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Synthesis and X–Ray Crystal Structure of 1',7',7'–Trimethylbicyclo[2.2.1]heptane[2',3'–*b*]–2,3–dicyanopyrazine

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Dedicated to Academician Irina P. Beletskaya on the occasion of her Birthday

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*1',7',7'-Trimethylbicyclo[2.2.1]heptane[2',3'-b]-2,3-dicyanopyrazine **1** was prepared as a mixture of stereoisomers by the reaction of (±)camphorquinone and diaminomaleonitrile in acetic acid and was characterized by mass-spectrometry, ^{1}H, ^{13}C NMR, IR spectroscopy and elemental analysis. Its structure was revealed by X-Ray diffraction of a single crystal grown from ethanol. Quantum chemical calculations at DFT level were carried out for the same compound. The results of theoretical study were found to be in a good agreement with crystallography data.*

Keywords: Camphorquinone, diaminomaleonitrile, synthesis, structure, dicyanopyrazine.

Синтез и структура 1′,7′,7′–триметилбицикло[2.2.1]–гептано[2′,3′–*b*]–2,3–дицианопиразина по данным РСА

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Посвящается академику Ирине Петровне Белецкой по случаю её юбилея

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1',7',7'-Триметилбицикло[2.2.1]гептано[2',3'-b]-2,3-дицианопиразин в виде смеси стереоизомеров получен взаимодействием (±)камфорахинона с диаминомалеонитрилом и охарактеризован данными ИК, ^{1}H и ^{13}C ЯМР спектроскопии, масс-спектрометрии, элементного анализа, а его строение подтверждено с помощью РСА.

Ключевые слова: Камфорахинон, диаминомалеонитрил, синтез, структура, дицианопиразин.

Introduction

Macroheterocyclic compounds (Mc), being the nearest structural analogues of porphyrazine and phthalocyanine, remain objectives of an extensive study during the last decades.[1-6] Their properties can be easily tuned by an insertion of different heterocyclic moieties. Nevertheless, pyrazine-containing Mc are not numerous, despite nitrogen-rich aromatic framework, and can give rise to the new advanced functional materials with desirable properties. Unsubstituted macroheterocyclic compounds with pyrrolepyrazine fragments are known to possess low solubility in organic solvents.[7] Herein, peripheral substitution of macrocycle with bulky groups facilitates synthesis and study of these compounds.[4,8] In this regard, a present paper describes preparation, as well as X-Ray and quantum chemical study of (±)1,2-camphorquinone-derived pyrazine-containing nitriles as further precursors for synthesis of macroheterocyclic compounds.

Various substituted pyrazines were obtained by condensation of diaminomaleonitrile with 1,2-dicarbonyl compounds in acetic acid at room temperature[9] as well as at 118 °C and 130 °C.[10] 5,6-Alkyl- and 5,6-aryl substituted pyrazines and their derivatives, such as 2,3-dichloroquinoxaline-6,7-carbonitrile, were obtained by condensation with diaminomaleonitrile in methanol, using acetic[11] or hydrochloric[12] acids as a catalyst. Synthesis of 5,6-bis(1*H*-pyrrol-2-yl)pyrazine-2,3-dicarbonitrile with a 55 % yield in dichloromethane, using BF_3 as a catalyst, was described.[13] Some 2,3-dicyanopyrazine derivatives[14,15] and, in particular, 1',7',7'-trimethylbicyclo[2.2.1]heptane-[2',3'-*b*]-2,3-dicyanopyrazine **1**[16] were obtained in an alcoholic medium, using *p*-toluene sulfonic acid as the catalyst.

Experimental

Elemental analysis was performed on Flach EA 1112 instrument and IR spectra were recorded on Avatar 360 FT-IR ESP spectrophotometer. EI+ MS spectra (Bruker Reflex III spectrometer), NMR spectra (Bruker AC-300 instrument) and X-Ray structure analysis (Oxford N-HELIX device, Bruker diffractometer) were carried out in Autonomous University of Madrid. Column chromatography was carried out on silica gel (Fluka, 40-200 mesh). Chemicals were purchased from Aldrich Chemical Co. and used as received without purification.

