

1,3-Dipolar cycloadditions of heterocycles. V.*

Reaction of *C*-acetyl-*N*-phenylnitrilimine with furan derivatives

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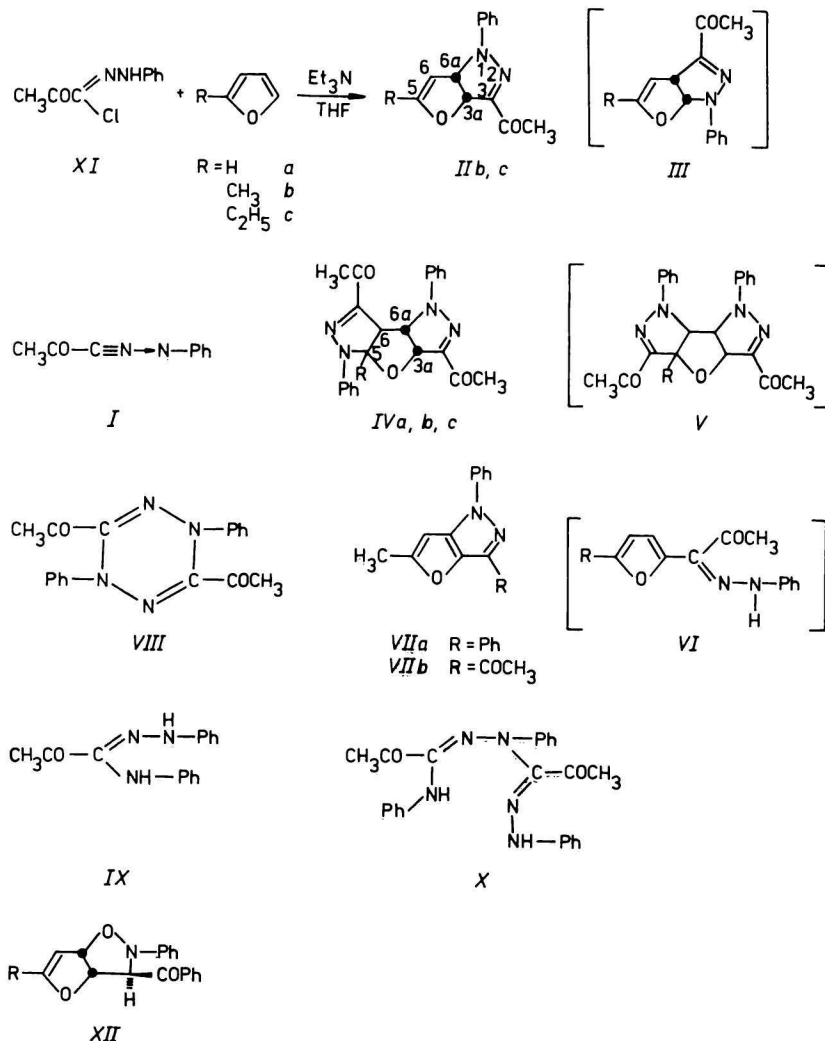
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1,3-Dipolar cycloaddition reactions of *C*-acetyl-*N*-phenylnitrilimine with furan derivatives are described. 2-Methyl- and 2-ethylfuran afforded in addition to a bicycloadduct, a monocycloadduct, 1-phenyl-3-acetyl-5-methyl(ethyl)-3*a*,6*a*-dihydrofuro[3,2-*c*]pyrazole. The reaction with furan resulted only in the bisadduct. As by-products, the dimer 3,6-diacetyl-1,4-diphenyl-1,4-dihydro-1,2,4,5-tetrazine and the products of decomposition of nitrilimine were isolated in all cases. The presence of the 1,3-addition product in the reaction mixture was not proved. The structures of the products were determined by ¹H-n.m.r., u.v., and i.r. spectroscopy as well as by dehydrogenation of the monoadduct with DDQ under the formation of 1-phenyl-3-acetyl-5-methylfuro[3,2-*c*]pyrazole.

Описываются 1,3-биполярные реакции циклоприсоединения *C*-ацетил-*N*-фенилнитрилимина с производными фурана. Из 2-метил- и 2-этилфурана образуется продукт моноциклоприсоединения 1-фенил-3-ацетил-5-метил(этил)-3*a*,6*a*-дигидрофуоро[3,2-*c*]пиразол помимо продукта бисциклоприсоединения. Реакция с фураном приводит только к образованию продукта бисциклоприсоединения. Во всех случаях в качестве побочных продуктов был изолирован продукт реакции нитрилимина: димер 3,6-диацетил-1,4-дифенил-1,4-дигидро-1,2,4,5-тетразин и продукты разложения нитрилимина. Присутствие продукта 1,3-присоединения в реакционной смеси не было обнаружено. Структура продуктов была определена ¹H-ЯМР, УФ и ИК спектроскопией и также дегидрированием продукта моноприсоединения с DDQ с образованием 1-фенил-3-ацетил-5-метилфуоро[3,2-*c*]пиразола.

