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The photocycloaddition of furo[3,2-*c*]pyridin-4(5*H*)-one (**1**) and its *N*-methyl derivative (**1-Me**) to acrylonitrile has been studied. The structures of the photoadducts isolated by column chromatography were determined on the basis of the nuclear magnetic resonance spectroscopy. The cycloaddition of **1** afforded an adduct **2** at the carbonyl oxygen and four possible isomers **3a**, **3b**, **3c** and **3d** of cyclobutane-fused adduct at the 6- and 7-position of **1**, and the addition of **1-Me** the *N*-methyl derivatives **3a-Me**, **3b-Me**, **3c-Me** and **3d-Me**.

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We have been continuously interested in the chemistry of furopyridines, and have reported the synthesis and the chemical properties of furo[2,3-*b*]-, furo[3,2-*b*]-, furo[2,3-*c*]- and furo[3,2-*c*]pyridine and their derivatives, particularly compounds having substituents at 2- and/or 3-position [2a-j]. Meanwhile, photochemical cycloaddition of a cyclic enone system with an ethylene derivative to form a cyclobutane provides a useful method for the construction of new carbon frameworks, and has been applied widely to heteroaromatic compounds, such as pyrones [3], 2-pyridones, 2-quinolones and 1-isoquinolones [4]. It has been reported that most of these photocycloadditions proceed with high regioselectivity.

In an extension for our chemical studies of furopyridines, we attempted the photo[2+2]cycloaddition of furopyridones to obtain a new heterocyclic framework and to see the effect of the furan ring upon the regio- and stereoselectivity of the addition. In this paper we describe the photo[2+2]cycloaddition of furo[3,2-*c*]pyridin-4(5*H*)-

one (**1**) and its *N*-methyl derivative (**1-Me**) with acrylonitrile.

Irradiation of **1** (1.0 mmole) in methanol (200 ml) containing a large excess of acrylonitrile (100 mmoles) by high pressure mercury lamp (400 w, Pyrex filter) until disappearance of the starting furopyridone afforded a mixture of addition products, from which compounds **2** (mp 102-104°), **3a** (mp 230-235°), a mixture of **3a** and **3c** (ca. 1:1) [5], **3b** (mp 249-253°) and **3d** (mp 218-220°) could be isolated by column chromatography on silica gel in yields of 4.7, 15, 5, 19 and 12% respectively. Compounds **3a-3d** were *N*-methylated with sodium hydride and iodomethane in tetrahydrofuran, respectively, to give **3a-Me** (mp 105.5-108°), **3b-Me** (mp 142-145.5°), **3c-Me** (mp 158-160°) and **3d-Me** (mp 179-184°).

The photocycloaddition of 5-methylfuro[3,2-*c*]pyridin-4(5*H*)-one (**1-Me**) with acrylonitrile in methanol afforded a mixture of the addition products, from which compound **3a-Me** (15%), **3b-Me** (20%), **3c** (7%) and **3d-Me** (20%)

Chart 1

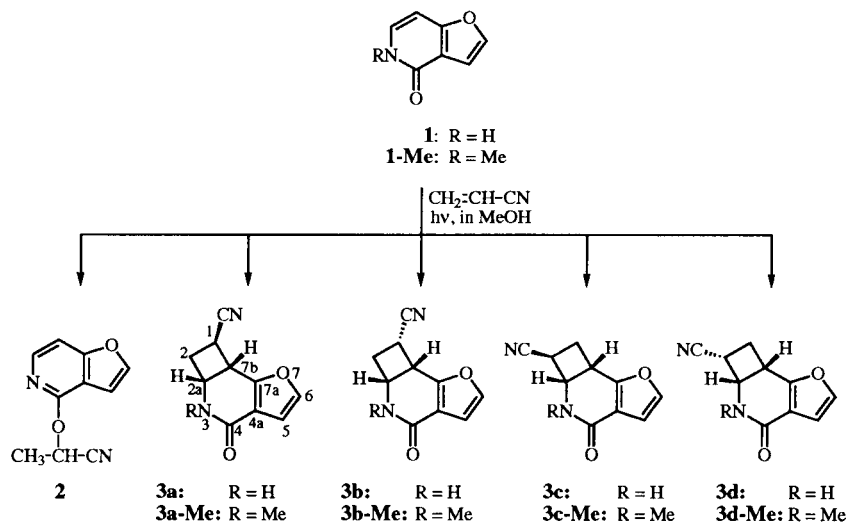
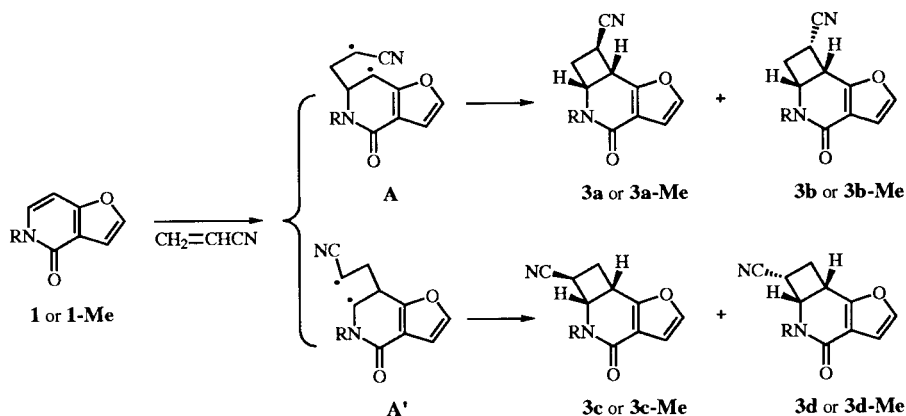


Chart 2



were isolated by column chromatography on silica gel.

The structure of compound **2** was determined on the basis of spectroscopic data. The elemental analysis indicated the molecular formula $C_{10}H_8N_2O_2$. The ir spectrum showed no carbonyl and NH absorption but an absorption for the cyano group at 2251 cm^{-1} (very weak). The ^1H -nmr spectrum of **2** exhibited signals for eight protons. Two AB-type quartets at 7.60 and 6.83 ppm (2H, $J = 2.4$ Hz), and at 8.01 and 7.18 ppm (2H, $J = 5.6$ Hz) were assigned to the protons of furan ring (2- and 3-position), and to those of the pyridine ring (6- and 7-position) respectively. The quartet at 5.92 ppm (1H, $J = 6.8$ Hz) and the doublet at 1.82 ppm (3H, $J = 6.8$ Hz) suggested the presence of partial structure O-CH-CH₃. Thus, the structure of compound **2** was confirmed as 4-(1-cycnoethoxy)furo[3,2-*c*]pyridine.