1',7',7'-Trimethylbicyclo[2.2.1]heptane-[2',3'-b]-2,3-dicyanopyrazine (1). A mixture of diaminomaleonitrile **3** (0.2 g; 18 mmol) and racemic mixture of camphorquinone **2 (**0.3 g; 18 mmol) was stirred in 15 ml of glacial acetic acid for 24 hours at room temperature and then for 3 hours at 50 ºC. Then the solvent was removed by evaporation and product was purified by column chromatography on silica gel (eluent: dichloromethane). Dinitrile **1** was obtained as a white solid with a good yield (0.34 g, 85 %). MM = 238.29. (EI+) *m/z*: 238.12 $[M]^+$, calc. for $C_{14}H_{14}N_4$ 238.12. ^{1}H NMR (300 MHz, $CDCl_3$) δ_H ppm: 3.14-3.15 (d, 1H, CH), 1.11-1.35, 2.09-2.18, 2.29-2.44 (m, 2H/1H/1H, CH_2), 0.60 (s, 3H, CH_3), 1.11, 1.36 (s, 3H/3H, $C(CH_3)_2$). ^{13}C NMR($CDCl_3$) δ_C ppm: 9.7, 18.7, 20.4, 24.2, 31.3, 53.7, 55.4, 57.0, 114.2, 131.2, 167.1, 169.1. IR (KBr) ν cm^{-1}: 2926, 2863 (CH_3, CH_2), 2229 (CN), 1737, 1654, 1552 ($C_{ar}N$), 1446 (CH_2), 1381 (CH), 1335, 1130, 1028, 907, 754, 699, 579. Elem. Anal. Found (%): C 70.52, H 6.2, N 23.56. Calc. for $C_{14}H_{14}N_4$ (%): C 70.57, H 5.92, N 23.51.

Results and Discussion

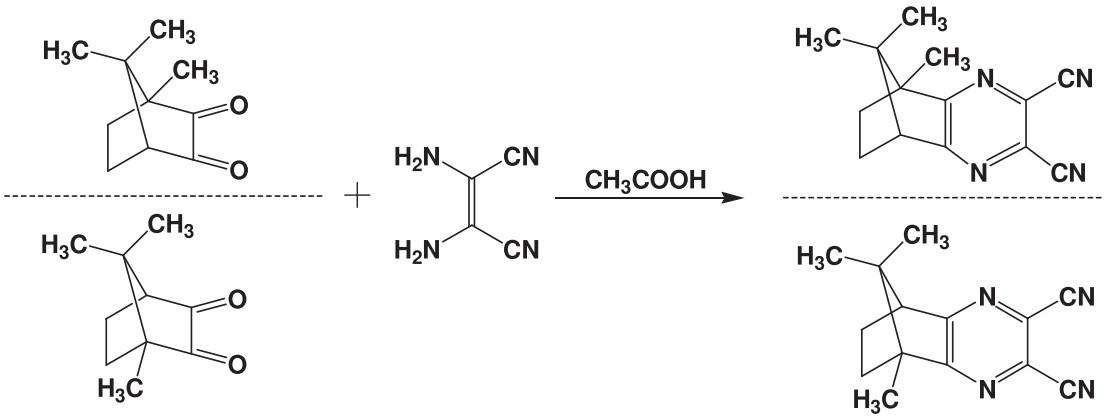
1 was synthesized by condensation of (±)1,2-camphorquinone **2** and diaminomaleonitrile **3**. Compound **1** was obtained as a racemic mixture of optical isomers highly soluble in organic solvents. Its use as a starting material in a synthesis of Mcs could give compounds with a good solubility in organic solvents, analogously to the corresponding porphyrazines.[16]

However, the usage of *p*-toluenesulfonic acid as catalyst and methanol as the reaction medium produces compound **1** with a 40 % yield only.[14] We succeeded in synthesizing this compound using acetic acid as a reaction medium with yield higher than 80 %.

Compound **1** was characterized by MS EI mass-spectrometry, ^{1}H and ^{13}C NMR spectroscopy and elemental analysis.

An intensive signal at 238 *m/z* that corresponds to molecular ion $[M]^+$ as well as signals of lower intensity produced by the products of fragmentation were detected in mass-spectrum of **1** (Figure S1 (Suporting Information)).

