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[2+2+2]-COCYCLOTRIMERIZATION OF 6-ALKYNYL-7-BENZYL-PURINES WITH α,ω-DIYNES

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Abstract – 6-Alkynyl-7-benzylpurines were prepared by the Sonogashira reaction from 6-chloro-7-benzylpurines and terminal alkynes. The prepared alkynylpurines were cyclotrimerized with various 1,6-diynes in the presence of $Ni(cod)_2/2PPh_3$ catalytic system into the corresponding 6-aryl-7-benzylpurines under ambient conditions. The prepared 6-alkynyl- and 6-aryl-7-benzylpurines were tested for cytostatic activity.

INTRODUCTION

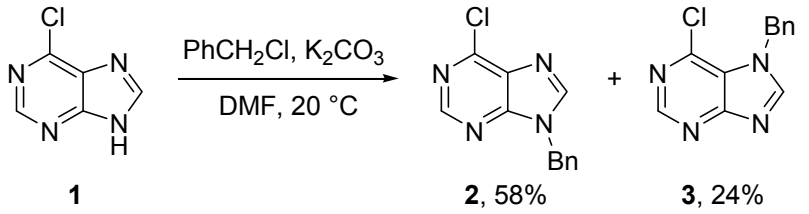
Purine bases and nucleosides bearing aryl moiety in the position 6 display diverse types of biological activity: some substituted 6-arylpurine bases are antagonists of corticotropin-releasing hormone,[1] or adenosine receptors,[2] or possess antimycobacterial and antibacterial activity,[3] while 6-arylpurine ribonucleosides show significant cytostatics[4] and anti-HCV[5] effect. Also 6-alkynylpurines are potent cytostatics[6] and inhibit 15-lipoxygenase.[7] All the above mentioned facts provided necessary impetus for synthesis of various derivatives and study of their properties. In our previous reports we studied catalytic cyclotrimerization of 6-alkynylpurines with α,ω-diynes in the presence of various transition metal complexes ($CoBr(PPh_3)_3$), $RhCl(PPh_3)_3$), $[IrCl(cod)]_2$, Cp_2Ni, $NiBr_2(PPh_3)_2/Zn$, $NiI_2(PPh_3)_2/Zn$, $NiBr_2$(dppe)/Zn, $Ni(cod)_2/PPh_3$, etc.).[8-10] The highest yields of the desired 9-Bn- or 9-THP-protected 6-arylpurines were obtained when the Ni(0)-catalyst was generated "in situ" from $NiBr_2$(dppe)/Zn.[8,9]

This paper is dedicated to Prof. Dr. Albert Eschenmoser on the occasion of his 85th birthday

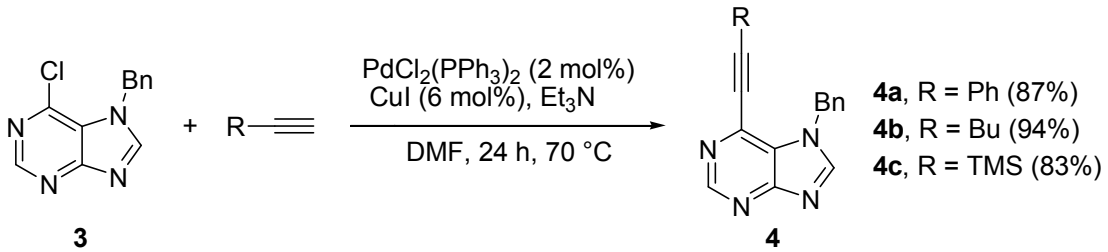
Later we showed further that increase in yields of the 6-arylpurines could be achieved by using the more effective catalytic system based on the use of $Ni(cod)_2/2PPh_3$.[10] Herein we would like to report on the use of the $Ni(cod)_2/2PPh_3$ catalytic system for the synthesis of 6-aryl-7-benzylpurines. In addition to the primary interest in biological properties of 6-aryl-7-benzylpurines, steric effect of benzyl group in the near vicinity of the triple bond on the course of the cyclotrimerization reaction was worthy of exploring.

RESULTS AND DISCUSSION

We envisioned that the same synthetic strategy used for the synthesis of 9-protected 6-arylpurines, i.e. Ni-catalyzed cyclotrimerization, could be also applied for preparation of 7-protected 6-arylpurines. The first step concerned a preparation of protected 7-benzyl-6-chloro-7-*H*-purine **3**. The starting material, commercially available 6-chloro-9-*H*-purine **1**, was dissolved with potassium carbonate in DMF and alkylated with benzyl chloride. Workup of the reaction mixture resulted in the isolation of two compounds: 9-benzyl-6-chloropurine **2** (58%) as the major product and 7-benzyl-6-chloropurine **3** (24%) as the minor product (Scheme 1). Then the Sonogashira reaction under standard reaction conditions of 7-benzyl-6-chloropurine **3** with three different alkynes (trimethylsilylethyne, hex-1-yne, and phenylethyne) gave rise to the alkynyl purines **4a-4c** in good yields (83-94%, isolated) (Scheme 2).



Scheme 1. Alkylation of **1** to amixture of **2** and **3**

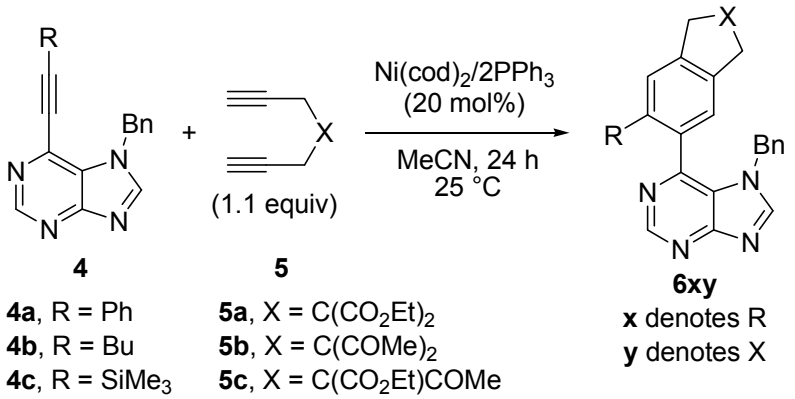


Scheme 2. Sonogashira cross-coupling reaction of 7- benzyl-6-chloropurine with alkynes