* Part CLVI in the series Furan Derivatives.

In our previous works we dealt with 1,3-dipolar cycloaddition of *C*-benzoyl-*N*-phenyl nitron to furan derivatives [1—4]. In the case of 2-methyl- and 2-ethylfuran we proved besides cycloaddition products also the presence of 1,3-addition product [2]. Interpretation of the perturbation interaction diagram of 1,3-dipolar cycloadditions of nitrones to furan revealed that the reaction was governed by the dominant frontier interaction LU (nitron) — HO (furan) [1] according to the Sustmann classification of cycloadditions [5—7]. Besides nitrones



Scheme 1

[5], also nitrilimines belong to the II type of 1,3-dipoles. Therefore, the aim of the present work was to investigate the 1,3-dipolar cycloadditions of nitrilimines to furan derivatives. In the literature there is only one work by *Caramella* [8] who obtained monocycloadducts similar to *II* (Scheme 1) in 6–34% yield by the reaction of nitrilimines $\text{Ar}-\text{C}\equiv\text{N} \rightarrow \text{N}-(\text{Ar}-\text{X})$ ($\text{X} = \text{H}, 4\text{-Cl}, 2,4\text{-diBr}$) with furan at 30°C. The formation of bisadducts and other by-products of the reaction was not described.

Nitrilimines are known only *in situ* and therefore no values for ionization potentials (IP) and electron affinities (EA) are available. The values of frontier orbitals for the basic hypothetical nitrilimine $\text{H}-\text{C}\equiv\text{N} \rightarrow \text{NH}$ ($\epsilon_{\text{HOMO}} = -9.2$ eV and $\epsilon_{\text{LUMO}} = 0.1$ eV) as well as for *C,N*-diphenylnitrilimine ($\epsilon_{\text{HOMO}} = -7.5$ eV and $\epsilon_{\text{LUMO}} = -0.5$ eV) have been determined [9, 10]. In [4] we determined the values of frontier orbitals for *C,N*-diphenyl nitron ($\epsilon_{\text{HOMO}} = -7.5$ eV and $\epsilon_{\text{LUMO}} = -0.35$ eV) and *C*-benzoyl-*N*-phenyl nitron ($\epsilon_{\text{HOMO}} = -8.8$ eV and $\epsilon_{\text{LUMO}} = -0.9$ eV) from linear correlations $\text{IP} \sim \lambda_{\text{max}}$. On the basis of the almost identical Hammett σ_p constants for CH_3CO (0.5) and $\text{C}_6\text{H}_5\text{CO}$ (0.43) groups, respectively, and the approximately identical values of ϵ_{HOMO} and ϵ_{LUMO} for diphenyl substituted nitron and nitrilimine we can assign the same values also to *C*-acetyl-*N*-phenylnitrilimine *I*. The ϵ_{HOMO} (-8.8 eV) and ϵ_{LUMO} (-0.9 eV) values are in good agreement with the above-mentioned Houk values for *C,N*-diphenylnitrilimine. From the values obtained in this manner we constructed the perturbation interaction diagram for 1,3-dipolar cycloadditions of nitrilimines to furan derivatives (Fig. 1). The IP and EA values of furan derivatives were determined in [4].

For 1,3-dipolar cycloadditions of nitrilimines to substituted furan derivatives ($\text{R} = \text{H}, \text{CH}_3, \text{C}_2\text{H}_5$), similarly as for nitrones, the LU (nitrilimine) — HO (furan) interaction is dominant. This leads to the formation of the regioisomer “head—tail” *II* (Scheme 1) as it is evident from the presented values of atomic orbital coefficients (interaction diagram, the values of atomic orbital coefficients for HCNNH [9], for furan [11]). The HO (nitrilimine) — LU (furan) interaction, the result of which would be the regioisomer “head—head” *III*, cannot be considered because the difference between both frontier interactions is higher than 1 eV. Also with alkyl substituted furan derivatives the LU (I) — HO (furan derivative) interaction takes place because the alkyl group increases not only ϵ_{HOMO} but also ϵ_{LUMO} . According to the perturbation interaction diagram, electron-donating substituents on furan ring increase the reaction rate by decreasing its IP value. Electron-accepting substituents in nitrilimine act similarly by increasing its EA value. Therefore, as a model nitrilimine for cycloaddition to furan derivatives we chose *C*-acetyl-*N*-phenylnitrilimine (the acetyl group in comparison to the phenyl group decreases the energy of LUMO and thus speeds up the reaction) and as a model furan derivative we chose 2-methylfuran which was more reactive than furan.