The elemental analysis of compounds **3a-3d** and **3a-Me-3d-Me** indicated the molecular formula $C_{10}H_8N_2O_2$ and $C_{11}H_{10}N_2O_2$, respectively. All of these compounds exhibited the absorption of a carbonyl and a cyano group in their ir spectra. The ^1H -nmr of these compounds showed no proton signal for the aromatic pyridine ring. Thus, these compounds were proposed as regio- and configurational isomers of a cyclobutane-fused adduct with the acrylonitrile group incorporated at the 6- or the 7-position of the newly fused furopyridone. It is evident that all of these compounds have thermodynamically more stable *cis*-configuration between C_{2a}-H and C_{7b}-H, because none of these compounds epimerized by treatment with basic alumina [3a,3f,4h,6].

Based on these facts, the following structures were assigned for the adducts **3a-d** and **3a-Me-3d-Me** by ^1H - and ^{13}C -nmr spectroscopy. Since the adducts **3a-Me-3d-Me** are soluble in deuteriochloroform, the detailed analysis was carried out for these compounds. The proton resonating furthest down field of the aliphatic protons (4.63 ppm for **3a-Me**, 4.26 ppm for **3b-Me**, 4.53 ppm for **3c-Me** and 4.60 ppm for **3d-Me**), except for **3b-Me**, and the

carbon resonating furthest downfield of the sp^3 carbons (54.3, 53.1, 59.9 and 55.9 ppm for **3a-Me**, **3b-Me**, **3c-Me** and **3d-Me**) for each compound can be assigned to a nitrogen-bearing methine, H-2a and C-2a, unambiguously. From the ^1H - ^{13}C COSY spectra of **3a-Me**, **3b-Me** and **3d-Me** (Figures 1, 2 and 4) and HSQC spectrum of **3c-**

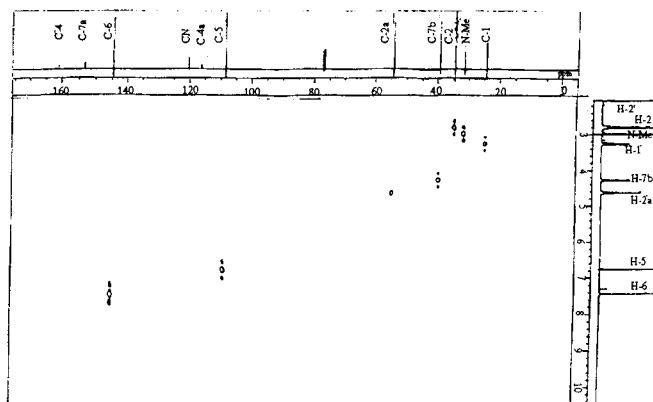
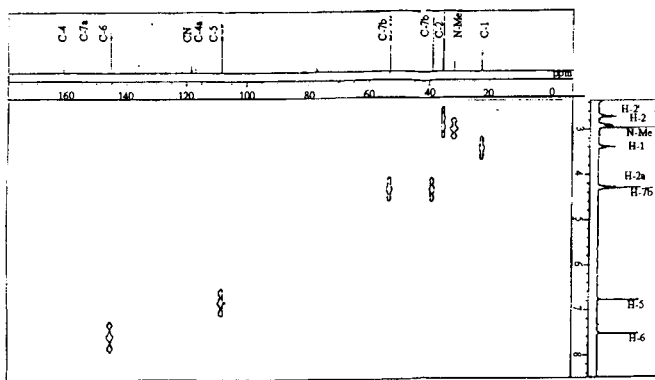


Figure 1. ^1H - ^{13}C COSY Spectrum of **3a-Me**.

Me (Figure 3), it is observed that the proton corresponding to H-2a is attached to the carbon assigned to C-2a in each compound. The carbon connectivity was established by decoupling studies.

In the spectrum of **3a-Me**, irradiation at 4.63 ppm (H-2a) changed the signal at 4.29 ppm (dt) to a triplet ($J = 3.2$ Hz), the signal at 2.82 ppm (dddd) to a doublet of double doublet ($J = 19.6, 8.8, 3.2$ Hz) and the signal at 2.79 ppm (ddd) to a double doublet ($J = 19.6, 5.2$ Hz), while the signal at 3.26 ppm did not change the coupling pattern; irradiation at 4.29 ppm changed the quartet at 4.63 ppm (H-2a) to a triplet ($J = 8.4$ Hz), the signal at 3.26 ppm (ddd) to a double doublet ($J = 8.8, 5.2$ Hz) and sharpened the signals at 2.82 ppm, while it did not change the coupling pattern of signal at 2.79 ppm; irradiation at 3.26 ppm

Figure 2. ^1H - ^{13}C COSY Spectrum of **3b-Me**.

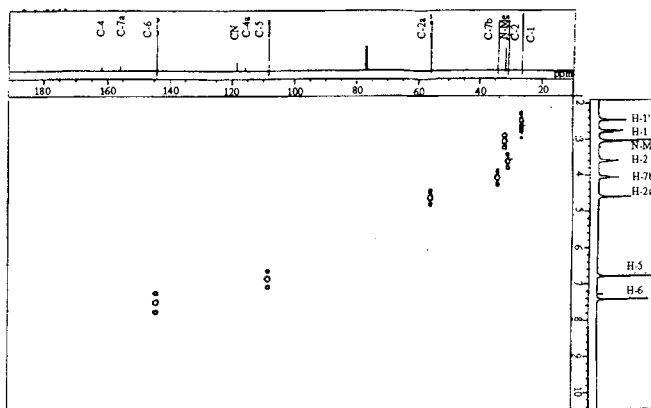
changed the double triplet at 4.29 ppm to a double doublet ($J = 8.4, 2.8$ Hz), sharpened the signals at 2.82 and 2.79 ppm, but did not change the coupling pattern of the signal at 4.63 ppm (H-2a). These facts suggested the signals at 4.29 and 3.26 ppm are assignable to H-7b and H-1' respectively.

The ^1H - ^{13}C COSY spectrum of **3a-Me** showed that the protons resonating at 2.82 (H-2) and 2.79 ppm (H-2') are attached to the carbon resonating at 34.48 ppm (C-2), and that the carbons resonating at 39.3 and 24.4 ppm are connected to the protons assigned to H-7b and H-1' respectively, identifying these carbons as C-7b and C-1.

