Monatshefte für Chemie 123, 999–1013 (1992)

Monatshefte für Chemie
Chemical Monthly

Preparation and Stereoselectivity of 1,3-Dipolar Cycloaddition of C-Glycosyl Nitrones to N-Arylmaleimides

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Summary. The cycloaddition of 3′-hydroxyglycosyl-N-methylnitrone (**1**) to N-arylmaleimides gave the *syn* isoxazolidines **6**, whereas 3′-acetoxyglycosyl-N-methylnitrone (**2**) afforded the *anti* isoxazolidines **8** and **10**. The formation of **6** was rationalized by an *exo* attack, stereoelectronically preferred through the hydrogen bond between the pentose hydroxyl group and one of the carbonyl groups of N-arylmaleimide. The sterically preferred *endo* attack avoiding the repulsions between N-arylmaleimide and sugar moiety was proposed for addition of **2**. The structure and steric configuration of the products have been assigned on the basis of ^{1}H- and ^{13}C-NMR spectroscopy, mainly by nuclear Overhauser effect difference spectroscopy. AM1 calculations of the nitrones and MM2 calculations of the adducts were performed.

Keywords. 1,3-Dipolar cycloaddition of chiral nitrones; 3′-Hydroxy- and 3′-acetoxyglycosyl-N-methylnitrones; Stereoselectivity of 1,3-dipolar cycloaddition; AM1 calculations.

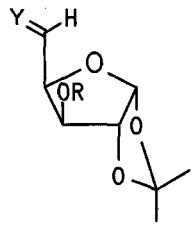
Darstellung und Stereoselektivität der 1,3-dipolaren Cycloaddition von C-Glycosyl-Nitronen an N-Arylmaleimiden

Zusammenfassung. Die Cycloaddition von 3′-Hydroxyglycosyl-N-methylnitron (**1**) an N-Arylmaleimide gab die *syn*-Isoxazolidine **6**, mit 3′-Acetoxyglycosyl-N-methylnitron (**2**) wurden hingegen die *anti*-Isoxazolidine **8** und **10** erhalten. Die Bildung von **6** wurde mit einem *exo*-Angriff erklärt, der stereoelektronisch wegen einer Wasserstoffbrückenbindung zwischen der Hydroxylgruppe der Pentose und einer Carbonylgruppe des N-Arylmaleimides bevorzugt wird. Für die Addition von **2** wurde ein sterisch bevorzugter *endo*-Angriff vorgeschlagen, da dabei ungünstige Wechselwirkungen zwischen der N-Arylmaleimid- und der Zuckereinheit vermieden werden. Die Struktur und Stereochemie der Produkte wurde mittels ^{1}H- und ^{13}C-NMR unter Verwendung von NOE-Differenzmessungen ermittelt. Es wurden auch AM1-Rechnungen für die Nitrone und MM2-Rechnungen für die Addukte durchgeführt.

Introduction

A large part of the research of stereocontrolled versions of 1,3-dipolar cycloaddition in the last few years dealt with the influence exerted by a stereocentre located in

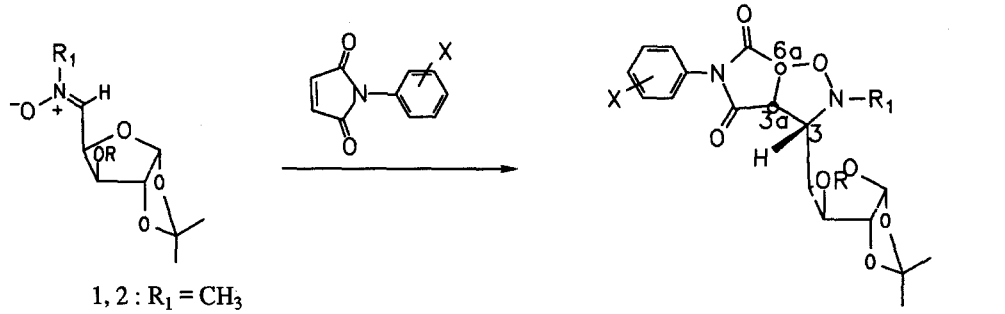
either one of the two cycloaddends [1]. With our efforts to utilize heterocyclic compounds as dipolarophile components in 1,3-dipolar cycloaddition reactions [2] we have recently demonstrated that nitrile oxides [3] and nitrones [4] react with chiral sugar-derived alkene to produce mainly *anti*-adducts with $\geqslant 95\%$ π-facial stereoselectivity. Now we have focused our attention to the preparation of chiral nitrones. Among the chiral nitrones a fundamental role was played by N-sugar-derived nitrones [5, 6]. Only scattered reports deal with chiral nitrones possessing a sugar rest on their carbon substituent [11]. Here we report now on the preparation and 1,3-dipolar cycloaddition of a series of closely related C-sugar substituted nitrones to N-arylmaleimides. We also discuss the stereochemical aspects of these cycloadditions and show how AM1 and MM2 calculations can be used and refined to predict the stereochemical outcome in such cycloadditions.