In the ^{1}H NMR spectrum of **1** (Figure S2 (SI)), singlets at 0.60, 1.11, 1.36 ppm induced by protons resonance of methyl groups of camphor fragment are observed. Multiplets at the regions of 1.11-1.35, 2.09-2.18, 2.29-2.44 ppm can be assigned to protons of secondary methyl groups. Signal of 3.14-3.15 ppm corresponds to proton resonance of tertiary methyl group, that is in agreement with the date.[14]



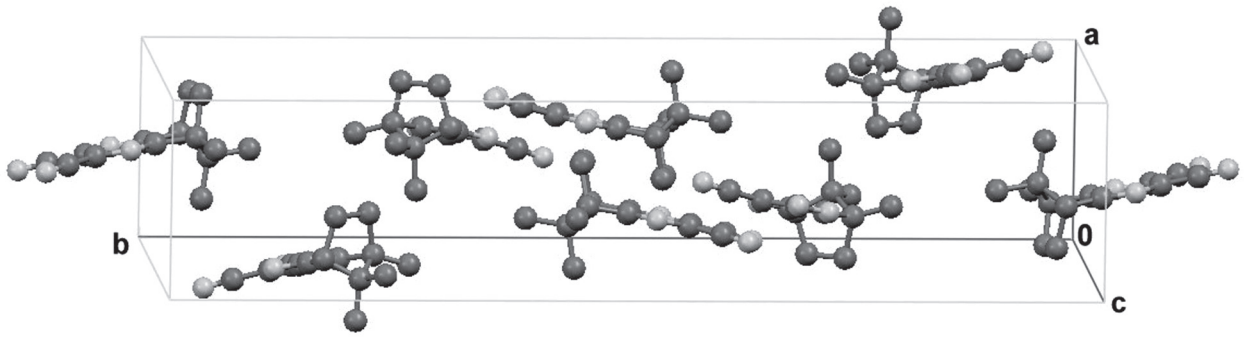


Figure 1. Crystal packing of **1**, shown along *b* axis.

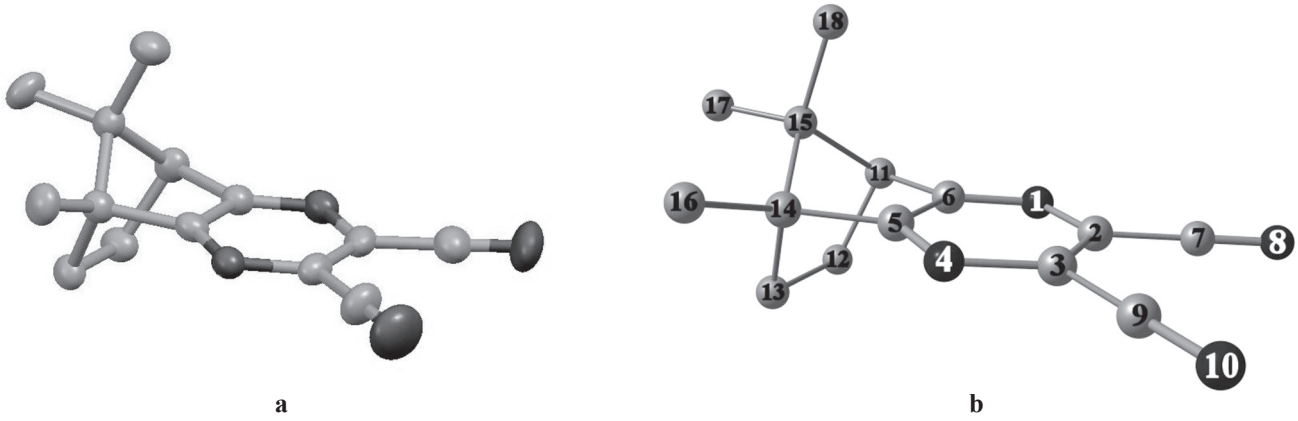


Figure 2. Structure of R(-)**1** by X-Ray analysis (a), and optimized by DFT/B3LYP/cc-pVTZ (b). Hydrogen atoms are eliminated for clarity.