The long-range correlations observed in the HMBC spectrum provided the additional evidence. In the HMBC spectrum of **3a-Me**, the carbon resonating at 24.4 ppm correlates with the protons corresponding to H-2, H-2', H-7b and H-2a, and therefore corresponds to C-1. The carbon resonating at 34.5 ppm correlates with the protons corresponding to H-1, H-2a and H-7b thus identifying this

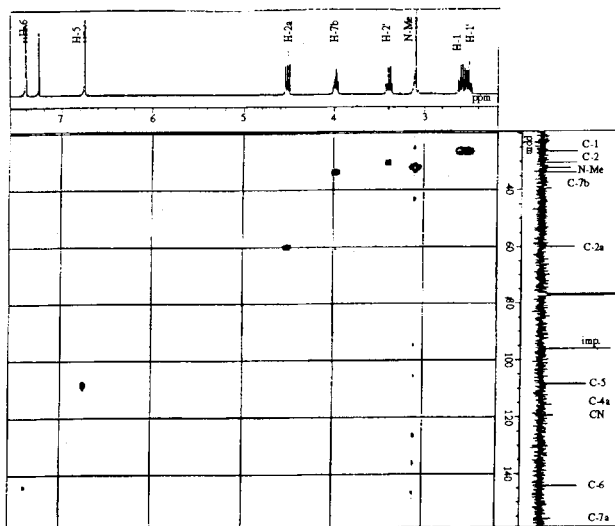
as C-2. Likewise, the resonance at 39.3 ppm correlates with the protons corresponding to H-1', H-2, H-2' and H-2a. These correlations identify the resonance at 39.3 ppm as C-7b. The carbon resonance at 54.3 ppm correlates with the protons corresponding to H-1', H-2, H-2', N-Me and H-7b thus identifying this resonance as C-2a. The carbon resonance at 116.3 ppm correlates with the proton resonances corresponding to H-5, H-6 and H-7b identifying this resonance as C-4a.

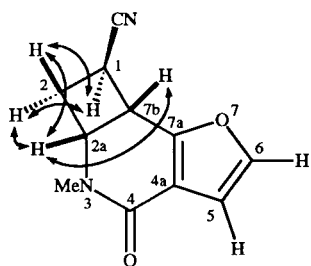
The spin decoupled spectra of **3b-Me** established the carbon connectivity; irradiation at 3.36 ppm changed the signal at 2.91 ppm (ddd) to a doublet of double doublet ($J = 11.2, 5.6, 3.6$ Hz), the signal at 2.73 ppm (ddd) to a double doublet ($J = 11.2, 7.6$ Hz), the signal at 4.30 ppm (ddd) to a double doublet ($J = 8.0, 3.6$ Hz), but did not change the signal at 4.26 ppm (ddd) (H-2a); irradiation at

Figure 4. ^1H - ^{13}C COSY Spectrum of **3d-Me**.

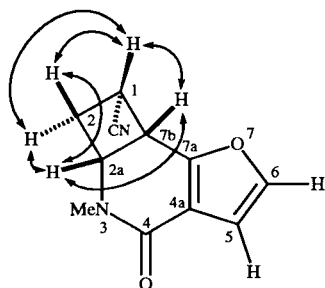
2.91 ppm changed the signal at 4.30 ppm (ddd) to a double doublet ($J = 8.0, 6.4$ Hz), the signal at 4.26 ppm (ddd) (H-2a) to a double doublet ($J = 8.0, 7.6$ Hz), the signal at 3.36 ppm (ddd) to a double doublet ($J = 10.0, 6.4$ Hz), and the signal at 2.73 ppm (ddd) to a double doublet ($J = 10.0, 7.6$ Hz). These facts indicate that there is no spin-spin interaction between signals at 4.26 (H-2a) and 3.36 ppm; thus the protons at 3.36 and 4.30 ppm were assigned to H-1 and H-7b respectively.

In the ^1H - ^{13}C COSY spectrum of **3b-Me**, it is observed that the protons resonating at 2.91 and 2.73 ppm are attached to the carbon at 35.2 ppm, which are assigned to H-2, H-2' and C-2 respectively; and that the carbons resonating at 22.5 and 38.8 ppm are connected to the protons assigned to H-1 and H-7b respectively, identifying these carbons as C-1 and C-7b respectively. These assignments were supported by the long-range correlations observed in the HMBC spectrum. The carbon resonating at 22.5 ppm correlates with the proton corresponding to H-2, H-2' and weakly with that of H-7b, and therefore corresponds to C-1. The carbon resonating at 35.2 ppm correlates with the

Figure 3. HSQC Spectrum of **3c-Me**.

Figure 5. Main NOE correlations of **3a-Me**.

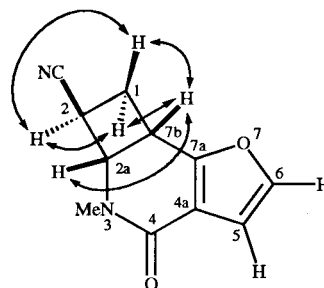
proton resonances corresponding to H-1', H-2a and H-7b thus identifying this as C-2. The resonance at 38.8 ppm correlates with the proton resonances corresponding to H-1, H-2, H-2' and H-2a identifying this resonance as C-7b, and the carbon resonating at 53.1 ppm correlates with the proton resonances corresponding to H-2, H-2', H-7b and N-Me identifying this as C-2a. The carbon resonating at 117.1 ppm correlates with the proton resonances corresponding to H-5, H-6 and H-7b identifying this resonance as C-4a. Likewise the resonance at 152.8 ppm correlates

Figure 6. Main NOE correlations of **3b-Me**.

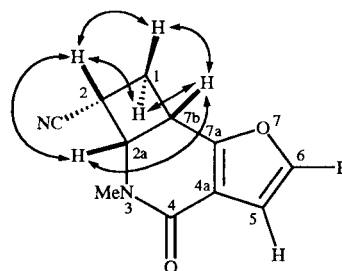
with the proton resonances corresponding to H-1', H-2, H-2a, H-5, H-6 and H-7b thus identifying this resonance as C-7a.