1: R=H, Y=N(O)Me
2: R=Ac, Y=N(O)Me
3: R=Ac, Y=N(O)Ph
4: R=H, Y=O
5: R=Ac, Y=O

Results and Discussion

A series of novel 3′-hydroxy-N-methyl- (**1**), 3′-acetoxy-N-methyl- (**2**) and 3′-acetoxy-N-phenylnitrones (**3**) was prepared, isolated, and treated with N-arylmaleim-



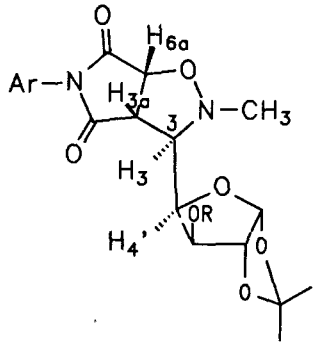
1, 2 : $R_1 = CH_3$
3 : R_1 = Ph

a) X= H
b) X= 2,6–diCH_3
c) X= 2–CH_3,6–C_2H_5
d) X= 2,6–diC_2H_5
e) X= 2,5–diCl
f) X= 4–Cl
g) X= 4–F
h) X= 4–Br
i) X= 3,4–diCl

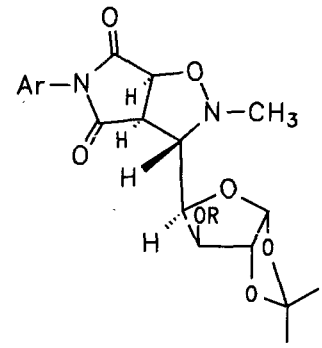
6: R=H; R′=Me
9: R=Ac; R′=Me
11: R=Ac; R′=Ph

7: R=H; R′=Me
8: R=Ac; R′=Me
10: R=Ac; R′=Ph

Scheme 1

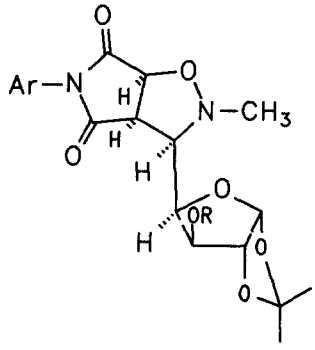


anti – syn 7, 8

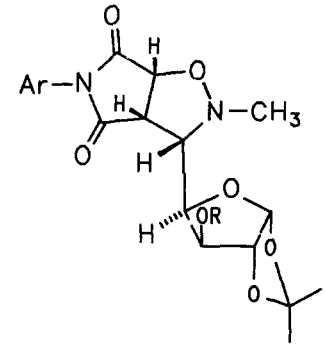


anti – anti 7, 8

H-3a,H-6a = 7.2 Hz
H-3, H-4' = 8.4 Hz



syn – syn 6, 9



syn – anti 6, 9

H-3a, H-6a = 7.2 Hz
H-3, H-3a = 7.2 Hz

Scheme 2

ides. The nitrone used, together with details of the products isolated, are given in the Experimental Part (Tables 1 – 3). Preparation of nitrones was accomplished from the corresponding aldehydes **4** and **5** [7] which were converted to the *Z*-nitrones **1**, **2** , and **3** by treatment with N-methylhydroxylamine and N-phenylhydroxylamine, respectively. The geometry of nitrones **1** and **2** were verified by an NOE experiment which showed an enhancement of the N-methyl signal upon irradiation of the azomethine hydrogen as well as an enhancement of the azomethine proton signal upon irradiation of the N-methyl group. The coupling constant $J_{4'-5} = 5.1$ Hz is indicative of a gauche H-4′ and H-5 relationship.

Table 1. 2-Methyl-3-(1,2-O-isopropylidene-α-*D*-xylo-tetrofuranos-4-yl)-5-aryl-4,6-dioxo-2,3,3 a,4,6,6 a-hexahydropyrrolo[3,4-d]-isoxazoles **6**

Compound	M. p.(°C)	Yield (%)	Formula[a]	M. w.	$[\alpha]_D$ (°) (*c*)
a	120–122	67	$C_{19}H_{22}N_2O_7$	390.3	−276 (1.5)
b	145–147	78	$C_{21}H_{26}N_2O_7$	418.4	−109 (1.1)
c	145–146	75	$C_{22}H_{28}N_2O_7$	432.4	− 91 (1.2)
d	162–163	70	$C_{23}H_{30}N_2O_7$	446.4	− 92 (1.4)
e	245–247	73	$C_{19}H_{20}Cl_2N_2O_7$	459.3	b
f	150–152	70	$C_{19}H_{21}ClN_2O_7$	424.8	−116 (1.2)
g	195–196	80	$C_{19}H_{21}FN_2O_7$	408.3	−278 (1.1)
h	183–185	81	$C_{19}H_{21}BrN_2O_7$	469.3	−183 (1.2)
i	150–151	75	$C_{19}H_{20}Cl_2N_2O_7$	459.3	+ 54 (1.1)

