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STRUCTURAL FEATURES OF *N*-ACYLCYTISINES

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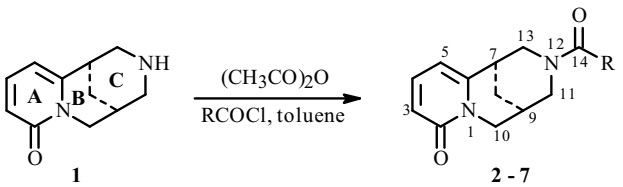
N-*Acyl cytisine derivatives were synthesized by acylation with acetic anhydride; benzoyl and* o-*bromo- and* p-*nitrobenzoyl chlorides; and crotonyl and cinnamoyl chlorides. The structures of the synthesized compounds were studied using IR, PMR, and x-ray structure analysis (XSA). PMR spectra of the* N-*acylcytisines in solution typically had two rotational isomers around the N12–CO bond. Conformational analysis was performed using XSA for the position of the acyl group relative to the cytisine core. Bond lengths and angles of the acyl groups involved in the conjugation were analyzed.*

Key words: alkaloids, cytisine derivatives, IR spectroscopy, PMR spectroscopy, x-ray structure analysis.

The broad spectrum of biological activity of cytisine (**1**) and its derivatives [1, 2] makes them a promising class for practical application. On the other hand, the chiral 3,7-diazobicyclo[3.3.1]nonane skeleton is interesting for studying structural features of substituted cytisines [3–6]. Until now, a large number of cytisine derivatives with various groups on the N atom have been synthesized [7–12], including acryloyl groups [13], thiazoles, benzthiazoles [11], and 1,2,4-thiadiazole groups [12]. In continuation of our research on transformations of **1** [11, 12] and in order to find biologically active compounds in this series, we synthesized acyl derivatives via acylation of **1** with acetic anhydride and acid chlorides. The acylating agents were acetic anhydride; benzoyl- and *o*-bromo- and *p*-nitrobenzoyl chlorides; and crotonyl and cinnamoyl chlorides. The reaction with acetic anhydride occurred with an excess of it. Acylation by the acid chlorides occurred in anhydrous toluene under reflux:



1 **2 - 7**

R = -CH_3 (**2**); -C_6H_5 (**3**); -C_6H_4-Br-*o* (**4**); -C_6H_4-NO_2-*n* (**5**); -CH=CH-C_6H_5 (**6**); -CH=CH-CH_3 (**7**)

Acylation of **1** by acid chlorides was carried out without a HCl acceptor. Atom N12 of ring C played this role. Structures of **2**–**7** were confirmed by IR and PMR spectra and by an x-ray structure analysis (XSA) for *N*-*o*-bromobenzoylcytisine (**4**), *N*-*p*-nitrobenzoylcytisine (**5**), and *N*-crotonylcytisine (**6**).

IR spectra contained absorption bands at 1643–1653 cm^{-1} (ν_{CO}) and 1634–1647 (ν_{CO}). The physicochemical properties of **2**, **3**, and **7** agreed with those published. PMR spectra of the *N*-acylcytisines in solution characteristically showed several rotational isomers around the N12–CO and CO–R bonds. They could produce spectra of several conformers or simply give very broad spectral lines because the barriers to rotation were small. In several instances resonances could not be unambiguously assigned.