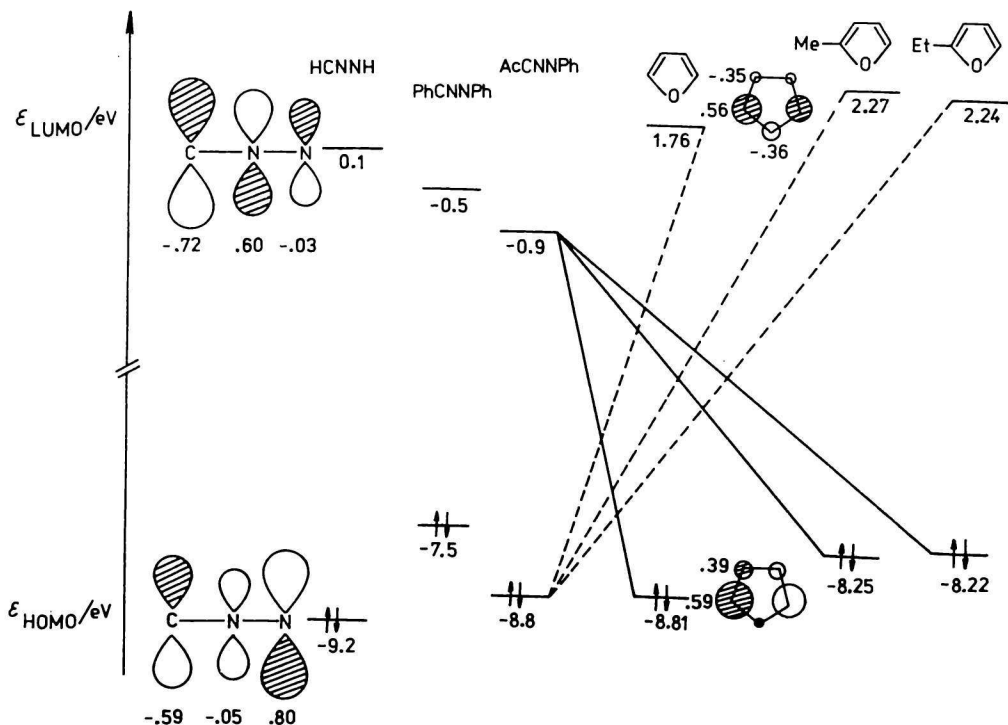


Fig. 1. Interaction diagram of cycloaddition of nitrilimines to furan derivatives.

C-Acetyl-N-phenylnitrilimine *I* was generated *in situ* from α -chloro- α -(N-phenylhydrazono)acetone *XI* by treatment with triethylamine in absolute tetrahydrofuran in the presence of 2-methylfuran. The use of *XI* for 1,3-dipolar cycloadditions of heterocycles is described in several cases, for example with indole derivatives [12, 13], pyrrole derivatives [14–16], and 1-methyl-1*H*-indazole [17]. With the furan derivatives used in this work, staying at laboratory temperature for a longer time proved to be the most advantageous way. After working up and chromatographic separation (SiO_2 , chloroform–n-heptane 8:2), the isolated products could be classified into two groups. In the first one, there were the products of mutual reaction of nitrilimine *I* with 2-methylfuran and in the second one the decomposition products of 1,3-dipole. The primary identification of the products has been carried out by mass spectrometry because the formed monoadducts *IIB* were thermostable, contrary to the monoadducts of nitrones to furan derivatives *XII* which on heating easily cycloreversed. The difference in thermostability can be explained by the effect of the C=N bond on stability of the heterocycle. The reaction of *I* with 2-methylfuran resulted in the compounds *IIB* (22%), *IVb* (32%), and *IVd* (6%). We assigned the structure of 1-phenyl-3-acetyl-5-methyl-3*a*,6*a*-dihydrofuro[3,2-*c*]pyrazole *IIB* to the product of m.p.