[a] Satisfactory microanalyses obtained: C±0.3, H±0.3, N±0.25
[b] Not soluble

Table 2. 2-Methyl-3-(1,2-O-isopropylidene-3-acetoxy-α-*D*-xylo-tetrofuranos-4-yl)-5-aryl-4,6-dioxo-2,3,3 a,4,6,6 a-hexahydropyrrolo[3,4-d]-isoxazoles **8**

Compound	M. p.(°C)	Yield (%)	Formula[a]	M. w.	$[\alpha]_D$ (°) (*c*)
a	165–166	92	$C_{21}H_{24}N_2O_8$	432.4	+ 28 (0.7)
b	240–241	91	$C_{23}H_{28}N_2O_8$	460.4	+287 (0.8)
c	210–211	90	$C_{24}H_{30}N_2O_8$	474.5	+239 (0.7)
d	180–181	87	$C_{25}H_{32}N_2O_8$	488.5	+212 (0.6)
g	195–196	85	$C_{21}H_{23}FN_2O_8$	450.4	+200 (0.6)

[a] Satisfactory microanalyses obtained: C±0.3, H±0.3, N±0.25

Table 3. 2-Phenyl-3-(1,2-O-isopropylidene-3-acetoxy-α-*D*-xylo-tetrofuranos-4-yl)-5-aryl-4,6-dioxo-2,3,3 a,4,6,6 a-hexahydropyrrolo[3,4-d]-isoxazoles **10**

Compound	M. p.(°C)	Yield (%)	Formula[a]	M. w.	$[\alpha]_D$ (°) (*c*)
a	203–205	88	$C_{25}H_{26}N_2O_8$	496.3	−118 (1.3)
b	113–115	85	$C_{28}H_{30}N_2O_8$	522.5	− 31 (1.3)
e	138–140	83	$C_{26}H_{24}C_{12}N_2O_8$	563.4	− 50 (0.3)
g	118–120	88	$C_{26}H_{25}FN_2O_8$	512.4	+ 81 (1.2)
h	115–117	80	$C_{26}H_{25}BrN_2O_8$	573.4	+ 71 (1.1)

[a] Satisfactory microanalyses obtained: C±0.3, H±0.3, N±0.25

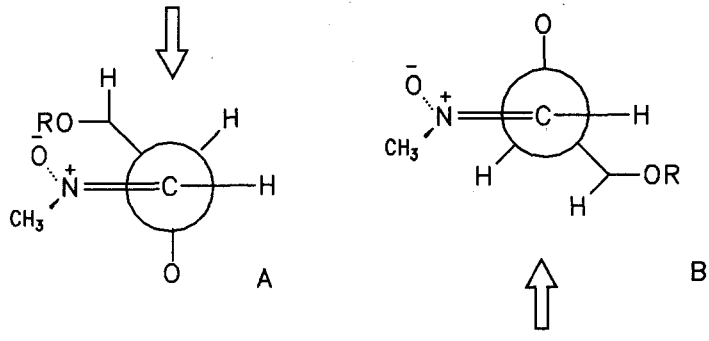
It was found that 3′-hydroxy-N-methylnitrone (**1**) reacted with N-arylmaleimides in toluene at 110°C to give the *syn*-isoxazolidines **6** (Scheme 1, H-3, H-3 a *syn*-relationship). In contrast, the 3′-acetoxy-N-methyl- (**2**)and 3′-acetoxy-N-phenylnitrone (**3**) gave the *anti*-isoxazolidines **8** and **10**, respectively (H-3, H-3 a *anti*-relationship). It would appear that the introduction of an acetoxy group into a C-

3′ carbon of nitrone can significantly influence its stereochemical behaviour. New asymmetric centers were generated in the cycloaddition and, since the condensed adducts have a *cis*-arrangement of H-3 a and H-6 a bridgehead protons, four diastereomeric cycloadducts were possible (Scheme 2).