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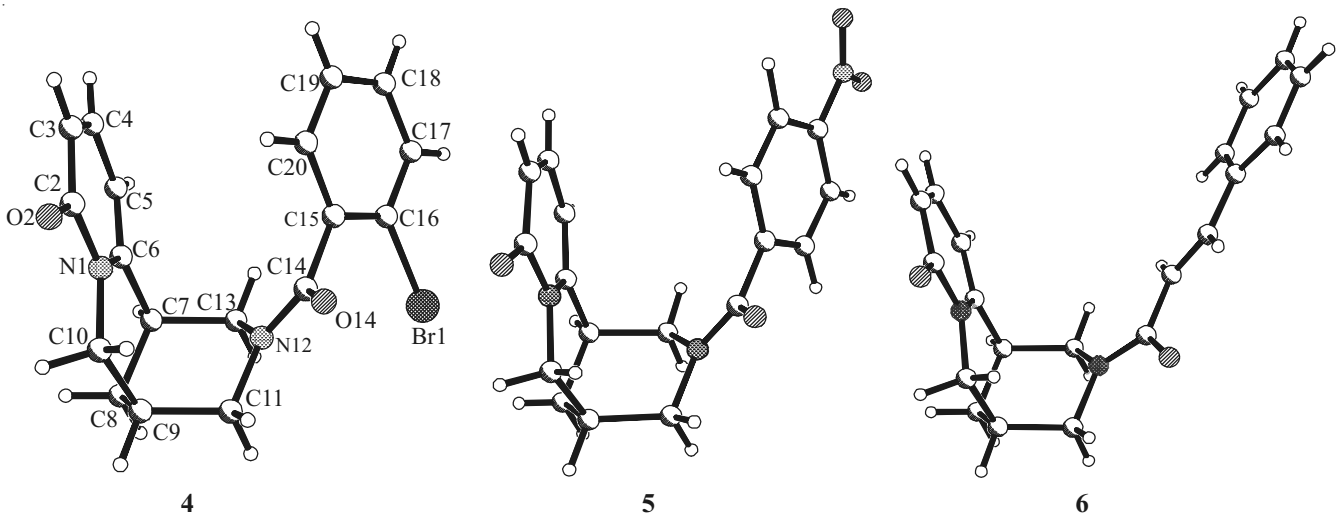

Fig. 1. Molecular structures of **4**–**6**.

The PMR spectrum of **3** was studied in most detail. A characteristic of this compound was that all resonances in $CHCl_3$ at room temperature (20–22°C) were very strongly broadened and overlapped so much that only resonances of H-3, H-5, H-9, and the methylene pair H-8 could be identified individually. Heating the sample to 58°C and the accelerated rotation around the N–CO bond because of this caused all resonances to narrow. The chemical shifts from all chemical groups in the molecule could be determined. However, the presence of the barrier to rotation was still observed from the very characteristic resonances of methylene protons H-11 and H-13. The axial components of these methylene proton pairs appeared as two completely resolved doublets with J = 12.5 Hz at about 3.10 ppm. The equatorial protons of these methylenes formed one common resonance at ~4.3 ppm with a width of about 80 Hz.

The positions of the resonances for the benzoyl aromatic protons in this spectrum were unusual. The α-protons of the aromatic ring at 58°C appeared as a poorly resolved doublet of doublets (J = 8.0 and 2.0 Hz) at 6.92 ppm. The other aromatic protons together with H-4 of cytisine itself resonated at ~7.24 ppm as a complicated 4H multiplet. The unusual position of the resonance for the benzoyl α-protons was apparently due to the conjugation of its carbonyl with N12 of cytisine.

X-ray structure analyses of **4**–**6** were performed in order to establish reliably the structures of the synthesized compounds. The results allowed most PMR resonances of the synthesized *N*-acyl cytisine derivatives to be assigned.

The XSA showed that **4** crystallized without solvent; **5**, as a hemihydrate; **6**, as a monohydrate. Figure 1 shows the molecular structures of **4**–**6** in the crystals in approximately the same projection (perpendicular to the plane of C7, C9, C11, C13 of ring C). The cytisine core in these derivatives had the same conformation. Pseudoaromatic ring A was planar (within ±0.01 Å for **4**; ±0.03, **5**; ±0.01, **6**). The next six-membered ring B adopted the chair conformation (±0.04 Å, **4**; ±0.06, **5**; ±0.02, **6**) with C8 deviating from the plane of the other five atoms by 0.72 Å (**4**), 0.74 (**5**), and 0.74 (**6**). The third six-membered ring C adopted an ideal chair conformation.

However, PMR spectra of the *N*-acylcytisines showed that the acyl groups tended to form rotational isomers. For this reason it seemed interesting to perform a stereochemical analysis of the conformationally fluxional acyl groups.