141–142°C with the molecular peak M^{+} , m/z 242 in the mass spectrum on the basis of interpretation of the perturbation interaction diagram and spectral analysis. In the mass spectrum, contrary to that of *XII* [3], fragments of cycloreversion were not detected. Mass spectroscopy is not a sufficient method for distinguishing the products of substitution (1,3-addition) and cycloaddition, respectively. The value of the last absorption maximum in the u.v. spectrum λ_{\max} 380 nm as well as the blue-green fluorescence is typical for the condensation 2-pyrazoline derivatives. Absorption bands belonging to the vibration of NH groups, which would indicate the formation of the substitution product *VI*, were not present at 3500–3300 cm^{-1} in the i.r. spectrum. Interpretation of the ^1H -n.m.r. spectrum proved unambiguously that the isolated compound was the regioisomer *Iib* and not *III*. The ^1H -n.m.r. spectrum revealed a significant doublet of δ 6.10 p.p.m. for the bridge proton 3a—H with the coupling constant $J = 10$ Hz (typical for *cis* arrangement of bridge protons) proving the *cis* stereospecificity of 1,3-dipolar cycloaddition of nitrilimines to furan derivatives. The other bridge proton 6a—H appeared at higher resolution as a multiplet in consequence of the coupling constant $J_{3a-6a} = 10$ Hz, coupling constant with the proton of the double bond of the dihydrofuran ring $J_{6-6a} = 2.5$ Hz (typical for dihydrofuran derivatives [1]), and the “long-range” coupling constant with the methyl group attached to the dihydrofuran part $J_{\text{CH}_3-6a} = 1$ Hz. The regioisomer *III* should contain in the ^1H -n.m.r. spectrum a significant doublet with high δ value in consequence of deshielding by two heteroatoms (nitrogen and oxygen). The structure of *Iib* was proved also by chemical dehydrogenation with 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) in benzene during 4 h at the boiling point of the solvent. A heterocyclic system of furo[3,2-*c*]pyrazole, *i.e.* 1-phenyl-3-acetyl-5-methylfuro[3,2-*c*]pyrazole *VIIb* was obtained. The 2-pyrazoline system vanished by dehydrogenation as indicated by disappearance of the absorption band belonging to 2-pyrazoline (for *Iib* $\lambda_{\max} = 380$ nm, for *VIIb* $\lambda_{\max} = 248$ nm) in the u.v. spectrum. The last value is typical for the u.v. spectra of pyrazole derivatives [18]. Signals of bridge protons were not observed in the ^1H -n.m.r. spectrum and the values of chemical shifts of the other protons were affected by the reappearance of the heterocyclic system (“ring current effect”). For the methyl group on the furan ring $\Delta\delta = 0.28$ p.p.m., for CH_3CO $\Delta\delta = 0.11$ p.p.m., and for 6-H of the furopyrazole skeleton $\Delta\delta = 1.80$ p.p.m. Similarly, the aromatic multiplet was shifted to higher δ values. The obtained spectral data are in good agreement with those given for *VIIa* in the literature [19]. Dehydrogenation of *Iib* with DDQ is a second preparation of the heterocyclic system *VII*; the first one was accomplished by *Yoshina* [19] by oxidation of hydrazones with lead(IV) acetate and subsequent cyclization with BF_3 . The appropriate hydrazones were prepared by condensation of 5-methyl-2-furancarbaldehyde with phenylhydrazine.

The further compound isolated was the bisadduct *IVb* of m.p. 264—266°C as indicated by the molecular peak $M^{+\bullet}$, m/z 402. The u.v. spectrum was characteristic of 2-pyrazoline derivatives, $\lambda_{\max} = 356$ nm. Further 1,3-dipolar cycloaddition reaction of the *Ib* derivative can afford the following bisadducts *IV syn* and *anti*, *V syn* and *anti* by arrangement of the bridge protons of the tetrahydrofuran skeleton (Scheme 1). In the ^1H -n.m.r. spectrum two doublets of δ 5.06 and 5.50 p.p.m. with the coupling constant $J = 6.7$ Hz were observed in the region of tetrahydrofuran protons indicating their *cis* arrangement and one singlet of low δ value (4.18 p.p.m.). As assumed, the disappearance of the double bond was indicated by the shift of the tetrahydrofuran protons to lower δ values in consequence of the disappearance of the "ring current effect". The presence of two doublets and one singlet points to *anti* arrangement of the bridge protons 6-6a of the tetrahydrofuran skeleton, $J_{6-6a} = 0$ Hz. It means that the structures of *syn* bisadducts can be excluded. Further, comparison of the aromatic multiplets of the monoadduct *Ib* (δ 6.90—7.45) and of the isolated bisadduct (δ 7.05—7.97) shows that the phenyl group should be on the same side of the heterocycle as the acetyl group. The shielding effect of the carbonyl group is indicated by the shift of the aromatic protons to higher δ values [15]. The above-mentioned interpretation helped to elucidate the structure of bisadducts formed by the reaction of *I* with pyrrole derivatives [14, 15]. Thus, the structure *V* is excluded. This statement is supported also by interpretation of the perturbation diagram. The formation of the bisadduct is also governed by the LU (I) — HO (2-methylfuran) interaction because the IP's of the dihydrofuran derivatives are in the range of 7.9—8.5 eV [4, 11]. Contrary to furan, in 2,3-dihydrofuran the highest atomic orbital coefficient in HOMO is on C-3 atom ($c_2 = 0.455$ and $c_3 = 0.590$) [11] and thus, the reverse regioisomer is formed. Therefore, we assigned the structure *IVb* to the isolated bisadduct of m.p. 264—266°C. We have isolated one more bisadduct *IVd* of m.p. 190—192°C in 6.5% yield. Its mass spectrum revealed a molecular ion, $M^{+\bullet}$, m/z 402 with the same fragmentation as *IVb* but different relative intensities of the fragments. The i.r. spectrum showed significant differences when compared to the spectrum of *IVb* in the region of 600—1300 cm^{-1} , $\nu(\text{CO})$ for *IVb* was 1662 and for *IVd* 1656 cm^{-1} . The u.v. spectrum showed slight differences; *IVb* $\lambda_{\max} = 241$ nm (4.33) and 350 nm (4.49), *IVd* $\lambda_{\max} = 240$ nm (4.33) and 356 nm (4.54). The ^1H -n.m.r. spectra of both compounds *IVb* and *IVd* were identical, which is very surprising. The exact configuration of the bisadduct *IVd* could not be determined on the basis of the obtained spectral data.