Recently, we have found, that 6-arylpurines bearing various groups in the position 9 (benzyl, tetrahydropyranyl, and ribosyl) could be achieved by [2+2+2]-cocyclotrimerization reactions.[8-10] These cocyclotrimerizations were carried out in the presence of various catalysis such as $CoBr(PPh_3)_3$, $RhCl(PPh_3)_3$, $[IrCl(cod)]_2$, Cp_2Ni, $NiBr_2(PPh_3)_2/Zn$, $NiI_2(PPh_3)_2/Zn$, $NiBr_2(dppe)/Zn$, $Ni(cod)_2/PPh_3$, etc

in various solvents. The best yields of the corresponding products were obtained in cyclotrimerizations catalyzed by the catalytic system composed of $Ni(cod)_2/PPh_3$ in MeCN and 20 °C. Thus we decided to apply the same Ni(0)-based protocol for the cyclotrimerization reactions of 6-alkynyl-7-benzylpurines **4** with α,ω-diynes **5** (Scheme 3). It is necessary to emphasize, that although the combination of $Ni(cod)_2$ with PPh_3 give rise to a very reactive catalyst, it is also moisture and air sensitive and requires careful storing and handling.

In the first set of experiments 6-(phenylethynyl)-7-benzylpurine **4a** was reacted with various α,ω–diynes **5**, concretely diester **5a**, diketone **5b**, and ketoester **5c** for 24 h (Table 1). All reactions proceeded uneventfully and the corresponding 6-aryl-7-benzylpurines **6aa**, **6ab**, and **6ac** were isolated in very good 81, 80, and 62% yields. The structure of 6-aryl-7-benzylpurine derivative **6aa** was unequivocally confirmed by a single-crystal X-ray analysis (Figure 1). The second set of reactions was based on the cyclotrimerizations of 6-(hexyn-1-yl)-7-benzylpurine **4b** with α,ω–diynes **5a**-**5c**. These reactions resulted in the formation of expected products **6ba**, **6bb**, and **6bc** that were isolated in very good yields of 73, 73, and 84%. Analogically, the cyclotrimerization reactions of 6-(trimethylsilylethynyl)-7-benzylpurine **4c** were carried out. Although in all cases were obtained the desired products **6ca**-**6cc**, their yields were considerable lower than in previous cases: **6ca** 32%, **6cb** 26%, and **6cc** 27%. The low yields of the isolated products were caused by two reasons: firstly, by difficult separation of **6ca-6cc** from the remaining starting 7-trimethylsilyl-6-alkynylpurine **4c** and secondly, the lower reactivity of the TMS-derivative (probably caused by steric hindrace of the the triple bond by the TMS group) resulted also in lower conversions. The comparison of these results with those obtained in cyclotrimerization reactions of 9-benzyl-6-alkynylpurines[8,9] clearly shows that the yields were within the region. This indicates that the presence of benzyl group in the near vicinty of the triple bond does not exert any steric effects on its reactivity, i.e. ability to participate in the cyclotrimerization reaction.



4 **5** **6xy**

4a, R = Ph **5a**, X = $C(CO_2Et)_2$ **x** denotes R

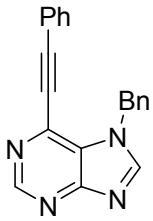
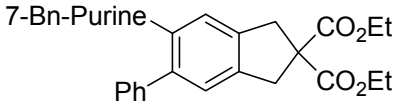
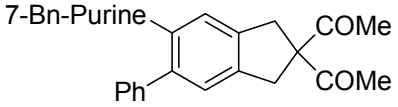
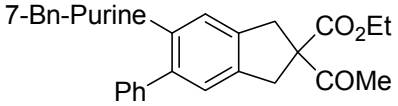
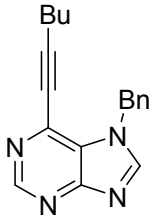
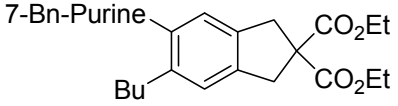
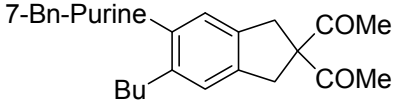
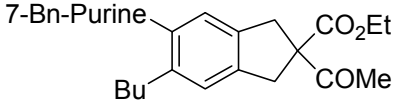
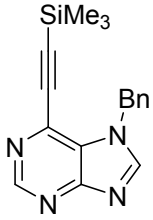
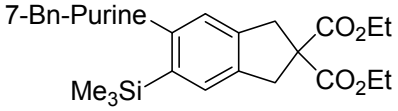
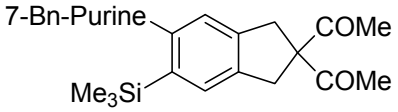
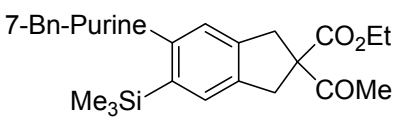
4b, R = Bu **5b**, X = $C(COMe)_2$ **y** denotes X

4c, R = $SiMe_3$ **5c**, X = $C(CO_2Et)COMe$

Scheme 3. General scheme of cocyclotrimerization of 7-benzyl-6-alkynylpurines with diynes

Herein some remarks regarding difficulties pertaining to the isolation of products from reaction mixtures should be mentioned. We observed two problems during work-up procedure: 1) the residual starting 6-alkynylpurines had a similar retention factor like the formed 6-arylpurines and 2) the presence of triphenylphosphinoxide formed by the oxidation of the catalyst's ligand. This made the product separation a rather tedious process and in some cases the products had to be purified several times. Logically, it decreased the final reaction yields.

Table 1. Cocyclotrimerization of 6-alkynyl-7-benzylpurines with α,ω-diynes

Purine	Diyne	Product		Yield (%)[a]
4a 	**5a**		**6aa**	81
	5b		**6ab**	80
	5c		**6ac**	62
4b 	**5a**		**6ba**	73
	5b		**6bb**	73
	5c		**6bc**	84
4c 	**5a**		**6ca**	32
	5b		**6cb**	26
	5c		**6cc**	27

[a] Isolated yields

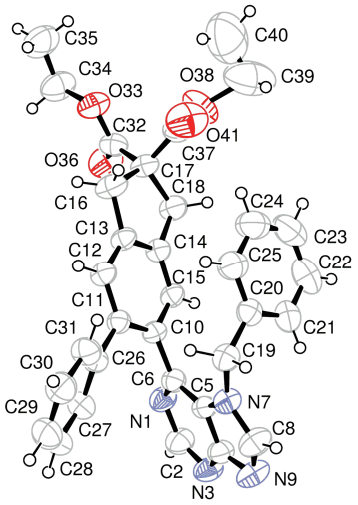


Figure 1. ORTEP drawing of **6aa** with the atom numbering scheme. Thermal ellipsoids are drawn at the 50 % probability level