The spectrum ^{13}C NMR of **1** as well as assignment of its signals are shown in Figure S3 (SI).

Infra-red spectrum of **1** is characteristic for substituted phthalonitriles due to a strong absorption observed at 2229 cm^{-1}, induced by stretching vibrations of C≡N bonds. The bands at 2926 and 2863 cm^{-1} correspond to symmetric and asymmetric vibrations of C-H bonds of camphor fragment.

Compound **1** was also characterized by X-Ray analysis. Single crystals of racemic mixture suitable for X-ray diffraction measurement were grown by slow evaporation from its ethanol solution. Monoclinic crystal with parameters 0.20×0.08×0.04 mm^3 was analyzed at 100 K (cooling Oxford Cryosystem). The following parameters of the unit cell were obtained from 4326 independent reflections collected at intensity R_{int} = 0.0385: a = 7.1410 (5), b = 33.579 (2), c = 10.5417 (8) Å, V = 2517.7 (3) $Å^3$, $d_{calc.}$ = 1.257 g/cm^3, space group P2(1)/n. Four R(-)-isomers and four S(+)-isomer can be observed in the crystal unit cell. Crystal packing and structure of R(-) isomer are shown in Figures 1 and 2, respectively. The crystal structure has been deposited at Cambridge Crystallographic Data Centre (CCDC 853128).

X-Ray diffraction data of camphor fragment of compound **1** are in a good agreement with those of camphorquinone reported in literature.[17] Herein, a deviation of bond lengths for asymmetric C14 and the neighbor atoms C5, C13, C15, C16 (atoms numeration is given in Figure 2b) was found to be only 0.016 Å. On going from **1** to camphorquinone, there is an insignificant increase in the values of angles (C14-C5-C6, C11-C6-C5, C12-C13-C14 and C11-C12-C13 of 1-2º). The maximal deviation (near 1º) was only observed for angles

Table 1. Experimental and calculated bond lengths (Å) and some bond angles (˚) of **1** (R(-)) (Figure 2).

Bonds, angles	X-Ray	cc-pVTZ
N1-C2	1.366	1.353
C2-C3	1.388	1.401
C3-N4	1.365	1.353
N4-C5	1.315	1.311
C5-C6	1.430	1.416
N1-C6	1.311	1.311
C2-C7	1.451	1.433
C3-C9	1.440	1.433
C7-N8	1.144	1.152
C9-N10	1,149	1.152
C6-C11	1.503	1.499
C11-C12	1.557	1.561
C12-C13	1.539	1.554
C13-C14	1.564	1.569
C5-C14	1.495	1.509
C14-C16	1.504	1.514
C14-C15	1.580	1.588
C11-C15	1.560	1.569
C15-C17	1.522	1.531
C15-C18	1.525	1.535
C3-C2-C7	120.670	121.150
C2-C3-C9	121.260	121.140
C15-C14-C16	119.280	119.160
C5-C14-C16	116.160	116.360
C13-C14-C16	115.150	115.230

formed by the asymmetric carbon atom C14. Hence, the formation of pyrazine ring by interaction of camphorquinone with diaminomaleonitrile produces a very low influence on geometry of the camphorquinone fragment.

Quantum-chemical calculations at the DFT level[18] for *R*(-)- and *S*(+)-isomer of **1** were carried out with the aim to compare geometric characteristics of molecules in a solid and an isolated states. Calculations of the second derivatives proved that optimized configurations correspond to the minima on potential energy surfaces. Resume data of X-Ray diffraction analysis and quantum-chemical calculations of *R*(-)-isomer of **1** are given in Table 1 for comparison. The geometrical parameters of **1**, revealed by X-Ray analysis were found to be in a good agreement with those derived from theoretical calculations.

Conclusions

In a conclusion, an improved method of the synthesis of 1',7',7'-trimethylbicyclo[2.2.1]heptane[2',3'-*b*]-2,3-dicyanopyrazine **1** by interaction of racemic mixture of camphorquinone with diaminomaleonitrile in acetic acid was developed. Structure of the compound **1** was established by X-Ray analysis. The experimental data were found to be in a good agreement with quantum-chemical calculations.

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