From by-products of the reaction a red crystalline compound *VIII* with the molecular peak $M^{+\bullet}$, m/z 320, m.p. 173—176°C was obtained in the highest yield 16%. It was a dimer of nitrilimine *I* formed *in situ* during the reaction. Its ^1H -n.m.r. spectrum was very simple, had a signal at δ 2.46 p.p.m. corresponding to the acetyl group and a symmetric multiplet at δ 7.11—7.43 p.p.m. corresponding

to aromatic protons. The ratio of the intensities was 10:6. In the i.r. spectrum the vibrations of the NH groups were absent and only one absorption band belonging to the carbonyl group was present at 1710 cm^{-1} which, together with the $^1\text{H-n.m.r.}$ spectrum, indicated a highly symmetric structure. We assigned to this compound the structure of 3,6-diacetyl-1,4-diphenyl-1,2,4,5-tetrazine.

The further compound of the mutual reaction of nitrilimine *I* and its decomposition products was a yellow crystalline compound *IX* with m.p. $103\text{--}105^\circ\text{C}$. The i.r. spectrum revealed the vibrations of the NH groups at 3350 cm^{-1} and the stretching vibrations of the carbonyl group at 1678 cm^{-1} . In the $^1\text{H-n.m.r.}$ spectrum the signal of the methyl protons of acetyl group appeared at $\delta\ 2.57$ p.p.m. Contrary to the dimer *VIII*, the part of the signals of the aromatic protons was less symmetric; the signals appeared in a wider range $\delta\ 6.57\text{--}7.35$ p.p.m. The ratio of the intensities was 12:3, which meant that also two protons of the NH groups were involved. In the mass spectrum a molecular peak $M^{+\bullet}$, $m/z\ 253$ of relative intensity 100% was found. The elemental composition of this compound ($\text{C}_{15}\text{H}_{15}\text{N}_3\text{O}$) was derived from the exact measurement of its mass. Of the most important fragments (their composition was also determined by exact mass measurements) the following ones are significant: ($m/z\ 210$ (15%), (M) $^{+\bullet}$ $-\text{CH}_3\text{CO}$, $m/z\ 148$ (27%), (M) $^{+\bullet}$ $-\text{C}_6\text{H}_5\text{N}_2$, $m/z\ 118$ (31%), ($\text{C}_6\text{H}_5\text{N}_2\text{CH}$) $^+$, $m/z\ 108$ (69%), ($\text{C}_6\text{H}_5\text{NHNH}_2$) $^+$, $m/z\ 104$ (49%), $\text{C}_6\text{H}_5\text{NCH}$, $m/z\ 93$ (60%), ($\text{C}_6\text{H}_5\text{NH}_2$) $^+$, $m/z\ 92$ (63%), ($\text{C}_6\text{H}_5\text{NH}$) $^+$, $m/z\ 91$ (35%), ($\text{C}_6\text{H}_5\text{N}$) $^+$, $m/z\ 77$ (50%), (C_6H_5) $^+$, $m/z\ 65$ (73%), (C_3H_3) $^+$, $m/z\ 43$ (70%), (CH_3CO) $^+$. On the basis of spectral data we assigned to this compound the structure of *IX*. Its formation can be explained by the reaction of the starting α -chloro- α -(*N*-phenylhydrazono)acetone *XI* with aniline. In several reactions of nitrilimines, when tetrahydrofuran is used as reaction medium, R-CN [20] and R-NH_2 [21] are formed from the fragments of nitrilimines after a so far unknown mechanism.

To the further isolated compound of m.p. $182\text{--}184^\circ\text{C}$ with the molecular peak $M^{+\bullet}$, $m/z\ 413$, formed probably by the subsequent reaction of *I* with *IX*, we assigned the structure *X* on the basis of spectral data ($\delta\ 2.63$ for acetyl group, $6.88\text{--}7.36$ for aromatic protons, the presence of the NH group vibrations in the i.r. spectrum and interpretation of its mass spectrum).

When carrying out the reaction with 100-fold excess of 2-methylfuran at 65°C for 10 h, a good yield (53%) of the monoadduct *Iib* was obtained; the yield of the bisadduct *IVb* was only 7%. The yield of the dimer *VIII* was 12%. Thus, to obtain the monoadduct *Iib*, large excess of 2-methylfuran is necessary because the forming monoadduct *Iib* is much more reactive than 2-methylfuran due to different conjugation energies which must be overbalanced at cycloaddition. When only 10-fold excess of 2-methylfuran was used at the above-mentioned reaction conditions, the yields were the following: *Iib* 11%, *IVb* 26%, and *VIII* 20%. The

reaction of *I* with 2-ethylfuran gave two products: the monoadduct *IIIc* (10%) and the bisadduct *IVc* (24%). Their structure is similar (Scheme 1) as that obtained in the reaction with 2-methylfuran and was determined in a similar way. At cycloaddition of *I* to furan itself at laboratory temperature for 36 days, we isolated only products of decomposition of nitrilimine *I* (*VIII* 8%, *IX* 6%, and *X* 6%). When the reaction mixture with the same excess of furan was refluxed at 50°C for 12 h, the bisadduct *IVa* was obtained in 8% yield. *Anti* arrangement of the bridge tetrahydrofuran protons was proved by the presence of four significant doublets in the ¹H-n.m.r. spectrum. In the case of *syn* arrangement the protons 6-H and 6a-H should appear as doublets of doublets. The high δ value (6.08) of 5-H in comparison to the bisadducts *IVb* and *IVc* was due to the shielding effect of two heteroatoms, nitrogen and oxygen and proved the regioisomerism of the bisadduct *IVa*.