Preliminary *in vitro* cytostatic activity tests of the starting 6-alkynyl-7-benzylpurines **4a-4c** and some of the products **6** were performed using the following cell cultures: mouse leukemia L1210 cells (ATCC CCL 219); human promyelocytic leukemia HL60 cells (ATCC CCL 240); human cervix carcinoma HeLa S3 cells (ATCC CCL 2.2); and human T lymphoblastoid CCRF-CEM cell line (ATCC CCL 119). The testing showed that the prepared 6-aryl-7-benzylpurines **6** were entirely inactive (IC_{50} >250 μmol.l^{-1}). On the other hand, the testing of the starting 6-alkynyl-7-benzylpurines **4a-4c** revealed them to be active against all cell cultures: the compound **4a** (IC_{50} = 5.07, 9.40, 1.81, and 2.04 μM against L1210, HL60, HeLa S3, and CCRF-CEM cell-lines, respectively), the compound **4b** (IC_{50} = 2.78, 3.10, 3.24, and 2.63 μM against L1210, HL60, HeLa S3, and CCRF-CEM cell-lines, respectively), and the compound **4c** (IC_{50} = 7.52, 11.81, 4.92, and 1.53 μM against L1210, HL60, HeLa S3, and CCRF-CEM cell-lines, respectively).

Table 2. Biological activity of prepared 6-alkynyl-7-benzylpurines

	IC_{50}, μmol.l^{-1} (XTT)			
Compound	*L1210*	*HL60*	*HeLa S3*	*CCRF-CEM*
4a	5.07 ± 0.14	9.40 ± 0.70	1.81 ± 0.05	2.04 ± 0.15
4b	2.78 ± 0.08	3.10 ± 0.11	3.24 ± 0.18	2.63 ± 0.15
4c	7.52 ± 0.35	11.81 ± 1.34	4.92 ± 0.04	1.53 ± 0.03

In conclusion, the cyclotrimerization of 6-alkynyl-7-benzylpurines with various α,ω–diynes can be conveniently carried out in the presence of $Ni(cod)_2/PPh_3$ catalytic system with good yields of the

corresponding 6-aryl-7-benzylpurines. Although, the cytostatic activity tests showed that the obtained arylpurine derivatives were inactive, the starting alkynylpurines exhibited interesting levels of activity. These results thus might indicate the next direction of further research.

EXPERIMENTAL

All solvents were used as obtained unless otherwise noted. DMF and acetonitrile were used as commercially available dry solvents stored under septum and above sieves. All other reagents were obtained from commercial sources. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker AVANCE 400 (^{1}H at 400 MHz, ^{13}C at 100.6 MHz), a Bruker AVANCE 500 (^{1}H at 500 MHz, ^{13}C at 125.8 MHz) or a Bruker AVANCE 600 (^{1}H at 600 MHz, ^{13}C at 151 MHz) as solutions in $CDCl_3$ with Me_4Si as an internal standard. Chemical shifts are given in δ-scale, coupling constants *J* are given in Hz. Melting points (uncorrected) were determined using a Kofler apparatus. Mass spectra were recorded on a ZAB-SEQ (VG-Analytical) instrument. Infrared spectra were recorded on a Bruker IFS 55 spectrometer as $CHCl_3$ solutions and are reported in wave numbers (cm^{-1}). Fluka 60 silica gel was used for flash chromatography. TLC was performed on silica gel 60 F_{254}-coated aluminum sheets (Merck). All cross-coupling and cyclotrimerization reactions were carried out under an argon atmosphere.

General procedure for cross-coupling reactions of 6-chloropurine with acetylenes. DMF (10 mL), acetylene (1.2 eq., 14.7 mmol) and triethylamine (2 mL) were added to an argon purged mixture of 7-benzyl-6-chloropurine (3 g, 12.3 mmol), CuI (140 mg, 6 mol%, 0.736 mmol), and $PdCl_2(PPh_3)_2$ (176 mg, 0.245 mmol) and the reaction mixture was stirred at 70 °C for 24 h. The course of the reaction was monitored by TLC. Then volatiles were evaporated under reduced pressure and the residue was chromatographed on silica gel column to give the corresponding products **4a-4c**.

6-[(Phenyl)ethynyl]-7-benzyl-7*H*-purine (4a). Column chromatography on silica gel (EtOAc) afforded 3,318 g (87%) of a reddish brown solid. Recrystallization from CH_2Cl_2/hexane gave 2.88 g (76%) of yellowish crystals: mp 135–136.5 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 5.83 (s, 2H, CH_2Ph), 7.24 (m, 2H, H-*o*-Bn), 7.34–7.40 (m, 5H, H-*m* -Ph a H-*m,p*-Bn), 7.44 (m, 1H, H-*p*-Ph), 7.45 (m, 2H, H-*o*-Ph), 8.24 (s, 1H, H-8), 9.14 (s, 1H, H-2); ^{13}C NMR (151 MHz, $CDCl_3$) δ 49.88 (CH_2Ph), 83.75 (Pur-**C**≡C-Ph), 98.09 (Ph-**C**≡C-Pur), 120.59 (C-*i*-Ph), 124.73 (C-5), 127.01 (CH-*o*-Bn), 128.65 (CH-*m*-Ph), 128.77 (CH-*p*-Bn), 129.35 (CH-*m*-Bn), 130.28 (CH-*p*-Ph), 132.02 (CH-*o*-Ph), 134.31 (C-6), 135.01 (C-*i*-Bn), 148.74 (CH-8), 153.46 (CH-2), 161.17 (C-4); IR ($CHCl_3$) ν 3000, 2212, 1600, 1589, 1556, 1486, 1444, 1396, 1375 cm^{-1}; MS (FAB, m/z (rel. %)) 311 (M^+ + H, 100), 221 (11), 91 (36); HR-MS (FAB) calcd for $C_{20}H_{15}N_4$ [M^++H] 311.1296, found 311.1300. Anal. Calcd for $C_{20}H_{14}N_4$: C 77.40, H 4.55, N 18.05. Found: C 77.34, H 4.39,

N 17.79. R_f(5/1 EtOAc/MeOH) =0.66.