Atom N12 in these cytisine derivatives has sp^2 hybridization because the unshared electron pair of N12 is conjugated to the π-electrons of the C14 carbonyl, which is evident in the torsion angles C11–N12–C14–C15 (179.2°, 177.6, and 178.8) and the sum of the bond angles around N12 (359.7°, 359.0, and 359.8 in **4**–**6**, respectively) (Table 1). The C14=O14 carbonyl was also situated parallel to the plane of C11, N12, C13, and C14 in *N*-crotonylcytisine (**7**), *N*-betamorpholinepropionylcytisine [3], and in other cytisine derivatives [4]. This shows that formation of the conjugated system is favored. Carbonyl C14 was oriented such that it was *syn* to the other carbonyl (C2=O2) (of the two possible *syn* and *anti* orientations) (Fig. 1). Such mutual placement of carbonyls is also characteristic of known cytisine acyl derivatives.

TABLE 1. Bond Lengths (Å) and Angles (°) in **4**–**6**

Bond	**4**	**5**	**6**	Angle	**4**	**5**	**6**
Br1-C16	1.895(5)			C6-N1-C2	122.7(4)	123.6(4)	122.49(18)
N1-C6	1.369(5)	1.387(6)	1.375(3)	C6-N1-C10	122.6(4)	122.2(4)	122.76(17)
N1-C2	1.395(6)	1.413(6)	1.393(3)	C2-N1-C10	114.6(4)	114.1(4)	114.50(17)
N1-C10	1.485(5)	1.494(6)	1.483(3)	C14-N12-C13	125.1(4)	125.8(4)	126.7(2)
O2-C2	1.232(6)	1.237(6)	1.243(3)	C14-N12-C11	119.9(4)	119.8(4)	119.4(2)
O14-C14	1.229(5)	1.232(6)	1.231(3)	C13-N12-C11	114.6(4)	113.4(4)	113.61(19)
N12-C14	1.348(6)	1.363(6)	1.347(3)	O14-C14-N12	123.1(4)	123.5(5)	120.7(2)
N12-C13	1.447(5)	1.471(6)	1.453(3)	O14-C14-C15	118.8(4)	118.0(5)	120.3(2)
N12-C11	1.463(6)	1.482(6)	1.463(3)	N12-C14-C15	118.1(4)	118.5(4)	119.0(2)
C14-C15	1.498(6)	1.533(7)	1.485(3)	C5-C6-N1	120.1(4)	118.8(5)	119.3(2)
C6-C5	1.349(6)	1.367(7)	1.354(3)	C5-C6-C7	120.7(4)	121.5(5)	122.0(2)
C6-C7	1.512(6)	1.520(6)	1.495(3)	N1-C6-C7	119.1(4)	119.6(4)	118.7(2)
C15-C16	1.379(6)	1.392(7)	1.297(3)	C16-C15-C20	117.9(5)	119.9(5)	
C15-C20	1.403(7)	1.398(8)		C16-C15-C14	124.4(4)	121.6(5)	120.5(2)
C2-C3	1.435(7)	1.434(7)	1.413(3)	C20-C15-C14	117.5(4)	118.3(5)	
C13-C7	1.541(6)	1.540(7)	1.529(3)	O2-C2-N1	119.7(4)	119.6(4)	118.8(2)
C7-C8	1.522(6)	1.539(7)	1.518(3)	O2-C2-C3	124.8(5)	126.0(5)	125.0(2)
C10-C9	1.509(7)	1.518(7)	1.518(3)	N1-C2-C3	115.5(4)	114.4(5)	116.2(2)
C8-C9	1.520(7)	1.526(7)	1.517(4)	N12-C13-C7	110.1(3)	109.4(4)	111.23(17)
C5-C4	1.400(7)	1.410(8)	1.396(3)	C6-C7-C8	111.5(3)	111.7(4)	110.29(18)
C16-C17	1.399(8)	1.381(7)	1.459(3)	C6-C7-C13	108.1(3)	107.8(4)	111.08(18)
C9-C11	1.529(7)	1.530(7)	1.521(4)	C8-C7-C13	110.0(4)	110.0(4)	110.3(2)
C3-C4	1.342(8)	1.346(9)	1.349(4)	N1-C10-C9	114.9(3)	114.4(4)	115.07(18)
C17-C18	1.377(11)	1.398(7)	1.386(4)	C9-C8-C7	106.6(3)	106.3(4)	106.48(19)
C18-C19	1.399(11)	1.368(8)	1.382(3)	C6-C5-C4	120.0(4)	119.9(5)	120.5(2)
C19-C20	1.353(9)	1.397(9)	1.370(4)	C15-C16-C17	121.6(5)	120.2(5)	129.2(2)
O4-N2		1.210(6)		C15-C16-Br1	120.6(4)		
N2-O3		1.218(6)		C17-C16-Br1	117.8(4)		
N2-C18		1.493(7)		C10-C9-C8	110.1(4)	108.9(4)	110.4(2)
C17-C22			1.391(3)	C10-C9-C11	112.6(4)	113.3(4)	112.3(2)
C22-C21			1.370(4)	C8-C9-C11	110.6(4)	111.3(4)	110.3(2)
C20-C21			1.370(5)	N12-C11-C9	110.2(3)	112.4(4)	110.5(2)
				C4-C3-C2	121.4(4)	122.0(5)	121.6(2)
				C18-C17-C16	118.8(6)	118.7(5)	118.6(2)
				C3-C4-C5	120.4(4)	120.9(5)	120.0(2)
				C17-C18-C19	120.3(6)	122.5(5)	120.9(3)
				C20-C19-C18	120.0(6)	118.4(5)	119.5(3)
				C19-C20-C15	121.5(5)	120.2(5)	
				O4-N2-O3		123.9(5)	
				O4-N2-C18		118.1(4)	
				O3-N2-C18		118.0(5)	
				C19-C18-N2		118.5(5)	
				C17-C18-N2		119.0(4)	
				C20-C21-C22			120.8(3)
				C21-C20-C19			120.2(2)
				C21-C22-C17			120.1(3)
				C18-C17-C22			118.5(2)
				C22-C17-C16			122.9(2)