With 2-methylfuran 60.9%, 2-ethylfuran 34%, and furan only 8% of nitrilimine *I* reacted by 1,3-dipolar cycloaddition reaction. *C*-Benzoyl-*N*-phenyl nitrene had 88% conversion with 2-methylfuran and 65% with furan proving that the reactivity of *C*-acetyl-*N*-phenylnitrilimine was much lower. The low reactivity of *I* towards the furan derivatives is evident also from the amounts of by-products, mainly of the dimer *VIII*. Dimerization of nitrilimines is a frequent phenomenon at 1,3-dipolar cycloadditions in those cases when the 1,3-dipole reacts with the double bond of low reactivity by cycloaddition 3+2 \rightarrow 5. The formation of 1,4-dihydro-1,2,4,5-tetrazines points to low reactivity of the used dipolarophile, in our case, the furan derivatives. The residues after the chromatographic separation were yellow to brown crystalline compounds with the vibrations of NH groups in the i.r. spectrum and the presence of the signals of acetyl groups and aromatic protons in the ¹H-n.m.r. spectrum. They were probably oligomers of nitrilimine *I* and the precursor *XI*.

Experimental

¹H-n.m.r. spectra of the synthesized derivatives were measured on a Tesla BS 487C 80 Hz apparatus in deuteriochloroform or deuterated dimethyl sulfoxide. Tetramethylsilane was used as internal standard. Mass spectra were measured on an MS 902 S spectrometer using direct inlet probe. The ionization energy was 70 eV, trap current 100 μ A, temperature of the ion chamber 70–110°C according to the volatility of the samples. The u.v. spectra were recorded on a UV VIS spectrometer in cells at 20 \pm 0.2°C in methanol. The i.r. spectra of compounds were measured on a UR-20 (Zeiss, Jena) spectrometer in carbon tetrachloride and KBr technique.

The melting points are uncorrected. The separation of the reaction mixtures was carried out by column chromatography (SiO₂) and thin-layer chromatography on silica gel plates LSL₂₅₄ (Lachema, Brno); 45 g of the mixture was spotted on one 20 \times 20 cm plate of 2 mm thickness. Chloroform–*n*-heptane (8:2) was used as eluent.

α -Chloro- α -(*N*-phenylhydrazono)acetone *XI* was prepared after [22] (taking special care because this compound evokes serious allergy). Furan and 2-methylfuran were commercial products, freshly distilled with sodium before use, 2-ethylfuran was prepared after [23].

Cycloaddition of *C*-acetyl-*N*-phenylnitrilimine (*I*) to 2-methylfuran

The reaction mixture containing *XI* (3 g; 15.25 mmol), 2-methylfuran (30 ml; 0.33 mol), triethylamine (7.2 ml; 53 mmol), and absolute tetrahydrofuran (10 ml) was allowed to stay at laboratory temperature for 26 days. The precipitated triethylammonium chloride (1.9 g; 13.9 mmol) was filtered off and after evaporation under reduced pressure a brown thick oil (3.5 g) was obtained and analyzed by chromatography. The isolated products are listed according to their decreasing R_f values.

The light-yellow crystalline compound *IX* of m.p. 103—105°C, yield 0.3 g (12%). For $C_{15}H_{15}N_3O$ (253.30) calculated: 71.12% C, 5.97% H, 16.59% N; found: 71.33% C, 5.81% H, 16.41% N. IR spectrum (CCl_4) $\nu(CO)$ 1678 cm^{-1} , $\nu(NH)$ 3350 cm^{-1} . Mass spectrum M^{+} , m/z 253. 1H -NMR ($CDCl_3$) δ 2.57 (s, 3H, $COCH_3$), 6.57—7.35 (m, 12 H, aromatic protons, and 2NH).

The yellow crystalline compound *X* of m.p. 182—184°C, yield 0.2 g (5%). For $C_{24}H_{23}N_3O_2$ (413.48) calculated: 69.71% C, 5.60% H, 16.93% N; found: 69.86% C, 5.61% H, 16.65% N. IR spectrum (CCl_4) $\nu(CO)$ 1681 cm^{-1} and $\nu(NH)$ 3348 cm^{-1} . In the mass spectrum the molecular peak M^{+} , m/z 413 (6%) was present. The base peak in the spectrum was the fragmentation ion with m/z 251. 1H -NMR ($CDCl_3$) δ 2.63 (s, 6H, $2 \times COCH_3$), 6.88—7.36 (m, 10H, aromatic protons, and 2NH).