6-(Hex-1-yn-1-yl)-7-benzyl-7*H*-purine (4b). Column chromatography on silica gel (EtOAc) afforded 3,337 g (94%) of a deep red oil. Crystallization from CH_2Cl_2/hexane gave 3.07 g (86%) of brownish crystals: mp 91–92 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.88 (t, J_{vic} = 7.3 Hz, 3H, C**H$_3$**$CH_2CH_2CH_2$-), 1.40 (m, 2H, CH_3C**H$_2$**CH_2CH_2-), 1.53 (m, 2H, CH_3CH_2C**H$_2$**CH_2-), 2.47 (t, J_{vic} = 7.1 Hz, 2H, $CH_3CH_2CH_2$C**H$_2$**-), 5.76 (s, 2H, CH_2Ph), 7.18 (m, 2H, H-*o*-Ph), 7.34–7.41 (m, 3H, H-*m,p*-Ph), 8.21 (s, 1H, H-8), 9.07 (s, 1H, H-2); ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 13.50 (**C**$H_3CH_2CH_2CH_2$-), 19.35 ($CH_3CH_2CH_2$**C**H_2-), 22.04 (CH_3**C**$H_2CH_2CH_2$-), 29.74 (CH_3CH_2**C**H_2CH_2-), 49.68 (CH_2Ph), 75.86 (Pur-**C**≡C-Bu), 101.32 (Bu-**C**≡C-Pur), 124.65 (C-5), 126.79 (CH-*o*-Ph), 128.60 (CH-*p*-Ph), 129.18 (CH-*m*-Ph), 134.86 (C-6), 135.17 (C-*i*-Ph), 148.50 (CH-8), 153.31 (CH-2), 160.87 (C-4); IR ($CHCl_3$) ν 2999, 2234, 1593, 1558, 1490, 1448, 1396, 1376 cm^{-1}; MS (FAB, m/z (rel. %)) 291 (M^+ + H, 100), 91 (56); HR-MS (FAB) calcd for $C_{18}H_{19}N_4$ [M^++H] 291.1610, found 291.1616. R_f(5/1 EtOAc/MeOH) = 0.60.

6-[(Trimethylsilyl)ethynyl]-7-benzyl-7*H*-purine (4c). Column chromatography on silica gel (hexane/EtOAc 1/3) afforded 3.14 g (83%) of a deep brown solid. Recrystallization from CH_2Cl_2/heptane gave 2.49 g (66%) of brownish crystals: mp 119–121 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.23 (s, 9H, CH_3Si), 5.77 (s, 2H, CH_2Ph), 7.21 (m, 2H, H-*o*-Ph), 7.34–7.41 (m, 3H, H-*m,p*-Ph), 8.22 (s, 1H, H-8), 9.10 (s, 1H, H-2); ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 0.80 (CH_3Si), 49.57 (CH_2Ph), 98.36 (Pur-**C**≡C-$SiMe_3$), 105.93 (Me_3Si-**C**≡C-Pur), 124.77 (C-5), 127.01 (CH-*o*-Ph), 128.72 (CH-*p*-Ph), 129.28 (CH-*m*-Ph), 133.72 (C-6), 135.10 (C-*i*-Ph), 148.84 (CH-8), 153.33 (CH-2), 161.20 (C-4); IR ($CHCl_3$) ν 3001, 1591, 1558, 1397, 1375 cm^{-1}; MS (FAB, m/z (rel. %)) 307 (M^+ + H, 100), 91 (52); HR-MS (FAB) calcd for $C_{17}H_{19}N_4Si$ [M^++H] 307.1379, found 307.1390. Anal. Calcd for $C_{17}H_{18}N_4Si$: C 66.63, H 5.92, N 18.28. Found: C 66.55, H 5.80, N 18.21. R_f(5/1 EtOAc/MeOH) = 0.65.

General procedure for preparation of 6-aryl-7-benzylpurines 6*xy* by cyclotrimerization reactions. $Ni(cod)_2$ (0.022 g, 0.08 mmol) was placed into the Schlenk flask with a mixture of 6-alkynyl-7-benzylpurine (0.4 mmol), diyne (0.44 mmol), and PPh_3 (0.052 g, 0.2 mmol) in a glove-box and the final mixture of components was dissolved in MeCN (8 mL). The reaction mixture was stirred at 20 °C for 24 h. The course of the reaction was monitored by TLC. Then volatiles were evaporated under reduced pressure and the residue was chromatographed on silica gel or aluminium oxide column to give the corresponding products **6*xy***.

6-[6-Phenyl-2,2-di(ethoxycarbonyl)indan-5-yl]-7-benzyl-7*H*-purine (6aa). Column chromatography on aluminum oxide (toluene, 10/1 to 9/1 toluene/acetone) yielded 177 mg (81%) of a white solid: mp 160–162.5 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.28, 1.32 (2 × t, J_{vic} = 7.1 Hz, 2 × 3H, C**H$_3$**CH$_2$), 3.52, 3.61 (2 × dd, J_{gem} = 16.7 Hz, $J_{3',4'}$ = 0.6 Hz, 2H, H-3′), 3.69, 3.76 (2 × dd, J_{gem} = 17.5 Hz, $J_{1',7'}$ = 0.6 Hz, 2H, H-1′), 4.23, 4.24 (2 × dq, J_{gem} = 12.7 Hz, J_{vic} = 7.1 Hz, 2H, C**H$_2$**CH$_3$), 4.29 (q, J_{vic} = 7.1 Hz, 2H, C**H$_2$**CH$_3$), 4.83, 4.97 (2 × d, J_{gem} = 15.4 Hz, 2H, CH$_2$Ph), 6.47 (m, 2H, H-*o*-Bn), 6.95 (m, 2H, H-*o*-Ph), 6.99 (q, $J_{4',3'} = J_{4',7'}$ = 0.6 Hz, 1H, H-4′), 7.07 (m, 2H, H-*m*-Ph), 7.10 (m, 1H, H-*p*-Ph), 7.14 (m, 2H, H-*m*-Bn), 7.20 (m, 1H, H-*p*-Bn), 7.37 (q, $J_{7',1'} = J_{7',4'}$ = 0.6 Hz, 1H, H-7′), 8.00 (s, 1H, H-8), 9.12 (s, 1H, H-2); ^{13}C NMR (151 MHz, $CDCl_3$) δ 14.02, 14.07 (**C**H$_3$CH$_2$) 40.12 (CH$_2$-3′), 40.44 (CH$_2$-1′), 50.36 (CH$_2$-Ph), 60.30 (C-2′), 61.91, 61.95 (**C**H$_2$CH$_3$), 123.03 (C-5), 125.70 (CH-7′), 125.96 (CH-4′), 126.54 (CH-*o*-Bn), 127.30 (CH-*p*-Ph), 128.32 (CH-*m*-Ph, CH-*p*-Bn), 128.74 (CH-*m*-Bn), 128.94 (CH-*o*-Ph), 133.42 (C-5′), 134.47 (C-*i*-Bn), 139.28 (C-*i*-Ph), 139.71 (C-3′a), 140.07 (C-6′), 142.59 (C-7′a), 148.67 (CH-8), 152.91 (CH-2), 153.08 (C-6), 161.32 (C-4), 171.09, 171.64 (CO); IR ($CHCl_3$) ν 2986, 1730, 1592, 1497, 1456, 1446, 1369, 1265, 1248, 1191 cm^{-1}; MS (FAB, m/z (rel. %)) 547 (M^+ + H, 100), 473 (8), 417 (7), 398 (10), 91 (30); HR-MS (FAB) calcd for $C_{33}H_{31}N_4O_4$ [M^+ + H] 547.2345, found 547.2355. R_f(5/1 EtOAc/MeOH) = 0.68.