These results suggested that compounds **3a-Me** and **3b-Me** are the epimers at C-1 of 1-cyano compound. In order to determine the configuration at C-1, the nuclear Overhauser effect (NOE) difference spectra were examined (Figures 5 and 6). The NOE was observed from H-1 to H-7b for **3b-Me** and was absent in **3a-Me** from H-1' to H-7b. These facts suggested a *trans* relationship of H-1' and H-7b of **3a-Me**, and a *cis* of H-1 and H-7b of **3b-Me**, which is supported by a smaller coupling constant (3.2 Hz) between H-1' and H-7b of **3a-Me** than that (6.4 Hz) between H-1 and H-7b of **3b-Me**. Appreciable long-range coupling between H-2 and H-7b ($J_{2,7b} = 3.2$ Hz for **3a-Me**, 3.6 Hz for **3b-Me**) in the spectra of these compounds suggests strongly that these two hydrogen atoms (H-2 and H-7b) are in a *W*-configuration [6]. Thus, the structure of **3a-Me** and **3b-Me** were assigned to (1*R**, 2*aS**, 7*bS**)-

and (1*S**, 2*aS**, 7*bS**)-1-cyano-3-methyl-4-oxo-1,2,2a,3,4,7b-hexahydrocyclobuta[g]furo[3,2-c]pyridine, respectively.

Figure 7. Main NOE correlation of **3c-Me**.

The carbon connectivity of **3c-Me** was established again by spin decoupling technique. In the spectrum of **3c-Me**, irradiation at 4.53 ppm (H-2a) changed the signal at 3.99 ppm (dt) to a double doublet ($J = 8.4, 2.8$ Hz), the signal at 3.40 ppm (ddd) to a double doublet ($J = 11.6, 10.0$ Hz), but did not change the signals at 2.59 (ddd) and 2.51 ppm (ddd); irradiation at 3.99 ppm changed the triplet at 4.53 ppm (H-2a) to a doublet ($J = 8.4$ Hz), the signal at 2.59 ppm (ddd) to a double doublet ($J = 11.6, 9.6$ Hz), the signal at 2.51 ppm (ddd) to a double doublet ($J = 10.0, 9.6$ Hz), but did not change the signal at 3.40 ppm (ddd); irradiation at 3.40 ppm changed the triplet at 4.53 ppm (H-2a) to a doublet ($J = 8.4$ Hz), the signals at 2.59 ppm (ddd) to a double doublet ($J = 9.6, 8.4$ Hz), the signal at 2.51 ppm (ddd) to a double doublet ($J = 9.6, 2.8$ Hz), but did not change the signal at 3.99 ppm (dt). These results indicate that there is no spin-spin interaction between the signals at 3.99 and 3.40 ppm, between the signals at 4.53 (H-2a) and 2.59 ppm, and between the signals at 4.53 (H-2a) and 2.51 ppm; thus, the signal at 3.99 ppm is assigned to H-7b, 3.40 ppm to H-2', 2.59 ppm to H-1 and 2.51 ppm to H-1'.

Figure 8. Main NOE correlations of **3d-Me**.

In the HSQC spectrum of **3c-Me**, it was indicated that the protons resonating at 2.59 (H-1) and 2.51 ppm (H-1') are attached to the carbon resonating at 26.3 ppm identify-

Table I
¹H-NMR Spectral Data of Compounds **3a-Me**, **3b-Me**, **3c-Me** and **3d-Me**

	H-1	H-1'	H-2	H-2'	H-2a	H-7b	H-5	H-6	N-Me
3a-Me (8434)	—	3.26 (ddd) $J_{1'-2} = 8.8$ $J_{1'-2'} = 5.2$ $J_{1'-7b} = 3.2$	2.82 (dddd) $J_{2-2'} = 19.6$ $J_{2-1'} = 8.8$ $J_{2-2a} = 8.4$ $J_{2-7b} = 3.2$	2.79 (ddd) $J_{2'-2} = 19.6$ $J_{2'-1'} = 5.2$ $J_{2'-2a} = 8.4$	4.63 (q) $J_{2a-2} = J_{2a-2'}$ $= J_{2a-7b} = 8.4$	4.29 (dt) $J_{7b-2a} = 8.4$ $J_{7b-1'} = J_{7b-2}$ $= 3.2$	6.76 (d) $J_{5-6} = 2.0$	7.43 (d) $J_{6-5} = 2.0$	2.96 (s)
3b-Me	3.36 (ddd) $J_{1-2} = 8.4$ $J_{1-2'} = 10.0$ $J_{1-7b} = 6.4$	—	2.91 (dddd) $J_{2-1} = 8.4$ $J_{2-2'} = 11.2$ $J_{2-2a} = 5.6$ $J_{2-7b} = 3.6$	2.73 (ddd) $J_{2'-1} = 10.0$ $J_{2'-2} = 11.2$ $J_{2'-2a} = 7.6$	4.26 (ddd) $J_{2a-2} = 5.6$ $J_{2a-2'} = 7.6$ $J_{2a-7b} = 8.0$	4.30 (ddd) $J_{7b-1} = 6.4$ $J_{7b-2} = 3.6$ $J_{7b-2a} = 8.0$	6.80 (d) $J_{5-6} = 2.0$	7.53 (d) $J_{6-5} = 2.0$	2.97 (s)
3c-Me (8433)	2.59 (ddd) $J_{1-1'} = 9.6$ $J_{1-2'} = 11.6$ $J_{1-7b} = 8.4$	2.51 (ddd) $J_{1'-1} = 9.6$ $J_{1'-2'} = 10.0$ $J_{1'-7b} = 2.8$	—	3.40 (ddd) $J_{2'-1} = 11.6$ $J_{2'-1'} = 10.0$ $J_{2'-2a} = 8.4$	4.53 (t) $J_{2a-2'} = J_{2a-7b}$ $= 8.4$	3.99 (dt) $J_{7b-1} = J_{7b-2a}$ $= 8.4$ $J_{7b-1'} = 2.8$	6.75 (d) $J_{5-6} = 2.0$	7.41 (d) $J_{6-5} = 2.0$	3.10 (s)
3d-Me (8435)	2.77 (ddd) $J_{1-1'} = 12.8$ $J_{1-2} = 8.4$ $J_{1-7b} = 9.6$	2.45 (dt) $J_{1'-1} = 12.8$ $J_{1'-2} = J_{1'-7b}$ $= 2.8$	3.60 (ddd) $J_{2-1} = 8.4$ $J_{2-1'} = 2.8$ $J_{2-2a} = 7.6$	—	4.60 (dd) $J_{2a-2} = 7.6$ $J_{2a-7b} = 9.6$	4.06 (dt) $J_{7b-1} = J_{7b-2a}$ $= 9.6$ $J_{7b-1'} = 2.8$	6.78 (d) $J_{5-6} = 2.0$	7.43 (d) $J_{6-5} = 2.0$	3.05 (s)

ing this carbon as C-1. The HSQC spectrum also showed that the carbon resonating at 30.3 and 33.8 ppm are connected to the protons assigned to H-2 and H-7b respectively. Thus, these carbons are identified as C-2 and C-7b respectively.