Steric repulsion between the equatorial H atom (C-13-H) and the Br atom in **4** and the aromatic C16 H atom in **5** interfered with conjugation between the π-electron systems of the aromatic ring and the C14=O14 double bond, where the N12–C14–C15–C16 torsion angle was –71.5° and –58.5°, respectively. However, the bulky cinnamoyl group in **6**, which was bonded to N12, was planar (within ±0.083 Å) and there was no stereochemical hindrance to destroy the conjugation (mesomeric effect). Neighboring C14=O14 and C15=C16 double bonds were mutually *cis* oriented, as was observed in **7** [3].

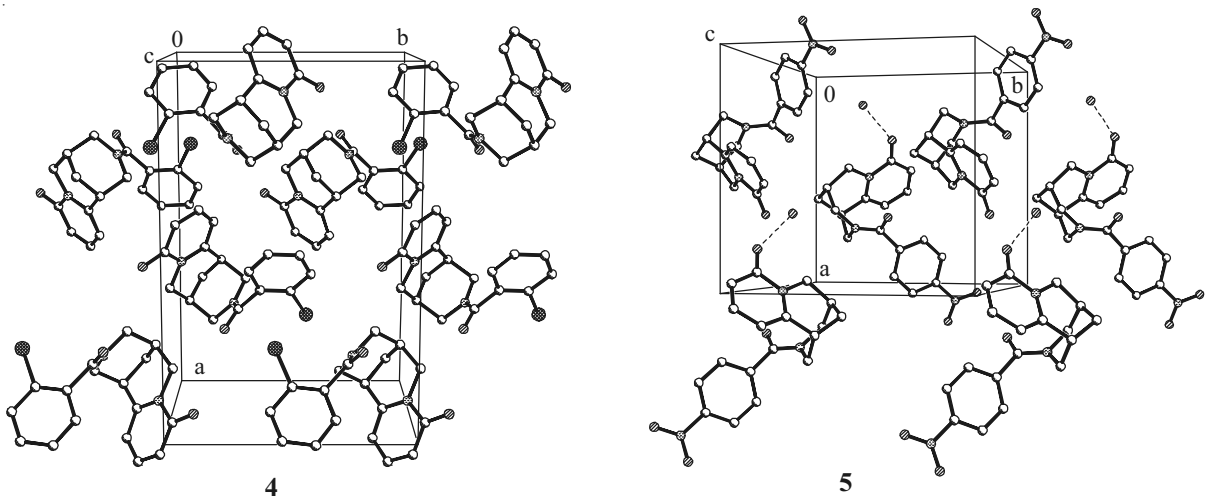

Fig. 2. Molecular packing of **4** and **5**.