6-[6-Phenyl-2,2-diacetylindan-5-yl]-7-benzyl-7*H*-purine (6ab). Column chromatography on silica gel (10/1, 8/1 to 6/1 Et_2O/acetone) yielded 155 mg (80%) of a white foam: ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.20, 2.25 (2 × s, 2 × 3H, CH_3CO), 3.42, 3.48 (2 × dd, J_{gem} = 16.7 Hz, $J_{3',4'}$ = 0.8 Hz, 2H, H-3′), 3.61, 3.67 (2 × dd, J_{gem} = 16.9 Hz, $J_{1',7'}$ = 0.8 Hz, 2H, H-1′), 4.80, 4.95 (2 × d, J_{gem} = 15.5 Hz, 2H, CH$_2$Ph), 6.45 (m, 2H, H-*o*-Bn), 6.96-7.00 (m, 3H, H-4′, H-*o*-Ph), 7.06–7.15 (m, 5H, H-*m,p*-Ph, H-*m*-Bn), 7.20 (m, 1H, H-*p*-Bn), 7.37 (td, $J_{7',1'}$ = 0.8 Hz, $J_{7',4'}$ = 0.4 Hz, 1H, H-7′), 7.98 (s, 1H, H-8), 9.13 (s, 1H, H-2); ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 26.43, 26.64 (**C**H$_3$CO), 37.07 (CH$_2$-3′), 37.35 (CH$_2$-1′), 50.24 (CH$_2$-Ph), 74.81 (C-2′), 123.00 (C-5), 125.85 (CH-7′), 126.15 (CH-4′), 126.37 (CH-*o*-Bn), 127.43 (CH-*p*-Ph), 128.29 (CH-*p*-Bn), 128.39 (CH-*m*-Ph), 128.74 (CH-*m*-Bn), 128.92 (CH-*o*-Ph), 133.62 (C-5′), 134.49 (C-*i*-Bn), 139.13 (C-*i*-Ph), 139.29 (C-3′a), 140.20 (C-6′), 142.25 (C-7′a), 148.71 (CH-8), 152.90 (C-6), 152.92 (CH-2), 161.30 (C-4), 203.89, 204.17 (CO); IR ($CHCl_3$) ν 3006, 1702, 1592, 1491, 1370, 1358, 1262 cm^{-1}; MS (FAB, m/z (rel. %)) 487 (M^+ + H, 18), 147 (25), 91 (18), 73 (100); HR-MS (ESI) calcd for $C_{31}H_{27}N_4O_2$ [M^+ + H] 487.2134, found 487.2129. R_f(5/1 EtOAc/MeOH) = 0.63.

6-[6-Phenyl-2-acetyl-2-(ethoxycarbonyl)indan-5-yl]-7-benzyl-7*H*-purine (6ac). Column chromatography on aluminum oxide (toluene, 10/1 to 8/1 toluene/acetone) followed by column chromatography on silica gel (10/1, 8/1 to 6/1 Et_2O/acetone) yielded 128 mg (62%) of a yellowish foam:

^{1}H NMR (500 MHz, $CDCl_3$) δ 1.29, 1.33 (2 × t, J_{vic} = 7.1 Hz, 2 × 3H, C**H$_3$**CH_2), 2.26, 2.31 (2 × s, 2 × 3H, CH_3CO), 3.40, 3.43, 3.52, 3.55 (4 × dd, J_{gem} = 16.8 Hz, $J_{3',4'}$ = 0.7 Hz, 4 × 1H, H-3′), 3.63, 3.64, 3.67, 3.69 (4 × dd, J_{gem} = 16.9 Hz, $J_{1',7'}$ = 0.7 Hz, 4 × 1H, H-1′), 4.25, 4.30 (2 × q, J_{vic} = 7.1 Hz, 2 × 2H, C**H$_2$**CH_3), 4.80, 4.82, 4.95, 4.96 (4 × d, J_{gem} = 15.5 Hz, 4 × 1H, CH_2Ph), 6.45, 6.47 (2 × m, 2 × 2H, H-*o*-Bn), 6.94–7.00 (m, 6H, H-4′, H-*o*-Ph), 7.05–7.14 (m, 10H, H-*m,p*-Ph, H-*m*-Bn), 7.20, 7.21 (2 × m, 2 × 1H, H-*p*-Bn), 7.36, 7.37 (2 × q, $J_{7',1'} = J_{7',4'}$ = 0.7 Hz, 2 × 1H, H-7′), 7.99 (s, 2H, H-8), 9.116, 9.121 (s, 1H, H-2); ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 14.01, 14.08 (**C**H_3CH_2), 26.07, 26.20 (**C**H_3CO), 38.57, 38.67 (CH_2-3′), 38.87, 38.89 (CH_2-1′), 50.29, 50.35 (CH_2-Ph), 62.03, 62.12 (**C**H_2CH_3), 66.67, 66.80 (C-2′), 123.03 (C-5), 125.73, 125.79 (CH-7′), 125.99, 126.06 (CH-4′), 126.44, 126.54 (CH-*o*-Bn), 127.34 (CH-*p*-Ph), 128.29, 128.34 (CH-*m*-Ph, CH-*p*-Bn), 128.74, 128.76 (CH-*m*-Bn), 128.93 (CH-*o*-Ph), 133.46, 133.53 (C-5′); 134.48 (C-*i*-Bn), 139.22, 139.25 (C-*i*-Ph), 139.45, 139.51 (C-3′a), 140.09, 140.18 (C-6′), 142.44, 142.49 (C-7′a), 148.66, 148.70 (CH-8), 152.90 (CH-2), 153.01, 153.04 (C-6), 161.30 (C-4), 171.95, 172.27 (COOEt), 201.89, 202.20 (CO); IR ($CHCl_3$) ν 3032, 2987, 1714, 1592, 1560, 1491, 1442, 1370, 1240, 1172 cm^{-1}; MS (FAB, m/z (rel. %)) 517 (M^++H, 30), 91 (55), 57 (100); HR-MS (ESI) calcd for $C_{32}H_{29}N_4O_3$ [M^++H] 517.2240, found 517.2249. R_f(5/1 EtOAc/MeOH) = 0.67.