The red crystalline dimer *VIII* of m.p. 173—176°C (n-heptane), yield 0.4 g (16%). Ref. [20] gives m.p. 168°C of the crude *VIII*. For $C_{16}H_{16}N_4O_2$ (320.18) calculated: 67.52% C, 5.04% H, 17.49% N; found: 67.78% C, 4.98% H, 17.24% N. IR spectrum (KBr) $\nu(CO)$ 1710 cm^{-1} . UV spectrum (methanol) λ_{max} 266 nm ($\log \epsilon = 3.94$), λ_{max} 349 nm ($\log \epsilon = 3.88$). Mass spectrum, M^{+} , m/z 320, the base peak m/z 251 ($M^{+} - CH_2COCN$). 1H -NMR ($CDCl_3$) δ 2.46 (s, 6H, $2 \times COCH_3$), 7.11—7.43 (m, 10H, aromatic protons).

The light-yellow crystalline monoadduct *Iib* of m.p. 141—142°C with yellow-green fluorescence, yield 0.8 g (22%). For $C_{11}H_{14}N_2O_2$ (242.27) calculated: 69.40% C, 5.82% H, 11.56% N; found: 69.69% C, 5.85% H, 11.82% N. 1H -NMR ($CDCl_3$) δ 1.82 (d, 3H, $J(CH-H) = 1.0$ Hz), 2.47 (s, 3H, $COCH_3$), 5.02 (m, 1H, $J(6-a) = 2.5$ Hz, $J(CH-H) = 1$ Hz), 5.48 (m, 1H, $J(3a-6a) = 10$ Hz, $J(6-a) = 2.5$ Hz, $J(CH-H) = 1$ Hz), 6.10 (d, 1H, $J(3a-6a) = 10$ Hz, $3a-H$), 6.90—7.45 (m, 5H, aromatic protons). IR spectrum (KBr) $\nu(CO)$ 1647 and 1662 cm^{-1} . UV spectrum (methanol) λ_{max} 241 nm ($\log \epsilon = 3.94$), λ_{max} 380 nm ($\log \epsilon = 4.09$). Mass spectrum showed impurities. Besides methods exist for the determination of acetyl residues, acetyl groups can be determined by other methods.

The light-yellow crystalline bisadduct *IVb* of m.p. 263—264°C, yield 1.0 g (32.4%). For $C_{23}H_{22}N_4O_2$ (402.45) calculated: 68.64% C, 5.51% H, 13.92% N; found: 68.75% C, 5.42% H, 13.68% N. 1H -NMR ($CDCl_3$) δ 1.58 (s, 3H, CH_3), 2.54 and 2.56 (s, 6H, $2 \times COCH_3$), 4.18 (s, 1H), 6-H, 5.06 (d, 1H, $J(3a-6a) = 6.7$ Hz, $6a-H$), 5.50 (d, 1H,

$J(3a-6a) = 6.7$ Hz, $3a-H$), 7.05—7.97 (m, 10H, aromatic protons). IR spectrum (KBr) $\nu(CO)$ 1662 cm^{-1} UV spectrum (methanol) λ_{\max} 241 nm ($\log \epsilon = 4.33$), λ_{\max} 350 nm ($\log \epsilon = 4.49$). Mass spectrum showed $M^{+\bullet}$, m/z 402, base peak m/z 43 ($CH_3C\equiv O$).

The light-yellow crystalline bisadduct *IVd* of m.p. 190—192°C, yield 0.2 g (6.5%). For $C_{23}H_{22}N_4O_3$ (402.45) calculated: 68.64% C, 5.51% H, 13.92% N; found: 68.82% C, 5.35% H, 13.71% N. 1H -NMR ($CDCl_3$) was the same as with the compound *IVb*. IR spectrum (KBr) $\nu(CO)$ 1656 cm^{-1} UV spectrum (methanol) λ_{\max} 240 nm ($\log \epsilon = 4.33$), λ_{\max} 356 nm ($\log \epsilon = 4.54$). The mass spectrum showed $M^{+\bullet}$, m/z 402, base peak m/z 43 ($CH_3C\equiv O$).

Cycloaddition of *I* to 2-ethylfuran

The reaction mixture of *XI* (3 g; 15.25 mmol), 2-ethylfuran (9 ml; 0.085 mol), triethylamine (7.2 ml; 53 mmol), and absolute tetrahydrofuran (20 ml) was allowed to stay at laboratory temperature for 29 days. The precipitated triethylammonium hydrogen chloride (2 g; 14.5 mmol) was filtered off and after evaporation *in vacuo* the obtained brown thick oil (3.4 g) was worked up in the same way as at 2-methylfuran. The procedure yielded 0.2 g (8%) of *IX*, 0.2 g (5%) of *X*, and 0.1 g (4%) of *VIII*.