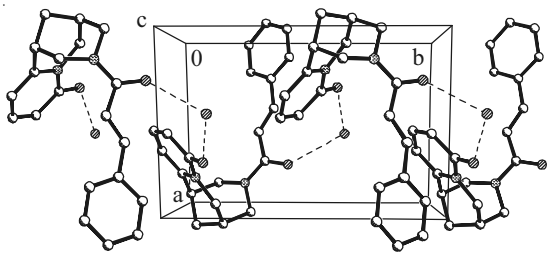

Fig. 3. Molecular packing of **6**.

The aforementioned mesomeric effects were also evident in the change of C14=O14, C14–N12, and C14–C15 bond lengths compared with their statistical mean values. The C14 carbonyl bond lengths lengthened to 1.229(5) Å, 1.232(6), and 1.231(3) and were comparable with those observed for C2=O2 of pseudoaromatic ring A of 1.232(6) Å, 1.238(6), and 1.243(3). Heterobonds C14–N12 were shortened to 1.348(5) Å, 1.363(7), and 1.347(3) in **4**–**6**, respectively. Several bonds in **6** were markedly shortened, e.g., C14–C15 [1.485(3) Å], C15=C16 [1.297(3)], and C16–C17 [1.459(3)], although the C14–C15 bonds in **4** and **5** were 1.498(5) and 1.533(7), respectively. Table 1 lists bond lengths and angles involving nonhydrogen atoms in **4**–**6**.

Figure 2 shows the molecular packing of **4** in the crystal. The molecules are situated at van-der-Waals distances. Noticeably shortened intermolecular contacts were not observed.

Compound **5** crystallized as a hemihydrate (Fig. 2) because the multiplicity (degree of position population) of the water O atom in the crystal cell was 0.13. An analysis of intermolecular contacts showed that the crystal had intermolecular H-bonds involving (not periodical) water and the carbonyl O of ring A (O1...O1w, 2.827 Å).

Figure 3 shows the molecular packing of **6** in the crystal. Compound **6** crystallized as a monohydrate. The crystal contained intermolecular H-bonds involving the two H atoms of a water molecule according to the scheme O2...H1–O1w and O1w–H2...O3.

The *N*-cinnamoylcytisine molecules formed an infinite chain of H-bonds along the *b* axis through the water of crystallization. The O2...H1w–O1w H-bond parameters were O2...O1w, 2.847 Å, O2...H1w, 1.92 Å, O2...H1–O1w, 169°; O1w–H2...O3 H-bond parameters, O1w...O3, 2.903, H2w...O3, 2.13 Å, O1w–H2...O3, 162°.

TABLE 2. Principal Crystallographic Parameters and Characteristics of X-ray Structure Analysis for **4**–**6**

Structure	**4**	**5**	**6**
Molecular formula	$C_{18}H_{17}N_2O_2Br$	$C_{18}H_{17}N_3O_4 \cdot H_2O$	$C_{20}H_{20}N_2O_2 \cdot H_2O$
MW	373.25	339.35	338.40
System	Orthorhombic	Orthorhombic	Monoclinic
Space group	$P2_12_12_1$	$P2_12_12_1$	$P2_1$
Z	4	4	2
a, Å	15.9128 (5)	10.899 (2)	7.7220 (15)
b, Å	10.6955 (3)	11.388 (2)	11.181 (2)
c, Å	9.5252 (4)	13.678 (3)	10.667 (2)
β	90.00	90.00	105.56 (3)
V, Å^3	1621.14 (10)	1697.7 (6)	887.2 (3)
ρ, g/cm^3	1.529	1.328	1.267
Crystal size, mm	0.25×0.50×0.65	0.35×0.50×0.75	0.35×0.45×0.50
Scan range 2θ	9.96≤θ≤151.8°	3.6≤θ≤55.0°	3.6≤θ≤52.0°
μ_{exp}, mm^{-1}	3.549	0.096	0.086
Number of reflections	2709	2210	1836
Number of reflections with I>2σ (I)	2634	1547	1725
R_1 (I>2σ (I) and total)	0.0531 (0.0541)	0.0628 (0.0951)	0.0389 (0.0425)
wR_2	0.1426 (0.1439)	0.1728 (0.2072)	0.0977 (0.1017)
S	1.006	0.969	1.157
Electron-density difference peaks, e Å^{-3}	0.842 and –1.359	0.165 and –0.181	0.169 and –0.244

