6,600); ^{1}H nmr (DMSO-d_6): δ 6.27 (d, 1 H, J = 5.07 Hz, $C_{1'}H$), 7.89 (s, 1 H, C_3H), 11.3 (s, 1 H, N*H*), 13.9 (s, 1 H, N*H*), and other sugar protons.

Anal. Calcd. for $C_{31}H_{30}N_4O_6$: C, 67.13; H, 5.40; N, 10.10. Found: C, 66.99; H, 5.42; N, 9.97.

4-(2,3,5-Tri-*O*-benzyl-β-D-arabinofuranosyl)pyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,6*H*)-dione (**17**) was obtained as a colorless glass, yield 5.5 g (29%), mp 73-75°; ir: ν max 1690, 1715 (C=O), 3100-3350 (NH) cm^{-1}; uv (methanol): λ max 281 nm (ε 3,400); ^{1}H nmr (DMSO-d_6): δ 6.19 (d, 1 H, J = 5.46 Hz, $C_{1'}H$), 7.91 (s, 1 H, C_3H), 11.4 (s, 1 H, N*H*), 14.1 (s, 1 H, N*H*), and other sugar protons.

Anal. Calcd. for $C_{31}H_{30}N_4O_6$: C, 67.13; H, 5.40; N, 10.10. Found: C, 66.90; H, 5.24; N, 10.03.

4-β-D-Arabinofuranosylpyrazolo[4,3-*d*]pyrimidine-5,7(1*H*,6*H*)-dione (**18**).

To a solution of **17** (1.9 g, 3.42 mmoles) in absolute ethanol (50 ml) were added cyclohexene (15 ml) and palladium hydroxide (1.5 g, 20% on carbon) and the mixture was heated under reflux for 17 hours. The reaction mixture was cooled, the catalyst was filtered through a Celite pad and washed with hot methanol (5 x 50 ml). The combined filtrate and washings was evaporated to dryness and the residue was crystallized from ethanol to yield 0.55 g (57%) of **18** as colorless needles, mp 240-241°; ir: ν max 1670, 1710 (C=O), 3020-3540 (OH, NH) cm^{-1}; uv (*p*H 1): λ max 284 nm (ε 6,300); (*p*H 7): λ max 282 nm (6,300); (*p*H 11): λ max 268 nm (ε 9,600), 283 (6,800); ^{1}H nmr (DMSO-d_6): δ 5.95 (d, 1 H, J = 5.26 Hz, $C_{1'}H$), 7.83 (s, 1 H, C_3H), 11.3 (s, 1 H, N*H*), and other sugar protons.

Anal. Calcd. for $C_{10}H_{12}N_4O_6$: C, 42.25; H, 4.25; N, 19.71. Found: C, 41.96; H, 3.99; N, 19.53.

1-β-D-Arabinofuranosylpyrazolo[4,3-*d*]pyrimidine-5,7(4*H*,6*H*)-dione (**20**).

In a similar manner as described for **18**, debenzylation of **19** (1.3 g, 2.34 mmoles) with palladium hydroxide (1 g, 20% on carbon) and crystallization of the material from aqueous ethanol yielded 0.4 g (60.1%) of **20** as needles, mp 252-253°; ir: ν max 1690, 1720 (C=O), 3000-3450 (NH) cm^{-1}; uv (*p*H 1): λ max 287 nm (ε 5,000); (*p*H 7): λ max 283 nm (ε 4,800), 287 (4,800); (*p*H 11): λ max 241 nm (ε 6,900), 285 (2,900); ^{1}H nmr (DMSO-d_6): δ 6.07 (d, 1 H, J = 4.4 Hz, $C_{1'}H$), 7.99 (s, 1 H, $C_{3'}H$), 11.2 (s, 1 H, N*H*), 13.7 (s, 1 H, N*H*), and other sugar protons.

Anal. Calcd. for $C_{10}H_{12}N_4O_6$: C, 42.25; H, 4.25; N, 19.71. Found: C, 42.25; H, 4.16; N, 19.43.

7-Amino-4-β-D-arabinofuranosylpyrazolo[4,3-*d*]pyrimidin-5(1*H*)-one (**23**).