The long-range correlations observed in the HMBC spectrum gave the additional evidence. In the HMBC spectrum of **3c-Me**, the carbon resonating at 30.3 ppm correlates with the proton resonances corresponding to H-1, H-1', H-2a and H-7b, and therefore corresponds to C-2. The carbon resonating at 33.8 ppm correlates with the proton resonances corresponding to H-1, H-1' and H-2a identifying this as C-7b. The carbon resonating at 59.9 ppm correlates with the proton resonances corresponding to H-1, H-1', H-2', N-Me and weakly with that of H-7b. These correlations identify the resonance at 59.9 as C-2a. Likewise, the resonance at 115.7 ppm correlates with the proton resonances corresponding to H-5, H-6 and weakly with that of H-7b, thus identifying this resonance as C-4a. The carbon resonance at 155.9 ppm correlates with the proton resonances corresponding to H-1, H-1', H-2a, H-5, H-6 and H-7b identifying this resonance as C-7a.

In the spin-decoupled spectra of **3d-Me**, irradiation at 4.60 ppm (H-2a) changed the double triplet at 4.06 ppm to a double doublet ($J = 9.6, 2.8$ Hz), the signal at 3.60 ppm (ddd) to a double doublet ($J = 8.4, 7.2$ Hz), but did not change the signals at 2.77 and 2.45 ppm (both ddd); irradiation at 4.06 ppm changed the double doublet at 4.60 ppm (H-2a) to a doublet ($J = 7.6$ Hz), the signal at 2.77 ppm (ddd) to a double doublet ($J = 12.8, 8.4$ Hz), the double triplet at 2.45 ppm to a double doublet ($J = 12.8, 2.8$

Hz), but did not change the signal at 3.60 ppm (ddd); irradiation at 3.60 ppm changed the double doublet at 4.60 ppm (H-2a) to a doublet ($J = 9.6$ Hz), the signal at 2.77 ppm (ddd) to a double doublet ($J = 12.8, 9.6$ Hz), the double triplet at 2.45 ppm to a double doublet ($J = 12.8, 2.8$ Hz), but did not change the signal at 4.06 ppm (dt), irradiation at 2.77 ppm changed the double triplet at 4.06 ppm to a double doublet ($J = 9.6, 2.8$ Hz), the signal at 3.60 ppm (ddd) to a double doublet ($J = 7.6, 2.8$ Hz), the double triplet at 2.45 ppm to a triplet ($J = 2.8$ Hz), while did not change the double doublet at 4.60 ppm (H-2a); irradiation at 2.45 ppm changed the double triplet at 4.06 ppm to a triplet ($J = 9.6$ Hz), the signal at 3.60 ppm (ddd) to a double doublet ($J = 8.4, 7.6$ Hz), the signal at 2.77 ppm (ddd) to a double doublet ($J = 9.6, 8.4$ Hz), but did not change the double doublet at 4.60 ppm (H-2a). These facts indicated that there is no spin-spin interaction between the

Table II
¹³C Assignments and HMBC Correlations of Compound **3a-Me**

Position	¹³ C	HMBC (¹ H)
1	24.4 (d)	2, 2', 2a, 7b
2	34.5 (t)	1, 2a, 7b
2a	54.3 (d)	1', 2, 2', 7b, N-Me
N-Me	31.4 (q)	2a
4	161.0 (s)	2a, N-Me
4a	116.3 (s)	5, 6, 7b
5	108.5 (d)	6
6	144.6 (d)	5
7a	153.5 (s)	1', 2a, 5, 6, 7b
7b	39.3 (d)	1', 2, 2', 2a
CN	120.5 (s)	1', 2, 2', 7b

signals at 4.06 and 3.60 ppm and between the signals at 4.60 (H-2a) and 2.77 ppm, and between the signals at 4.60 (H-2a) and 2.45 ppm. Thus, the signal at 4.06 ppm is assigned to H-7b, 3.60 ppm to H-2, 2.77 ppm to H-1 and 2.45 ppm to H-1'.

Table III

¹³C Assignments and HMBC Correlations of Compound **3b-Me**

Position	¹³ C	HMBC (¹ H)
1	22.5 (d)	2, 2', 7b
2	35.2 (t)	1', 2a, 7b
2a	53.1 (d)	2, 2', 7b, N-Me
N-Me	31.6 (q)	2a
4	161.2 (s)	2a, 7b, N-Me
4a	117.1 (s)	5, 6, 7b
5	108.3 (d)	6
6	145.3 (d)	5
7a	152.8 (s)	1', 2', 2a, 5, 6, 7b
7b	38.8 (d)	1', 2, 2', 2a
CN	118.4 (s)	1', 2, 2'

The ¹H-¹³C COSY spectrum of **3d-Me** indicated that the protons assigned to H-1 (2.77 ppm) and H-1' (2.45 ppm) are attached to the carbon resonating at 26.5 ppm identifying this carbon as C-1; and that the carbons resonating at 30.8 and 34.1 ppm are connected to the protons assigned to H-2 (3.60 ppm) and H-7b (4.06 ppm) identifying these carbons as C-2 and C-7b respectively. In the HMBC spectrum of **3d-Me**, the carbon resonating at 26.5 ppm correlates with the proton corresponding to H-2 and weakly with those of H-2a and H-7b, and therefore corresponds to C-1. The carbon resonating at 30.8 ppm correlates with the protons corresponding to H-1, H-1' and H-7b identifying this resonance as C-2. The carbon resonating at 55.9 ppm correlates with the protons corresponding to H-1', H-2, H-7b and N-Me and weakly with that of H-1, thus identifying this as C-2a. The carbon resonating at 115.9 ppm correlates with the proton resonances corresponding to H-5, H-6 and H-7b identifying this resonance as C-4a. The carbon resonating at 256.0 ppm correlates with the proton resonances

Table IV

¹³C Assignments and HMBC Correlations of Compound **3c-Me**

Position	¹³ C	HMBC (¹ H)
1	26.3 (t)	2'
2	30.3 (d)	1, 1', 2a, 7b
2a	59.9 (d)	1, 1', 2', 7b (w), N-Me
N-Me	32.2 (q)	2a
4	161.3 (s)	2a, N-Me
4a	115.7 (s)	5, 6, 7b (w)
5	108.4 (d)	6
6	144.3 (d)	5
7a	155.9 (s)	1, 1', 2a, 5, 6, 7b
7b	33.8 (d)	1, 1', 2a
CN	119.5 (s)	1, 1', 2', 2a

corresponding to H-1, H-1', H-2a, H-5, H-6 and H-7b, and therefore corresponds to C-7a. Likewise, the carbon resonance at 34.1 ppm correlates with the protons corresponding to H-1, H-1', H-2 and H-2a identifying this as C-7b.