EXPERIMENTAL

IR spectra were recorded on a Perkin–Elmer Model 2000 Fourier-IR spectrometer; PMR spectra in $CDCl_3$ and CD_3OD solutions, on Tesla B 567 (operating frequency 100 MHz) and Unity-400+ (operating frequency 400 MHz) spectrometers with hexamethyldisiloxane (HMDSO) internal standard.

***N*-Acetylcytisine (2).** Cytisine (1.9 g, 0.01 mol) was mixed with acetic anhydride (5 mL) and completely dissolved after a certain time. The mixture was left overnight. The resulting crystals were filtered off, washed with anhydrous ether, and dried to afford white crystals, yield 2.05 g (88.4%), mp 210°C (ether) (agreed with the literature [1]), R_f 0.12 (Silufol, acetone:$CHCl_3$, 1:1).

IR spectrum (KBr, ν, cm^{-1}): 3444, 3287, 3087, 3049, 2951, 2931, 1634, 1617, 1578, 1562, 1546, 1452, 1439, 1342, 1332, 1308, 1259, 1155, 1139, 796.

The PMR spectrum (100 MHz, CD_3OD, δ, ppm, J/Hz) at room temperature showed two conformers. Protons H-4, H-5, and H-7 and the methyl gave two resonances each. Protons H-3, H-9, and both H-8 protons appeared as individual singular resonances. Resonances of the other protons could not be assigned. 1.60 and 1.95 (3H, s, CH_3), 2.05 (2H, m, H-8), 2.49 (1H, br.s, H-9), 2.80 and 2.93 (H, m, H-7), 6.29 (H, d, $J_{5,4}$ = 7.7, H-5), 6.34 and 6.36 (H, d, $J_{3,4}$ = 9.0, H-3), 7.40 and 7.43 (H, dd, $J_{4,3}$ = 9.0, $J_{4,5}$ = 7.7, H-4).

***N*-Benzoylcytisine (3).** A mixture of cytisine (1.9 g, 0.01 mol) and benzoylchloride (1.55 g, 0.011 mol) in toluene (50 mL) was refluxed for 2 h and cooled. Yield 1.56 g (53.1%). It was recrystallized from acetone:ether (1:2), R_f 0.53 (Silufol, acetone:$CHCl_3$, 1:1), mp 116°C (agreed with the literature [1]).

IR spectrum (KBr, ν, cm^{-1}): 3450, 3238, 3087, 3052, 2942, 2911, 1651, 1625, 1577, 1569, 1546, 1450, 1439, 1349, 1304, 1272, 1240, 1225, 1180, 807, 792.

PMR spectrum (400 MHz, $CDCl_3$, δ, ppm, J/Hz, 58°C): 1.97 (2H, m, H-8), 2.41 (1H, br.s, H-9), 2.96 (1H, br.s, H-7), 3.09 (1H, d, $J_{11,11}$ = 12.5, H_{ax}-11*), 3.12 (1H, d, $J_{13,13}$ = 12.5, H_{ax}-13*), 3.77 (1H, dd, $J_{10,10}$ = 15.7, $J_{10,9}$ = 6.3, Ha-10), 4.14 (H, d, $J_{10,10}$ = 15.7, Hb-10), 4.30 (2H, br.s, H_{eq}-11 + H_{eq}-13), 5.90 (1H, br.s, H-5), 6.48 (1H, dd, $J_{3,4}$ = 9.1, $J_{3,5}$ = 1.3, H-3), 6.92 (2H, dd, J_{ortho} = 8.0, J_{meta} = 2.0, Hα-benzoyl), 7.17–7.30 (4H, m, H-4, Hβ + Hγ-benzoyl).