To a solution of **17** (2 g, 3.6 mmoles) in dry pyridine (20 ml) was added phosphorus oxychloride (0.66 ml) and the mixture was stirred at room temperature for 2 days. Excess pyridine and phosphorus oxychloride were evaporated to yield **21**. The crude **21** was dissolved in methanolic ammonia (200 ml, saturated at 0°) and the solution was stirred at room temperature for 24 hours in a pressure bottle. Methanol was removed by evaporation. The residue was suspended in water (50 ml) and the product was extracted with chloroform (3 x 50 ml). The combined organic extracts were dried over anhydrous sodium sulfate and evaporated under reduced pressure to yield 1.6 g of **22** as a gum.

To a solution of **22** in absolute ethanol (50 ml) were added palladium hydroxide (0.7 g, 20% on carbon) and cyclohexene (15 ml) and the mixture was heated under reflux for 22 hours with the exclusion of moisture. After cooling the reaction mixture to room temperature, it was filtered and the filtrate evaporated to dryness. The solid obtained was purified by flash chromatography over a silica gel column (2.5 x 15 cm) using ethyl acetate:ethanol:water (3:1:1) as the eluent. The homogeneous fractions were pooled and evaporated to yield 0.29 g (63%) of **23** as amorphous solid, mp 194-196° dec; ir: ν max 1690 (C=O), 3020-3560 (OH, NH, NH_2) cm^{-1}; uv (*p*H 1): λ max 305 nm (ε 7,200), 294 (3,800); (*p*H 7): λ max 297 nm (ε 3,800); (*p*H 11): λ max 265 nm (ε 6,600), 298 (3,700); ^1H nmr (DMSO-d_6): δ 6.02 (d, 1 H, J = 6.84 Hz, $C_{1'}H$), 7.77 (s, 1 H, C_3H), 7.8 (s, 2 H, NH_2), and other sugar protons; mass spec. (FAB) 284.09 (MH^+).

1-β-D-Ribofuranosylpyrrolo[3,2-*d*]pyrimidine-2,4(3*H*,5*H*)-dione (**26**).

In a similar manner as described for **7**, silylation of pyrrolo[3,2-*d*]pyrimidine-2,4(1*H*,3*H*,5*H*)-dione [24] (**24**, 1.0 g, 6.6 mmoles) with HMDS (20 ml) in the presence of pyridine (1 ml) and ammonium sulfate (30 mg), and subsequent glycosylation with **6** (4.0 g, 7.9 mmoles) in the presence of TMS triflate (1.8 ml, 9.6 mmoles) gave the crude reaction product which was purified by flash chromatography over a silica gel column (2.5 x 20 cm) using 20% acetone in chloroform as the eluent to yield 3.24 g (82%) of **25** as a glass, mp 142-143°; uv (methanol): λ max 230 nm (ε 58,400), 269 (21,600).

Debenzoylation of the above gummy **25** (3 g, 5.04 mmoles) with methanolic ammonia (100 ml), as described for **8**, gave 1.0 g (70%) of the title compound, mp 240°; ir: ν max 1685, 1710 (C=O), 2750-3500 (NH, OH) cm^{-1}; uv (*p*H 7): λ max 270 nm (ε 14,100); ^1H nmr (DMSO-d_6): δ 3.61 (m, 2 H, $C_{5'}CH_2$), 3.78 (m, 1 H, $C_{4'}H$), 4.06 (br s, 1 H, $C_{3'}H$), 4.39 (q, 1 H, $C_{2'}H$), 4.98 (q, 2 H, 2 OH), 5.17 (d, 1 H, OH), 5.94 (d, 1 H, J = 6.9 Hz, $C_{1'}H$), 6.42 (d, 1 H, J = 2.7 Hz, C_7H) and 7.18 (d, 1 H, J = 2.7 Hz, C_6H).

Anal. Calcd. for $C_{11}H_{13}N_3O_6 \cdot 0.3H_2O$: C, 45.77; H, 4.75; N, 14.56. Found: C, 45.56; H, 4.61; N, 14.40.

1-β-D-Ribofuranosyl-2-oxopyrrolo[3,2-*d*]pyrimidine-4(3*H*,5*H*)-thione (**28**).