These results suggested the compound **3c-Me** and **3d-Me** to be an epimer at C-2 of 2-cyano derivative. The configuration at C-2 of these compounds was determined by the NOE experiment (Figures 7 and 8). The NOE was observed between H-2 and H-2a for **3d-Me** but was absent in **3c-Me** between H-2' and H-2a. Therefore, the configuration of H-2' and H-2a of **3c-Me** is suggested to be *trans* and that of H-2 and H-2a of **3d-Me** *cis*. Thus, the structure of the former is assigned to (2*R**, 2*aR**, 7*bR**)-, and the latter (2*S**, 2*aR**, 7*bR**)-2-cyano-3-methyl-4-oxo-1, 2, 2a, 3, 4, 7b-hexahydrocyclobuta[g]furo[3,2-*c*]pyridine.

Accordingly, the structures of **3a**, **3b**, **3c** and **3d** are assigned to the corresponding *N*-dimethyl derivative of **3a-Me-3d-Me**.

Table V

¹³C Assignments and HMBC Correlations of Compound **3d-Me**

Position	¹³ C	HMBC (¹ H)
1	26.5 (t)	2, 2a (w), 7b (w)
2	30.8 (d)	1, 1', 7b
2a	55.9 (d)	1 (w), 1', 2, 7b, N-Me
N-Me	31.8 (q)	2a
4	161.9 (s)	2a, N-Me
4a	115.9 (s)	5, 6, 7b
5	108.4 (d)	6
6	144.2 (d)	5
7a	156.0 (s)	1, 1', 2a, 5, 6, 7b
7b	34.1 (d)	1, 1', 2, 2a
CN	118.5 (s)	1, 1', 2, 2a

It had been reported that in the photocycloaddition to monosubstituted olefin, isoquinolone-1 and/or its *N*-substituted derivatives afforded 1-substituted cyclobut[*c*]isoquinolones as the major products [4]. This research, however, has demonstrated that photocycloaddition of furo[3,2-*c*]pyridone and its *N*-methyl derivative with acrylonitrile afforded mainly a mixture of regio- and stereoisomers **3a-3d** and **3a-Me-3d-Me** of [2+2]-cycloaddition product at the 6- and 7-position in almost equal yield. This result may be interpreted by the low energy difference between the two possible biradical intermediates (**A** and **A'** shown in Chart 2) by the electron-donating effect of the furan oxygen. The minor product **2** formed in the reaction of furo[3,2-*c*]pyridin-4(5*H*)-one may be afforded by the addition at the carbonyl group in the excited state. Formation of such an addition at the carbonyl group in pyridones, quinolines and/or isoquinolones had not yet been reported.

EXPERIMENTAL

All melting points were determined on a micro-hot stage (Yanagimoto) and are uncorrected. Infrared spectra were recorded on a JASCO FT/IR 7300 spectrometer. The ^1H - and ^{13}C -nmr spectra were recorded on a JEOL JNM-PMX 60 (60 MHz), a JEOL JNM-GX 270 (270 MHz) or a JEOL JNM FX-A400 spectrometer (400 MHz) with tetramethylsilane as an internal standard. The spectral assignments were confirmed by spin-decoupling, ^1H - ^{13}C correlation spectroscopy (^1H - ^{13}C COSY) (512 x 256 data matrix size, 128 scans, interpulse delay 1.50 seconds) of **3a-Me**, **3b-Me** and **3d-Me**, HSQC (512 x 256 data matrix size, 16 scans, recycle delay 1.20 seconds) of **3c-Me**, HMBC (1024 x 512 data matrix size, 40 scans, recycle delay 1.00 second for **3a-Me**, **3b-Me** and **3d-Me**, 2048 x 256 data matrix size, 128 scans, recycle delay 1.50 seconds for **3c-Me**) and nuclear Overhauser effect (NOE) analyses.

Photolyses were carried out under nitrogen in a Pyrex immersion apparatus with Shigemi 400W high-pressure lamp cooled internally with running water, and correspond to irradiation at >300nm.

Photoreaction of Furo[3,2-*c*]pyridin-4(5*H*)-one (**1**) with Acrylonitrile

A solution of **1** (135 mg, 1.0 mmole) and acrylonitrile (5.3 g, 100 mmoles) in methanol (200 ml) was irradiated at >300 nm for 10 hours. The reaction mixture was filtered and evaporated to give a slightly yellow semi-solid residue. This reaction was repeated 5 times. The combined residue (1050 mg) was chromatographed on a silica gel (125 g) column eluting with chloroform-methanol. The first fraction eluted with chloroform-methanol (99:1) gave 50 mg of a crude sample of compound **2**, the second fraction eluted with chloroform-methanol (98:2) 240 mg of a mixture of compound **3a** and **3c** (ca. 5:1), the third fraction eluted with chloroform-methanol (97:3) 190 mg of a crude sample of compound **3b** and the fourth fraction eluted with chloroform-methanol (97:3) 130 mg of a crude sample of compound **3d**.

Further processing of the crude products is indicated in the following paragraph.

4-(1-Cyanoethoxy)furo[3,2-*c*]pyridine (**2**).