The light-yellow crystalline monoadduct *IIc* of m.p. 136—138°C with yellow fluorescence, yield 0.4 g (10%). For $C_{15}H_{16}N_2O_2$ (256.30) calculated: 70.29% C, 6.29% H, 10.92% N; found: 70.04% C, 6.27% H, 11.25% N. 1H -NMR ($CDCl_3$) δ 1.02 (t, 3H, $J = 6.0$ Hz, CH_3), 2.16 (q, 2H, $J = 6.0$ Hz, CH_2), 2.50 (s, 3H, $COCH_3$), 5.02 (d, 1H, $J(6-6a) = 2.0$ Hz, 6-H), 5.51 (d, 1H, $J(6-6a) = 2.0$ Hz, $J(3a-6a) = 10.5$ Hz, 6a-H), 6.13 (d, 1H, $J(3a-6a) = 10.5$ Hz, 3a-H), 7.17—7.37 (m, 5H, aromatic protons). IR spectrum (KBr) $\nu(CO)$ 1661 cm^{-1} UV spectrum (methanol) λ_{\max} 241 nm ($\log \epsilon = 4.13$), λ_{\max} 380 nm ($\log \epsilon = 4.31$). Mass spectrum showed $M^{+\bullet}$, m/z 256, base peak m/z 200 ($M^{+\bullet} - C_2H_4O$).

The light-yellow crystalline bisadduct *IVb* of m.p. 251—253°C, yield 0.8 g (24%). For $C_{24}H_{22}N_4O_3$ (416.48) calculated: 69.21% C, 5.80% H, 13.45% N; found: 69.01% C, 5.88% H, 13.21% N. 1H -NMR ($CDCl_3$) δ 0.56 (t, 3H, $J = 7.0$ Hz, CH_3), 1.93 (q, 2H, $J = 7.0$ Hz, CH_2), 2.53 and 2.55 (s, s, 6H, 2 \times $COCH_3$), 4.22 (s, 1H, 6-H), 4.99 (d, 1H, $J(3a-6a) = 6.2$ Hz, 6a-H), 5.47 (d, 1H, $J(3a-6a) = 6.2$ Hz, 3a-H), 7.05—8.00 (m, 10H, aromatic protons). IR spectrum (KBr) $\nu(CO)$ 1697 cm^{-1} UV spectrum (methanol) λ_{\max} 241 nm ($\log \epsilon = 4.37$), λ_{\max} 349 nm ($\log \epsilon = 4.56$). Mass spectrum showed $M^{+\bullet}$, m/z 416, base peak m/z 43 ($CH_3C\equiv O$).

The reaction mixture of *XI* (3 g; 15.25 mmol), furan (23 ml; 0.39 mol), and triethylamine (7.2 ml; 53 mmol) was heated in a glass autoclave for 12 h at 50°C. After cooling the precipitated triethylammonium hydrogen chloride (1.9 g; 13.9 mmol) was removed by filtration. Evaporation of the supernatant *in vacuo* gave a thick brown-black oil (3.8 g) which was worked up in the same way as in the previous cases. The following

compounds were obtained: IX 0.4 g (16%), X 0.4 g (10%), and VIII 0.4 g (16%). In addition, the light-yellow crystalline bisadduct IVa (0.2 g) of m.p. 312—314°C was obtained in 8% yield. ¹H-NMR (CDCl₃) δ 2.49 and 2.56 (s, s, 6H, 2 × COCH₃), 4.32 (d, 1H, J(5-6)=9.6 Hz, 6-H), 4.96 (d, 1H, J(3a-6a)=9.5 Hz, 6a-H), 5.45 (d, 1H, J(3a-6a)=9.5 Hz, 3a-H), 6.08 (d, 1H, J(5-6)=9.6 Hz, 5-H), 7.05—7.75 (m, 10H, aromatic protons). IR spectrum (KBr) ν(CO) 1649 cm⁻¹, mass spectrum showed M⁺, /z 388, base peak m/z 43 (CH₃CO)⁺

Dehydrogenation of IIb with DDQ

Monoadduct IIb (0.15 g; 0.6 mmol), DDQ (0.25 g; 1.1 mmol), and benzene (20 ml) were refluxed for 4 h. The cooled solution was stirred with ether (50 ml) and extracted with 2M sodium hydroxide till the alkaline solution was colourless. The ethereal solution was washed with water, dried (sodium sulfate), and evaporated *in vacuo*. The white crystalline compound VIIb of m.p. 111—113°C was obtained in 66% yield (0.1 g). For C₁₄H₁₂N₂O₂ (240.26) calculated: 69.98% C, 5.04% H, 11.66% N; found: 70.11% C, 4.88% H, 11.90% N. ¹H-NMR (CDCl₃) δ 2.1 (s, 3H, CH₃), 2.58 (s, 3H, COCH₃), 6.82 (s, 1H, 6-H), 7.35—7.55 (m, 5H, aromatic protons). IR spectrum (KBr) ν(CO) 1681 and 1710 cm⁻¹. UV spectrum (methanol) λ_{max} 248 nm (log ε=3.99).

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