In a similar manner as described for **13**, compound **25** (2 g, 3.36 mmoles) was converted to **27** using purified phosphorus pentasulfide (1.76 g, 3.97 mmoles). Purification of the reaction product on a flash silica gel column (3 x 25 cm) using 2% methanol in dichloromethane as eluent afforded **27** as a yellow foam. Treatment of compound **27** with methanolic ammonia (25 ml, saturated at 0°) at room temperature for 18 hours, followed by evaporation of methanol and purification of the debenzoylated product by flash chromatography on a silica gel column (2 x 20 cm) using ethyl acetate:*n*-propanol:water (4:1:2, upper phase) as eluent afforded an amorphous solid which was crystallized from aqueous ethanol to yield 0.26 g of the title compound, mp 224-226°; ir: ν max 1120 (C=S), 1680 (C=O), 3100-3400 (OH, NH) cm^{-1}; uv (*p*H 1): λ max 347 nm (ε 21,100), 268 (6,400); (*p*H 7): λ max 347 nm (ε 21,500), 267 (7,100); (*p*H 11): λ max 327 nm (ε 13,800), 286 (9,800); ^1H nmr (DMSO-d_6): δ 3.60 (m, 2 H, $C_{5'}CH_2$), 3.81 (m, 1 H, $C_{4'}H$), 4.05 (q, 1 H, $C_{3'}H$), 4.38 (q, 1 H, $C_{2'}H$), 5.02 (q, 2 H, 2 OH), 5.24 (d, 1 H, OH), 5.97 (d, 1 H, J = 6.9 Hz, $C_{1'}H$), 6.54 (d, 1 H, J = 2.7 Hz, C_7H), 7.35 (d, 1 H, J = 2.7 Hz, C_6H), 11.98 (s, 1 H, N_5H) and 12.14 (s, 1 H, N_3H).

Anal. Calcd. for $C_{11}H_{13}N_3O_5S$: C, 44.14; H, 4.38; N, 14.03; S, 10.71. Found: C, 43.91; H, 4.37; N, 14.19; S, 10.48.

1-β-D-Ribofuranosyl-2,2'-anhydropyrrolo[3,2-*d*]pyrimidin-4(5*H*)-one (**29**).

In a similar manner as described for **12**, reaction of 1-β-D-ribofuranosylpyrrolo[3,2-*d*]pyrimidine-2,4(3*H*,5*H*)-dione (**26**, 0.28 g, 1 mmole) with diphenyl carbonate (0.28 g, 1.2 mmoles) in hexamethylphosphoramide (1.5 ml) in the presence of sodium hydrogen carbonate (15 mg) gave the crude product. Crystallization of the product from aqueous methanol yielded 0.18 g (67%) of **29** as colorless needles, mp 238-241°; ir: ν max 1650 (C=O), 3100-3400 (OH, NH) cm^{-1}; uv (*p*H 1): λ max 269 nm (ε 13,100); (*p*H 7): λ max 269 nm (ε 13,800); (*p*H 11): λ max 269 nm (ε 13,600); ^1H nmr (DMSO-d_6): δ 4.92 (br s, 1 H, $C_{3'}OH$), 5.90 (br s, 1 H, $C_{5'}OH$), 6.24 (t, 1 H, $C_{1'}H$), 6.53 (d, 1 H, C_7H), 7.23 (d, 1 H, J = 2.7 Hz, C_6H), 12.04 (br s, 1 H, NH), and other sugar protons.

Anal. Calcd. for $C_{11}H_{11}N_3O_5$: C, 49.81; H, 4.18; N, 15.84. Found: C, 49.52; H, 3.90; N, 15.58.

1-β-D-Arabinofuranosylpyrrolo[3,2-*d*]pyrimidine-2,4(3*H*,5*H*)-dione (**34**) and 5-β-D-Arabinofuranosylpyrrolo[3,2-*d*]pyrimidine-2,4-(1*H*,3*H*)-dione (**35**).

In a similar manner as described for **17**, silylation of **24** (2 g, 13.23 mmoles) with HMDS (20 ml) in pyridine (8 ml) in the presence of ammonium sulfate (0.15 g) and subsequent glycosylation with **16** [prepared from 2,3,5-tri-*O*-benzyl-1-*O*-(*p*-nitrobenzoyl)-D-arabinose (8 g, 16.06 mmoles)] in the presence of tin(IV) chloride (0.7 ml) gave the crude reaction product, which was flash chromatographed over a silica gel column using 5% methanol in dichloromethane as the eluent to yield 6.2 g (85%) of a nucleoside product. The product was found to be a mixture of positional isomers **31** and **32** and the separation of these isomers using column chromatography was not successful in our hands.