***N*-*o*-Bromobenzoylcytisine (4).** The reaction was performed analogously to that above. Cytisine (1.9 g, 0.01 mol) and *o*-bromobenzoylchloride (2.41 g, 0.011 mol) produced white crystals (1.5 g, 40%), mp 245-246°C, R_f 0.15 (Silufol, benzene:acetone, 2:1).

IR spectrum (KBr, ν, cm^{-1}): 3052, 2941, 1717, 1651, 1626, 1563, 1482, 1422, 1368, 1323, 1256, 1168, 1144, 816, 771.

The PMR spectrum (100 MHz, $CDCl_3$, δ, ppm, J/Hz) at room temperature showed highly broadened resonances that overlapped each other. This prevented unambiguous assignment for some of them. 2.00 (2H, m, H-8), 2.30 and 2.60 (1H, br.s, H-9), ~3.00 (1H, br.s, H-7), 5.70 and 6.10 (1H, d, $J_{5,4}$ = 7.0, H-5), 6.30 (1H, m, Hα-benzoyl), 6.46 (1H, d, $J_{3,4}$ = 9.0, H-3), 6.75–7.60 (4H, m, H-4, Hβ + Hγ-benzoyl).

***N*-*p*-Nitrobenzoylcytisine (5).** A mixture of cytisine (1.9 g, 0.01 mol) and *p*-nitrobenzoylchloride (2.04 g, 0.011 mol) in toluene (50 mL) was refluxed for 2 h and cooled. The resulting crystals were filtered off, washed with water, and dried. It was recrystallized from acetone:hexane to give shiny white crystals, yield 1.9 g (56%), mp 205–206°C, R_f 0.51 (Silufol, acetone:$CHCl_3$, 1:1).

IR spectrum (KBr, ν, cm^{-1}): 3444, 3253, 3097, 3052, 2945, 2917, 1653, 1634, 1598, 1568, 1543, 1474, 1456, 1431, 1347, 1306, 1270, 1244, 1160, 802, 770.

The PMR spectrum (100 MHz, CD_3OD, δ, ppm, J/Hz) at room temperature showed that all resonances were highly broadened. 2.10 (2H, m, H-8), 2.40 and 2.60 (1H, br.s, H-9), 3.15 (1H, m, H-7), 6.05 (1H, br.d, $J_{5,3}$ = 7.0, H-5), 6.50 (1H, dd, $J_{3,4}$ = 9.0, $J_{3,5}$ = 1.5, H-3), 7.00 (2H, br.d, J_{ortho} ~ 8.0, Hα-benzoyl), 7.45 (1H, m, H-4), 8.15 (2H, br.d, J_{ortho} ~ 8.0, Hβ-benzoyl).

***N*-Cinnamoylcytisine (6)** was synthesized analogously as above from cytisine (1.9 g, 0.01 mol) and cinnamoylchloride (1.83 g, 0.011 mol) in toluene (50 mL) to afford **6** (1.58 g, 45%), mp 119–120°C (benzene:hexane, 1:3), R_f 0.18 (Silufol, benzene:acetone, 2:1), lit. [7] mp 104°C.

IR spectrum (KBr, ν, cm^{-1}): 3483, 3420, 3049, 2939, 1643, 1584, 1562, 1547, 1499, 1457, 1440, 1360, 1312, 1276, 1155, 810, 771.

The PMR spectrum (100 MHz, $CDCl_3$, δ, ppm, J/Hz) showed that only the resonances for methylene H-11 and H-13 were highly broadened. 2.00 (2H, m, H-8), 2.48 (1H, br.s, H-9), 2.90–3.30 (3H, m, H-7, H_{ax}-11, H_{ax}-13), 3.80 (1H, dd, $J_{10,10}$ = 16.0, $J_{10,9}$ = 7.0, Ha-10), 4.13 (1H, d, $J_{10,10}$ = 16.0, Hb-10), 4.37 (2H, br.s, H_{eq}-11 + H_{eq}-13), 6.04 (1H, dd, $J_{5,4}$ = 7.0, $J_{5,3}$ = 1.5, H-5), 6.37 (1H, dd, $J_{3,4}$ = 8.0, $J_{3,5}$ = 1.3, H-3), 6.54 (1H, d, $J_{1',2'}$ = 16.0, H-1′), 7.20–7.45 (7H, m, H-4, H-2′, H_{arom}).