6-[6-Butyl-2,2-di(ethoxycarbonyl)indan-5-yl]-7-benzyl-7*H*-purine (6ba). Column chromatography on aluminum oxide (toluene, 10/1 to 8/1 toluene/acetone) yielded 154 mg (73%) of a yellowish oil. Crystallization from CH_2Cl_2/heptane gave white crystals: mp 80–82 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.68 (t, J_{vic} = 7.8 Hz, 3H, C**H$_3$**$CH_2CH_2CH_2$), 1.05 (m, 2H, CH_3C**H$_2$**CH_2CH_2), 1.16, 1.26 (2 × m, 2H, CH_3CH_2C**H$_2$**CH_2), 1.27, 1.30 (2 × t, J_{vic} = 7.1 Hz, 2 × 3H, C**H$_3$**CH_2), 2.11 (m, 2H, $CH_3CH_2CH_2$C**H$_2$**), 3.48 (s, 2H, H-3′), 3.59, 3.69 (2 × d, J_{gem} = 17.1 Hz, 2H, H-1′), 4.21, 4.23 (2 × dq, J_{gem} = 12.6 Hz, J_{vic} = 7.1 Hz, 2H, C**H$_2$**CH_3), 4.26 (q, J_{vic} = 7.1 Hz, 2H, C**H$_2$**CH_3), 4.94, 5.03 (2 × d, J_{gem} = 15.7 Hz, 2H, CH_2Ph), 6.49 (m, 2H, H-*o*-Bn), 6.82 (s, 1H, H-4′), 7.10 (s, 1H, H-7′), 7.15 (m, 2H, H-*m*-Bn), 7.22 (m, 1H, H-*p*-Bn), 8.27 (s, 1H, H-8); 9.15 (s, 1H, H-2); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 13.66 (**C**$H_3CH_2CH_2CH_2$), 14.01, 14.07 (**C**H_3CH_2), 22.35 (CH_3**C**$H_2CH_2CH_2$), 32.54, 32.84 (CH_3CH_2**C**H_2**C**H_2), 40.05 (CH_2-3′), 40.47 (CH_2-1′), 50.60 (CH_2-Ph), 60.41 (C-2′), 61.80, 61.83 (**C**H_2CH_3), 123.29 (C-5), 124.74 (CH-4′), 125.04 (CH-7′), 126.23 (CH-*o*-Bn), 128.25 (CH-*p*-Bn), 128.74 (CH-*m*-Bn), 133.41 (C-5′), 134.60 (C-*i*-Bn), 137.56 (C-3′a), 140.17 (C-6′), 142.03 (C-7′a), 149.07 (CH-8), 153.01 (CH-2), 153.06 (C-6), 161.52 (C-4), 171.17, 171.79 (CO); IR ($CHCl_3$) ν 2985, 1729, 1591, 1456, 1369, 1250, 1191 cm^{-1}; MS (FAB, m/z (rel. %)) 527 (M^+ + H, 100), 453 (7), 437 (10), 91 (78); HR-MS (FAB) calcd for $C_{31}H_{35}N_4O_4$ [M^++H] 527.2658, found 527.2669. Anal. Calcd for $C_{31}H_{34}N_4O_4$: C 70.70, H 6.51, N 10.64. Found: C 70.71, H 6.56, N 10.67. R_f(5/1 EtOAc/MeOH) = 0.80.

6-[6-Butyl-2,2-diacetylindan-5-yl]-7-benzyl-7*H*-purine (6bb). Column chromatography on silica gel (10/1 to 7/1 Et_2O/acetone) yielded 137 mg (73%) of a yellowish oil. Crystallization from CH_2Cl_2/heptane gave white crystals: mp 133–134.5 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.69 (t, J_{vic} = 7.3 Hz, 3H, C**H$_3$**$CH_2CH_2CH_2$), 1.05, 1.07 (2 × dt, J_{gem} = 14.8 Hz, J_{vic} = 7.3 Hz, 2H, CH_3C**H$_2$**CH_2CH_2), 1.17, 1.32 (2 × m, 2H, CH_3CH_2C**H$_2$**CH_2), 2.14 (m, 2H, $CH_3CH_2CH_2$C**H$_2$**), 2.18, 2.22 (2 × s, 2 × 3H, CH_3CO), 3.36 (s, 2H, H-3′), 3.55 (s, 2H, H-1′), 4.90, 5.02 (2 × d, J_{gem} = 14.8 Hz, 2H, CH_2Ph), 6.50 (m, 2H, H-*o*-Bn), 6.81 (s, 1H, H-4′), 7.11 (s, 1H, H-7′), 7.16 (m, 2H, H-*m*-Bn), 7.23 (m, 1H, H-*p*-Bn), 8.25 (s, 1H, H-8), 9.16 (s, 1H, H-2); ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 13.66 (**C**$H_3CH_2CH_2CH_2$), 22.34 (CH_3**C**$H_2CH_2CH_2$), 26.11, 26.24 (**C**H_3CO), 32.61 ($CH_3CH_2CH_2$**C**H_2), 32.89 (CH_3CH_2**C**H_2CH_2), 37.09 (CH_2-3′), 37.84 (CH_2-1′), 50.49 (CH_2-Ph), 74.88 (C-2′), 123.32 (C-5), 124.97 (CH-4′), 125.24 (CH-7′), 126.13 (CH-*o*-Bn), 128.30 (CH-*p*-Bn), 128.81 (CH-*m*-Bn), 133.52 (C-5′), 134.62 (C-*i*-Bn), 137.25 (C-3′a), 140.35 (C-6′), 141.74 (C-7′a), 149.15 (CH-8), 152.79 (C-6), 153.04 (CH-2), 161.46 (C-4), 204.04, 204.41 (CO); IR ($CHCl_3$) ν 2998, 2962, 2933, 1701, 1592, 1498, 1456, 1372, 1358, 1233 cm^{-1}; MS (FAB, m/z (rel. %)) 467 (M^+ + H, 100), 91 (63); HR-MS (FAB) calcd for $C_{29}H_{31}N_4O_2$ [M^++H] 467.2447, found 467.2424. R_f(5/1 EtOAc/MeOH) = 0.67.