Subsequent debenzoylation of the mixture of **31** and **32** (6.0 g, 10.84 mmoles) with palladium hydroxide (3.0 g, 20% on carbon), as described for the preparation of **18**, gave the crude reaction product. Purification of the crude product by preparative liquid chromatography (hplc) using 40% methanol in water as the eluent gave the following two nucleosides: 1-β-D-Arabinofuranosylpyrrolo[3,2-*d*]pyrimidine-2,4(3*H*,5*H*)-dione (**34**), crystallized from aqueous ethanol, yield 1.3 g (42%), mp 229-230°; ir: ν max 1690, 1710 (C=O), 2800-3600 (OH, NH) cm^{-1}; uv (*p*H 1): λ max 270 nm (ε 12,900); (*p*H 7): λ max 271 nm (ε 12,900); (*p*H 11): λ max 271 nm (ε 11,200); ^1H nmr (DMSO-d_6): δ 5.98 (d, 1 H, J = 7.38 Hz,

$C_{1'}H$), 6.15 (d, 1 H, J = 2.7 Hz, C_7H), 7.24 (d, 1 H, J = 2.64 Hz, C_6H), 11.4 (s, 1 H, 2 N*H*), and other sugar protons.

Anal. Calcd. for $C_{11}H_{13}N_3O_6 \cdot 0.55H_2O$: C, 45.07; H, 4.85; N, 14.3. Found: C, 45.34; H, 4.63; N, 13.79.

5-β-D-Arabinofuranosylpyrrolo[3,2-*d*]pyrimidine-2,4(1*H*,3*H*)-dione (**35**).

This compound was crystallized from water, yield 0.45 g (15%), mp 172-173°; ir: ν max 1685, 1715 (C=O), 2820-3560 (NH) cm^{-1}; uv (*p*H 1): λ max 271 nm (ε 10,700); (*p*H 7): λ max 270 nm (ε 18,300); (*p*H 11): λ max 272 nm (ε 10,700); ^1H nmr (DMSO-d_6): δ 6.12 (d, 1 H, J = 5.19 Hz, $C_{1'}H$), 6.43 (d, 1 H, J = 2.73 Hz, C_7H), 7.05 (d, 1 H, J = 2.7 Hz, C_6H), 11.3 (br s, 2 H, 2 N*H*), and other sugar protons.

Anal. Calcd. for $C_{11}H_{13}N_3O_6 \cdot 0.3H_2O$: C, 45.77; H, 4.75; N, 14.56. Found: C, 45.70; H, 4.58; N, 14.53.

1-(2,3,5-Tri-*O*-acetyl-β-D-arabinofuranosyl)pyrrolo[3,2-*d*]pyrimidine-2,4(3*H*,5*H*)-dione (**33**).

To a solution of **34** (0.71 g, 2.5 mmoles) in dry pyridine (5 ml) was added acetic anhydride (1 ml, 10.6 mmoles) and the mixture was stirred at room temperature for 2.5 hours. Methanol (1 ml) was added to the reaction mixture and after 30 minutes it was poured into saturated aqueous sodium hydrogen carbonate solution (30 ml). The aqueous mixture was extracted with chloroform (3 x 30 ml). The combined organic layer was dried over anhydrous sodium sulfate and evaporated to dryness. The residue thus obtained was purified by flash chromatography over a silica gel column (2 x 30 cm) using 2-4% ethanol in dichloromethane gradient as the eluent to yield 0.95 g (93%) of **33** as a colorless glass, mp 97-99°; ir: ν max 1685, 1710, 1750 (C=O), 2920-3500 (NH) cm^{-1}; uv (*p*H 1): λ max 271 nm (ε 15,200); (*p*H 7): λ max 270 nm (ε 15,200); (*p*H 11): λ max 275 nm (ε 13,700); ^1H nmr (DMSO-d_6): δ 6.17 (d, 1 H, J = 5.7 Hz, $C_{1'}H$), 6.25 (d, 1 H, J = 2.7 Hz, C_7H), 7.26 (d, 1 H, J = 2.7 Hz, C_6H), 11.1 (s, 1 H, N*H*), 12.19 (s, 1 H, N*H*), and other sugar protons.

Anal. Calcd. for $C_{17}H_{19}N_3O_9$: C, 49.88; H, 4.68; N, 10.26. Found: C, 49.60; H, 4.80; N, 9.99.

4-Methoxy-1-β-D-arabinofuranosylpyrrolo[3,2-*d*]pyrimidin-2(5*H*)-one (**37**).