The first fraction was recrystallized from hexane to give 43.5 mg (4.7%) of the pure sample of **2** as colorless needles, mp 102-104°; ir (potassium bromide): 3144, 3118, 3025, 2951, 2251 (w), 1600, 1528, 1460, 1436, 1369, 1333, 1278, 1202, 1142, 1102, 1073, 1032, 1012, 799, 777, 755 cm^{-1} ; ^1H -nmr (deuteriochloroform, 60 MHz): δ 8.01 (d, J = 5.6 Hz, 1H, H-6), 7.60 (d, J = 2.4 Hz, 1H, H-2), 7.13 (dd, J = 5.6, 1.0 Hz, 1H, H-7), 6.83 (dd, J = 2.4, 1.0 Hz, 1H, H-3), 5.94 (q, J = 6.8 Hz, 1H, Me-CH(CN)-O-), 1.83 (d, J = 6.8 Hz, 3H, CH₃-CH).

Anal. Calcd. for C₁₀H₈N₂O₂: C, 63.83; H, 4.28; N, 14.89. Found: C, 64.05; H, 4.63; N, 14.80.

(1*R**, 2*aS**, 7*bS**)-1-Cyano-4-oxo-1,2,2*a*,3,4,7*b*-hexahydrocyclobuta[*g*]furo[3,2-*c*]pyridine (**3a**).

Recrystallization of the second fraction from methanol gave 141 mg (15%) of the pure sample of **3a** as colorless cubes of mp 230-235° ir (potassium bromide): 3266, 3161, 3096, 2956, 2921, 2853, 2242, 1678, 1641, 1592, 1487, 1318, 1221, 1065, 1023, 897, 749 cm^{-1} ; ^1H -nmr (deuteriochloroform, 270 MHz): δ 7.48

(d, J₆₋₅ = 1.5 Hz, 1H, H-6), 6.80 (d, J₅₋₆ = 1.5 Hz, 1H, H-5), 5.82 (br d 1H, NH), 4.74 (dddd, J_{2*a*-2'} = 9.6 Hz, J_{2*a*-7*b*} = 9.3 Hz, J_{2*a*-2} = 7.9 Hz, J_{2*a*-NH} = 4.2 Hz, 1H, H-2*a*), 4.26 (dt, J_{7*b*-2*a*} = 9.3 Hz, J_{7*b*-1'} = J_{7*b*-2} = 2.3 Hz, 1H, H-7*b*), 3.26 (dt, J_{1'-2'} = 9.6 Hz, J_{1'-7*b*} = J_{1'-2} = 2.5 Hz, 1H, H-1'), 2.84 (dt, J_{2'-2} = 12.5 Hz, J_{2'-2*a*} = J_{2'-1'} = 9.6 Hz, 1H, H-2'), 2.75 (dddd, J_{2'-2'} = 12.5 Hz, J_{2'-2*a*} = 7.9 Hz, J_{2'-1'} = 2.5 Hz, J_{2'-7*b*} = 2.3 Hz, 1H, H-2').

Anal. Calcd. for C₁₀H₈N₂O₂: C, 63.83; H, 4.28; N, 14.89. Found: C, 63.85; H, 4.34; N, 14.70.

Evaporation of the mother liquor afforded 50 mg of a mixture of **3a** and **3c** (1:1) [5].

(1*S**, 2*aS**, 7*bS**)-1-Cyano-4-oxo-1,2,2*a*,3,4,7*b*-hexahydrocyclobuta[*g*]furo[3,2-*c*]pyridine (**3b**).

The third fraction was recrystallized from methanol to give 178.6 mg (19%) of the pure sample of compound **3b** as colorless cubes, mp 249-252°; ir (potassium bromide): 3275, 3148, 3115, 2999, 2967, 2243, 1693, 1645, 1585, 1492, 1483, 1347, 1311, 1239, 1232, 1224, 1134, 1086, 1041, 892, 810, 750, 665 cm^{-1} ; ^1H -nmr (deuteriochloroform, 270 MHz): δ 7.59 (d, J₆₋₅ = 1.7 Hz, 1H, H-6), 6.82 (d, J₅₋₆ = 1.7 Hz, 1H, H-5), 4.36 (q, J_{2*a*-2'} = J_{2*a*-7*b*} = 8.3 Hz, 1H, H-2*a*), 4.28 (td, J_{7*b*-1'} = J_{7*b*-2*a*} = 8.3 Hz, J_{7*b*-2} = 3.3 Hz, 1H, H-7*b*), 3.48 (ddd, J₁₋₂ = 7.4 Hz, J_{1-2'} = 10.3 Hz, J_{1-7*b*} = 8.3 Hz, 1H, H-1), 3.37 (br s, 1H, NH), 2.83 (dddd, J₂₋₁ = 7.4 Hz, J_{2-2'} = 11.5 Hz, J_{2-2*a*} = 8.3 Hz, J_{2-7*b*} = 3.3 Hz, 1H, H-2), 2.78 (ddd, J₂₋₁ = 10.3 Hz, J_{2-2'} = 11.5 Hz, J_{2-2*a*} = 8.3 Hz, 1H, H-2').

Anal. Calcd. for C₁₀H₈N₂O₂: C, 63.83; H, 4.28; N, 14.89. Found: C, 64.05; H, 4.37; N, 14.53.

(2*S**, 2*aR**, 7*bR**)-2-Cyano-4-oxo-1,2,2*a*,3,4,7*b*-hexahydrocyclobuta[*g*]furo[3,2-*c*]pyridine (**3d**).

Recrystallization of the fourth fraction from methanol afforded 113 mg (12%) of the pure sample of compound **3d** as colorless cubes, mp 218-220°; ir (potassium bromide): 3443, 3199, 3147, 3129, 3078, 2966, 2927, 2235, 1668, 1592, 1509, 1489, 1318, 1310, 1122, 1055, 1029, 887, 794, 748 cm^{-1} ; ^1H -nmr (deuteriochloroform, 270 MHz): δ 7.45 (d, J₆₋₅ = 1.7 Hz, 1H, H-6), 6.80 (d, J₅₋₆ = 1.7 Hz, 1H, H-5), 6.01 (br d, J = 5.2 Hz, 1H, NH), 4.67 (dt, J_{2*a*-2'} = J_{2*a*-7*b*} = 7.2 Hz, J_{2*a*-NH} = 5.2 Hz, 1H, H-2*a*), 4.02 (dt, J_{7*b*-1'} = J_{7*b*-2*a*} = 7.2 Hz, J_{7*b*-1'} = 3.4 Hz, 1H, H-7*b*), 3.51 (ddd, J₂₋₁ = 8.4 Hz, J_{2-1'} = 3.4 Hz, J_{2-2*a*} = 7.2 Hz, 1H, H-2), 2.79 (ddd, J_{1-1'} = 13.3 Hz, J₁₋₂ = 8.4 Hz, J_{1-7*b*} = 7.2 Hz, 1H, H-1), 2.50 (dt, J_{1'-1'} = 13.3 Hz, J_{1'-2} = J_{1'-7*b*} = 3.4 Hz, 1H, H-1').