6-[6-Butyl-2-acetyl-2-(ethoxycarbonyl)indan-5-yl]-7-benzyl-7*H*-purine (6bc). Column chromatography on silica gel (12/1, 10/1 to 8/1 Et_2O/acetone) yielded 167 mg (84%) of a yellowish oil. Recrystallization from CH_2Cl_2/heptane gave white crystals: mp 131–134 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.68 (t, J_{vic} = 7.3 Hz, 6H, C**H$_3$**$CH_2CH_2CH_2$), 1.05 (m, 4H, CH_3C**H$_2$**CH_2CH_2), 1.16, 1.28 (2 × m, 4H, CH_3CH_2C**H$_2$**CH_2), 1.29, 1.31 (2 × t, J_{vic} = 7.1 Hz, 2 × 3H, C**H$_3$**CH_2), 2.12 (m, 4H, $CH_3CH_2CH_2$C**H$_2$**), 2.24, 2.28 (2 × s, 2 × 3H, CH_3CO), 3.33, 3.38, 3.43, 3.44 (4 × d, J_{gem} = 16.7 Hz, 4 × 1H, H-3′), 3.53, 3.55, 3.60, 3.62 (4 × d, J_{gem} = 17.3 Hz, 4 × 1H, H-1′), 4.24, 4.27 (2 × q, J_{vic} = 7.1 Hz, 2 × 2H, C**H$_2$**CH_3), 4.91, 4.93, 5.03 (3 × d, J_{gem} = 15.6 Hz, 4H, CH_2Ph), 6.48, 6.50 (2 × m, 2 × 2H, H-*o*-Bn), 6.79, 6.82 (2 × s, 2 × 1H, H-4′), 7.09, 7.10 (2 × s, 2 × 1H, H-7′), 7.16 (m, 4H, H-*m*-Bn), 7.22, 7.23 (2 × m, 2 × 1H, H-*p*-Bn), 8.26 (s, 2H, H-8), 9.15 (s, 2H, H-2); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ 13.66 (**C**$H_3CH_2CH_2CH_2$), 14.02, 14.08 (**C**H_3CH_2), 22.34 (CH_3**C**$H_2CH_2CH_2$), 26.12, 26.16 (**C**H_3CO), 32.55, 32.84, 32.87 (CH_3CH_2**C**H_2**C**H_2), 38.48, 38.63 (CH_2-3′), 38.92 (CH_2-1′), 50.50, 50.59 (CH_2-Ph), 61.93, 62.01 (**C**H_2CH_3), 66.79, 66.84 (C-2′), 123.28 (C-5), 124.76, 124.84 (CH-4′), 125.06, 125.13 (CH-7′), 126.12, 126.24 (CH-*o*-Bn), 128.21, 128.27 (CH-*p*-Bn), 128.75 (CH-*m*-Bn), 133.45, 133.52 (C-5′), 134.59, 134.63 (C-*i*-Bn), 137.31, 137.40 (C-3′a), 140.14, 140.28 (C-6′), 141.83, 141.94 (C-7′a), 149.05, 149.10 (CH-8), 152.96, 152.99 (C-6), 153.03 (CH-2), 161.47, 161.50 (C-4), 172.04, 172.41 (COOEt), 202.18, 202.38 (CO); IR ($CHCl_3$) ν 3020, 2988, 2962, 1714, 1591, 1456, 1370, 1240, 1220 cm^{-1}; MS (FAB, m/z (rel. %))

497 (M^+ + H, 83), 91 (100); HR-MS (FAB) calcd for $C_{30}H_{33}N_4O_3$ [M^++H] 497.2553, found 497.2569. R_f(5/1 EtOAc/MeOH) = 0.74.

6-[6-Trimethylsilyl-2,2-di(ethoxycarbonyl)indan-5-yl]-7-benzyl-7*H*-purine (6ca). Column chromatography on silica gel (Et_2O/acetone 10/1 to 8/1) followed by column chromatography on aluminum oxide (10/1 Et_2O/acetone) yielded 70 mg (32%) of a yellowish oil. Crystallization from CH_2Cl_2/heptane gave white crystals: mp 177.5–179 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ -0.26 (s, 9H, $(CH_3)_3Si$), 1.29 (t, J_{vic} = 7.1 Hz, 6H, C**H$_3$**CH_2), 3.53 (s, 2H, H-3′), 3.69 (s, 2H, H-1′), 4.24 (q, J_{vic} = 7.1 Hz, 4H, C**H$_2$**CH_3), 5.03 (s, 2H, CH_2Ph), 6.48 (m, 2H, H-*o*-Bn), 6.95 (bd, $J_{4',7'}$ = 0.6 Hz, 1H, H-4′), 7.14 (m, 2H, H-*m*-Bn), 7.20 (m, 1H, H-*p*-Bn), 7.48 (bd, $J_{7',4'}$ = 0.6 Hz, 1H, H-7′), 8.30 (s, 1H, H-8), 9.11 (s, 1H, H-2); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ -0.16 ($(CH_3)_3Si$), 14.04 (**C**H_3CH_2), 40.37 (CH_2-3′), 40.48 (CH_2-1′), 50.96 (CH_2-Ph), 60.27 (C-2′), 61.87 (**C**H_2CH_3), 123.29 (C-5), 124.97 (CH-4′), 126.60 (CH-*o*-Bn), 128.34 (CH-*p*-Bn), 128.76 (CH-*m*-Bn), 131.03 (CH-7′), 134.56 (C-*i*-Bn), 138.79 (C-6′), 140.02 (C-5′), 140.58 (C-7′a), 140.90 (C-3′a), 148.99 (CH-8), 152.50 (CH-2), 154.63 (C-6), 161.54 (C-4), 171.42 (CO); IR ($CHCl_3$) ν 2986, 2906, 1729, 1589, 1492, 1457, 1441, 1369, 1273, 1249 cm^{-1}; MS (FAB, m/z (rel. %)) 543 (M^+ + H, 76), 91 (100), 73 (58); HR-MS (FAB) calcd for $C_{30}H_{35}N_4O_4Si$ [M^++H] 543.2428, found 543.2434. Anal. Calcd for $C_{30}H_{34}N_4O_4Si$: C 66.39, H 6.31, N 10.32. Found: C 66.16, H 6.19, N 10.13. R_f(EtOAc/MeOH 5/1) = 0.71.