To a solution of **33** (0.9 g, 2.2 mmoles) and 3-nitrotriazole (1 g, 8.8 mmoles) in dry pyridine (15 ml) was added diphenylchlorophosphate (1.82 ml, 8.8 mmoles) and the mixture was stirred at room temperature for 18 hours. Saturated aqueous sodium hydrogen carbonate (1 ml) was added to the reaction mixture and after stirring for 15 minutes it was diluted with dichloromethane (50 ml). The organic phase was washed with saturated aqueous sodium hydrogen carbonate solution (2 x 25 ml). The combined organic layers were dried over anhydrous sodium sulfate and evaporated to dryness. The residue thus obtained was purified by flash chromatography over a silica gel column (2 x 30 cm) using 2% ethanol in dichloromethane as the eluent to yield 0.46 g (41%) of **36** as a glass.

To a solution of **36** (0.35 g, 0.6 mmole) in methanol (5 ml) was added 30% ammonium hydroxide (5 ml) and the mixture was stirred at room temperature for 18 hours. The volatile solvents were evaporated under reduced pressure and the residual solid was purified by flash chromatography over a silica gel column (2 x 30 cm) using 20% methanol in dichloromethane as the eluent to yield 0.13 g (63%) of **37**, mp 220-222°; ir: ν max 1640 (C=O), 3000-3400 (OH, NH) cm^{-1}; uv (*p*H 1): λ max 288 nm (ε 15,200); (*p*H 7): 287 nm (ε 13,800); (*p*H 11): λ max 289 nm (ε 13,700); ^1H nmr (DMSO-d_6): δ 3.96 (s, 3 H, OCH_3), 6.1 (d, 1 H, J = 6.9 Hz, $C_{1'}H$), 6.23 (d, 1 H, J = 2.0 Hz, C_7H), 7.36 (d, 1 H, J = 2.0 Hz, C_6H), 12.05 (s, 1 H, N*H*), and other sugar protons.

Anal. Calcd. for $C_{12}H_{15}N_3O_6$: C, 48.49; H, 5.09; N, 14.13. Found: C, 48.69; H, 5.22; N, 13.94.

4-Amino-1-β-D-arabinofuranosylpyrrolo[3,2-*d*]pyrimidin-2(5*H*)-one (**38**).

To a solution of **36** (0.4 g, 1.19 mmoles) in dioxane (15 ml) was added 30% ammonium hydroxide (10 ml). After stirring for 18 hours at room temperature, the reaction mixture was evaporated to dryness and the residue was purified by flash chromatography over a silica gel column (3 x 20 cm) using 15% methanol in dichloromethane as the eluent. The homogeneous product was crystallized from aqueous ethanol to yield 0.2 g (59.7%) of **38**, mp 228-230°; ir: ν max 1655 (C=O), 3000-3600 (NH) cm^{-1}; uv (*p*H 1): λ max 286 nm (ε 15,500); (*p*H 7): λ max 284 nm (ε 12,700); (*p*H 11): λ max 285 nm (ε 12,400); ^1H nmr (DMSO-d_6): δ 6.04 (d, 1 H, J = 6.9 Hz, $C_{1'}H$), 6.12 (d, 1 H, J = 2.7 Hz, C_7H), 7.14 (d, 2 H, NH_2), 7.27 (d, 1 H, J = 2.7 Hz, C_6H), 11.1 (s, 1 H, N*H*), and other sugar protons.

Anal. Calcd. for $C_{11}H_{14}N_4O_5$: C, 46.81; H, 5.00; N, 19.85. Found: C, 46.60; H, 4.96; N, 19.71.

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[27] Least-Squares:

Function minimized: $\Sigma w(|\,Fo\,|-|\,Fc\,|)^2$

Where: $w = 4Fo^2/\sigma^2(Fo^2)$

$\sigma^2(Fo^2) = [S^2(C+R^2B)+(pFo^2)^2]/LP^2$

S = Scan rate

C = Total Integrated Peak Count

R = Ratio of Scan Time to background counting time

B = Total Background Count

Lp = Lorentz-polarization factor

p = p-factor

[28] Standard deviation of an observation of unit weight:

$[\Sigma w(|\,Fo\,|-|\,Fc\,|)^2/(No-Nv)]^{1/2}$

where: No = number of observations

Nv = number of variables

[29] D. T. Cromer and J. T. Waber, International Tables for X-ray Crystallography, Vol **IV**, The Kynoch Press, Birmingham, England, Table 2.2 A, 1974.

[30] J. A. Ibers and W. C. Hamilton, *Acta Crystallog.*, **17**, 781 (1964).

[31] D. T. Cromer, International Tables for X-ray Crystallography, Vol **IV**, The Kynock Press, Birmingham, England, Table 2.3.1, 1974.

[32] TEXSAN-TEXRAY Structure Analysis Package, Molecular Structure Corporation, The Woodlands, Texas, 1985.