***N*-Crotonylcytisine (7).** A solution of cytisine (1.9 g, 0.01 mol) and crotonylchloride (1.055 g, 1.15 mL = 0.011 mol) in anhydrous toluene was refluxed for 2 h and cooled. The product was obtained as an oil that crystallized upon standing, mp 115–116°C (benzene:hexane, 1:3), lit. [7] mp 112–114°C, R_f 0.20 (Silufol, benzene:acetone, 2:1), yield 1.29 g (50%).

IR spectrum (oil, ν, cm^{-1}): 3432, 3059, 2992, 2942, 1707, 1660, 1651, 1645, 1634, 1567, 1548, 1494, 1429, 1348, 1274, 1162, 1142, 887, 800, 751.

The PMR spectrum (100 MHz, $CDCl_3$, δ, ppm, J/Hz) showed that only methylene protons H-11 and H-13 were highly broadened. 1.72 (3H, dd, $J_{3',2'}$ = 7.7, $J_{3',1'}$ = 1.5, H-3′), 1.98 (2H, m, H-8), 2.45 (1H, br.s, H-9), 3.05 (3H, br.s, H-7, H_{ax}-11, H_{ax}-13), 3.75 (1H, dd, $J_{10,10}$ = 16.0, $J_{10,9}$ = 6.0, Ha-10), 4.08 (1H, d, $J_{10,10}$ = 15.7, Hb-10), 4.30 (2H, br.s, H_{eq}-11, H_{eq}-13), 5.95 (1H, d, $J_{1',2'}$ = 17.0, H-1′), 6.01 (1H, dd, $J_{5,4}$ = 7.0, $J_{5,3}$ = 1.5, H-5), 6.35 (1H, dd, $J_{3,4}$ = 8.0, $J_{3,5}$ = 1.5, H-3), 6.60 (1H, dq, $J_{2',1'}$ = 17.0, $J_{2',3'}$ = 7.7, H-2′), 7.20 (1H, dd, $J_{4,3}$ = 8.0, $J_{4,5}$ = 7.0, H-4).

X-ray Structure Analyses. Single crystals for XSA were produced by slow evaporation from the appropriate solvents at room temperature. Unit-cell constants of **4** were determined and refined on a CCD Xcalibur diffractometer (Oxford Diffraction); of **5** and **6**, on a Stoe Stadi-4 diffractometer (300 K, graphite monochromator). Table 2 lists the principal parameters of the XSA and the calculations. A three-dimensional data set of reflections was collected on the same respective diffractometers with ω/2ω-scanning using Cu K_α-radiation for **4** and Mo K_α-radiation for **5** and **6**. Absorption corrections were applied for the structure of **4** using the Multi-scan method and were not applied for **5** and **6**.

Structures of **4**–**6** were solved by direct methods using the SHELXS-97 programs and were refined using the SHELXL-97 program. All nonhydrogen atoms were refined by full-matrix least-squares methods (over F^2). Positions of H atoms in the structures of **4** and **6** were found geometrically and refined with fixed isotropic thermal parameters $U_{iso} = nU_{eq}$, where n = 1.2 for all types of H atoms and U_{eq} was the equivalent isotropic thermal parameter of the corresponding C atom. All H atoms in the structure of **5** and the H atoms of the water of crystallization in the structure of **6** were found from difference electron-density (ED) syntheses. The difference ED syntheses of the structure of **5** during refinement showed a distinct peak located at nonbonding distance from the molecule. Designating this as an O atom from a water molecule, the multiplicity was refined and gave a value of 0.13. This indicated that **5** was a hemihydrate. The H atoms could not be found experimentally.

Data from the XSA were deposited as CIF files in the Cambridge Crystallographic Data Centre (CCDC 736505, 736506, 736507 for **4**–**6**, respectively).

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