Anal. Calcd. for C₁₀H₈N₂O₂: C, 63.83; H, 4.28; N, 14.89. Found: C, 63.96; H, 4.36; N, 14.69.

General Procedure for the *N*-Methylation of Compounds **1**, **3a**, **3b**, **3c** and **3d**.

To a stirred suspension of sodium hydride (48 mg of 60% dispersion in mineral oil, 1.2 mmoles, washed with hexane) in dry tetrahydrofuran (10 ml) was added a solution of furopyridone (**1**, **3a**, **3b**, **3d** or the mixture of **3a** and **3c**) (1.0 mmole) in dry tetrahydrofuran. Stirring was continued for 2 hours at room temperature. To this mixture was added iodo-methane (710 mg, 5 mmoles). After stirring at room temperature for 15 hours, the solvent was evaporated. The residual mixture was treated with chloroform and water. The chloroform layer was dried and evaporated to give a crystalline mass.

Further processing for the purification of the crude product is indicated in the subsequent paragraph.

5-Methylfuro[3,2-*c*]pyridin-4(5*H*)-one (**1-Me**).

Recrystallization of the crude solid from compound **1** from acetone-ether gave pure **1-Me** (95%) as colorless cubes of mp 117-119°; ir (potassium bromide): 3137, 3111, 3077, 3027, 2979, 2920, 1656, 1582, 1567, 1400, 1282, 1222, 1138, 1095, 1013, 887, 758 cm⁻¹; ¹H-nmr (deuteriochloroform, 60 MHz): δ 7.30 (d, J = 2.2 Hz, 1H, H-2), 7.13 (d, J = 7.0 Hz, 1H, H-6), 7.13 (dd, J = 2.2, 0.5 Hz, 1H, H-3), 6.45 (dd, J = 7.0, 0.5 Hz, 1H, H-7), 3.53 (s, 3H, N-Me).

Anal. Calcd. for C₈H₇NO₂: C, 64.42; H, 4.73; N, 9.39. Found: C, 64.36; H, 4.83; N, 9.43.

(1*R**, 2*aS**, 7*bS**)-1-Cyano-3-methyl-4-oxo-1,2,2*a*,3,4,7*b*-hexahydrocyclobuta[*g*]furo[3,2-*c*]pyridine (**3a-Me**).

The crude sample from **3a** was recrystallized from acetone-ether to give pure sample of **3a-Me** (92%) as colorless needles, mp 158-160°; ir (potassium bromide): 3160, 3127, 3002, 2974, 2954, 2930, 2875, 2852, 2239, 1663, 1606, 1502, 1399, 1326, 1280, 1225, 1204, 1125, 1090, 902, 754 cm⁻¹.

Anal. Calcd. for C₁₁H₁₀N₂O₂: C, 65.34; H, 4.98; N, 13.85. Found: C, 65.55; H, 5.09; N, 13.77.

(1*S**, 2*aS**, 7*bS**)-1-Cyano-3-methyl-4-oxo-1,2,2*a*,3,4,7*b*-hexahydrocyclobuta[*g*]furo[3,2-*c*]pyridine (**3b-Me**).

The pure sample of **3b-Me** was obtained by recrystallization of the crude product from **3b** in 90% yield, mp 142-145.5°; ir (potassium bromide): 3147, 3126, 3003, 2991, 2975, 2963, 2941, 2923, 2852, 2242, 1668, 1610, 1489, 1395, 1335, 1305, 1228, 1127, 1099, 1071, 889, 812, 750 cm⁻¹.

Anal. Calcd. for C₁₁H₁₀N₂O₂: C, 65.34; H, 4.98; N, 13.85. Found: C, 65.33; H, 5.11; N, 13.58.

(2*R**, 2*aR**, 7*bR**)-2-Cyano-3-methyl-4-oxo-1,2,2*a*,3,4,7*b*-hexahydrocyclobuta[*g*]furo[3,2-*c*]pyridine (**3c-Me**).

The crude product from the mixture of **3a** and **3c** was chromatographed on silica gel column eluting with hexane-ethyl acetate (1:1) to give a pure sample of **3a-Me** and **3c-Me** (1:1) in almost quantitative yield.

Compound **3c-Me** had mp 105.5-108°; ir (potassium bromide): 3156, 3127, 2958, 2933, 2236, 1666, 1487, 1396, 1305, 1226, 1175, 1131, 1086, 889, 751 cm⁻¹.

Anal. Calcd. for C₁₁H₁₀N₂O₂: C, 65.34; H, 4.98; N, 13.85. Found: C, 65.37; H, 5.05; N, 13.78.

(2*S**, 2*aR**, 7*bR**)-2-Cyano-3-methyl-4-oxo-1,2,2*a*,3,4,7*b*-hexahydrocyclobuta[*g*]furo[3,2-*c*]pyridine (**3d-Me**).

The crude sample from **3d** was recrystallized from acetone-ether to give a pure sample of **3d-Me** (95%), mp 179-184°; ir (potassium bromide): 3157, 3123, 3021, 2958, 2922, 2233, 1656, 1606, 1487, 1392, 1356, 1307, 1241, 1206, 1125, 1076, 1031, 891, 783, 767 cm⁻¹.

Photoreaction of 5-Methylfuro[3,2-*c*]pyridin-4(5*H*)-one with Acrylonitrile.

A solution of **1-Me** (149 mg, 1.0 mmole) and acrylonitrile (530 mg, 10 mmoles) in methanol (200 ml) was irradiated at >300 nm for 7 hours. The reaction mixture was filtered and evaporated to leave a semi-solid mass. This reaction was repeated 5 times. The combined residue (1.3 g) was chromatographed over silica gel (130 g). Elution with hexane-ethyl acetate (1:1) gave 71 mg (7%) of **3c-Me** (first fraction), 152 mg (15%) of **3a-Me** (second fraction), 202 mg (20%) of **3b-Me** (third fraction) and 202 mg (20%) of **3d-Me** (fourth fraction). The structures of these compounds were confirmed by comparison of the ir and ¹H-nmr spectra with those of the samples obtained by *N*-methylation of **3a**, **3b**, **3c** and **3d**.

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