6-[6-Trimethylsilyl-2,2-diacetylindan-5-yl]-7-benzyl-7*H*-purine (6cb). Column chromatography (10/1, 8/1 to 6/1 Et_2O/acetone) yielded 51 mg (26%) of a yellowish oil. Crystallization from CH_2Cl_2/heptane gave white crystals: mp 98–99 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ -0.24 (s, 9H, $(CH_3)_3Si$), 2.21 (s, 6H, CH_3CO), 3.40 (s, 2H, H-3′), 3.60 (s, 2H, H-1′), 5.00 (s, 2H, CH_2Ph), 6.49 (m, 2H, H-*o*-Bn), 6.93 (bd, $J_{4',7'}$ = 0.6 Hz, 1H, H-4′), 7.16 (m, 2H, H-*m*-Bn), 7.22 (m, 1H, H-*p*-Bn), 7.49 (bd, $J_{7',4'}$ = 0.6 Hz, 1H, H-7′), 8.29 (s, 1H, H-8), 9.12 (s, 1H, H-2); ^{13}C NMR (125.8 MHz, $CDCl_3$) δ -0.17 ($(CH_3)_3Si$), 26.54 (**C**H_3CO), 37.31 (CH_2-3′), 37.44 (CH_2-1′), 50.80 (CH_2-Ph), 74.69 (C-2′), 123.33 (C-5), 125.08 (CH-4′), 126.41 (CH-*o*-Bn), 128.35 (CH-*p*-Bn), 128.81 (CH-*m*-Bn), 131.20 (CH-7′), 134.57 (C-*i*-Bn), 138.93 (C-6′), 140.13 (C-5′), 140.20 (C-7′a), 140.50 (C-3′a), 149.02 (CH-8), 152.52 (CH-2), 154.42 (C-6), 161.45 (C-4), 204.12 (CO); IR ($CHCl_3$) ν 3004, 2960, 2930, 1702, 1589, 1491, 1456, 1370, 1359, 1249 cm^{-1}; MS (FAB, m/z (rel. %)) 483 (M^++H, 60), 91 (100), 73 (75); HR-MS (ESI) calcd for $C_{28}H_{31}N_4O_2Si$ [M^++H] 483.2216, found 483.2214. R_f(5/1 EtOAc/MeOH) = 0.56.

6-[6-Trimethylsilyl-2-acetyl-2-(ethoxycarbonyl)indan-5-yl]-7-benzyl-7*H*-purine (6cc). Column chromatography on silica gel (0/1, 8/1 to 6/1 Et_2O/acetone 1) followed by column chromatography on

aluminum oxide (10/1 toluene/acetone) afforded 56 mg (27%) of a yellowish oil. Crystallization from CH_2Cl_2/heptane gave white crystals: mp 136–137 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ -0.25 (s, 9H, $(CH_3)_3Si$), 1.30 (t, J_{vic} = 7.1 Hz, 3H, C**H$_3$**CH_2), 2.27 (s, 3H, CH_3CO), 3.41, 3.47 (2 × d, J_{gem} = 17.0 Hz, 2H, H-3′), 3.59, 3.65 (2 × d, J_{gem} = 16.6 Hz, 2H, H-1′), 4.26 (q, J_{vic} = 7.1 Hz, 2H, C**H$_2$**CH_3), 5.00, 5.04 (2 × d, J_{gem} = 15.5 Hz, 2H, CH_2Ph), 6.48 (m, 2H, H-*o*-Bn), 6.93 (s, 1H, H-4′), 7.15 (m, 2H, H-*m*-Bn), 7.19 (m, 1H, H-*p*-Bn), 7.48 (s, 1H, H-7′), 8.30 (s, 1H, H-8), 9.11 (s, 1H, H-2); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ -0.15 ($(CH_3)_3Si$), 14.05 (**C**H_3CH_2), 26.16 (**C**H_3CO), 38.83 (CH_2-3′), 38.99 (CH_2-1′), 50.89 (CH_2-Ph), 62.03 (**C**H_2CH_3), 66.65 (C-2′), 123.31 (C-5), 125.01 (CH-4′), 126.13 (CH-*o*-Bn), 128.30 (CH-*p*-Bn), 128.81 (CH-*m*-Bn), 131.09 (CH-7′), 134.59 (C-*i*-Bn), 138.81 (C-6′), 140.06 (C-5′), 140.41 (C-3′a), 140.69 (C-7′a), 149.00 (CH-8), 152.52 (CH-2), 154.56 (C-6), 161.51 (C-4), 172.17 (COOEt), 202.17 (CO); IR ($CHCl_3$) ν 2996, 1713, 1589, 1491, 1456, 1441, 1369, 1247 cm^{-1}; MS (FAB, m/z (rel. %)) 513 (M^++H, 100), 91 (82), 73 (35); HR-MS (FAB) calcd for $C_{29}H_{33}N_4O_3Si$ [M^++H] 513.2322, found 513.2311. R_f(5/1 EtOAc/MeOH) = 0.68.

Single crystal X-ray structure analysis. The diffraction data of single crystals of **6aa** (colourless, 0.17 × 0.25 × 0.43 mm) were collected on Xcalibur X-ray diffractometer with $Cu_{K\alpha}$ (λ=1.54180 Å) at 295 K. The structure was solved by direct methods with SIR92[11] and refined by full-matrix, least-squares methods based on *F* with CRYSTALS.[12] Non-hydrogen atoms were refined with anisotropic thermal displacement parameters; hydrogen atoms were treated as riding atoms. **Crystal data for 6aa**: $C_{36}H_{33}N_4O_4$, monoclinic, space group *C2/c*, *a* = 34.1117(4) Å, *b* = 14.9903(6) Å, *c* = 12.2830(5) Å, β = 103.7390(9)°, *V* = 6101.1(4) Å^3, *Z* = 8, *M* = 585.68, 92294 reflections measured, 6319 independent reflections. Final *R* = 0.049, *wR* = 0.059, *GoF* = 1.316 for 2464 reflections with $I > 2\sigma(I)$ and 398 parameters. CCDC 779450 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

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