Stereochemical assignments of H-3, H-3 a and H-6 a atoms were made to the condensed isoxazolidines on the basis of spectroscopic data, in particular using the J_{3-3a} and J_{3a-6a} coupling constant. The ring junction between two rings was always *cis* which was indicated by coupling constants and an examination of molecular models. Moreover, all up to date known 1,3-dipolar cycloaddition reactions of nitrones to alkenes proceeded with *cis*-stereospecificity [8]. For instance, in the compounds **6 a** the coupling constant for the *cis* ring junction protons H-6 a and H-3 a $J_{3a-6a}=7.2$ Hz and in **8 a** $J_{3a-6a}=7.8$ Hz, which is indicative of nearly eclipsed dihedral angles between H-3 a and H-6 a.

Proton NMR analysis of isoxazolidines **8** and **10** revealed that each diastereomer has a H-3, H-3 a *anti* relationship. In **8 a** for example, the signal for the H-3 a proton appears as a doublet at δ3.42 with a coupling constant of $J_{3a-6a}=7.8$ Hz from coupling solely to the H-6 a proton. In the H-3, H-3 a *anti* adducts, the protons H-3 and H-3 a fail to display coupling since Φ90°. This feature of the NMR spectrum is uniquely diagnostic for the H-3, H-3 a *anti* relationship [9]. Proton H-3 is coupled solely to H-4′ with the coupling constant $J_{3-4'}=8.4$ Hz, indicative of nearly eclipsed conformation of **8 a** between H-3 and H-4′. Moreover, ^{1}H-NMR data for **8** enable almost complete configurational assignments to be made, e. g. for irradiation of H-3′ of **8 b** NOE's for both H-4′ and H-3 a were observed, which suggested that these three protons were all on the same side. Irradiation of H-3 a results in signal enhancement of H-6 a and of H-3′ of the saccharide unit. This proves the *cis*-configuration of H-3 a and H-6 a.

In **8** and **10** the 0 – 1 Hz coupling constant between bridgehead H-3 a and isoxazolidine H-3 is consistent only with *anti* stereochemistry, since in a *syn* isomer **9** and **11** the two hydrogens would be nearly eclipsed and would give rise to a much larger coupling constants. Indeed, the isolated adduct **6** from the cycloaddition



exo attack ► syn – syn exo attack ► syn – anti

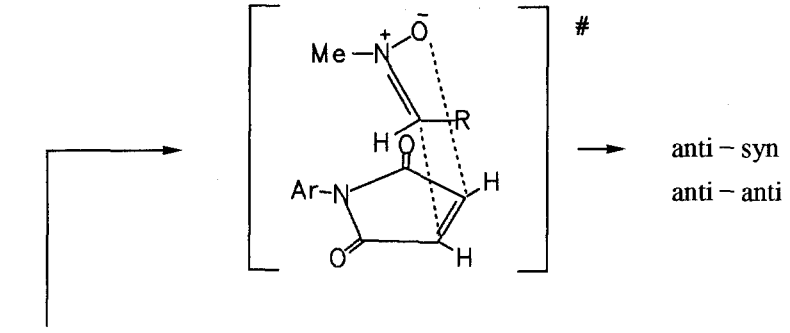
endo attack► anti – syn endo attack► anti – anti

Fig. 1. Felkin-Anh transition state for the cycloadditions of **1** and **2**

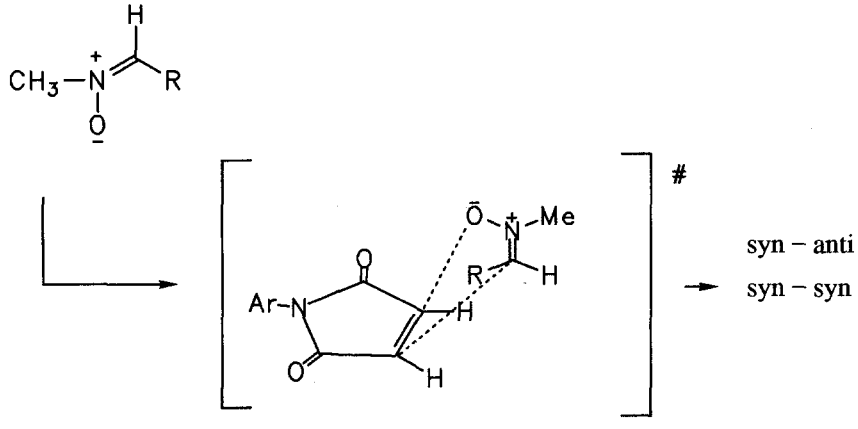
of 3′-hydroxy-N-methylnitrone (**1**) showed $J_{3-3a}=7.2$ Hz, which is in the range expected for a H-3, H-3 a *syn* relationship. Further support for this *syn* arrangement is the signal for the H-3 a proton appearing as a doublet of doublets and the multiplet for H-3.

It was not possible from the spectroscopic data available to decide if the *anti* isoxazolidines **8** and **10** obtained from the 3′-acetoxy-N-methyl- (or phenyl) nitrone and N-arylmaleimide corresponded to *anti-syn* isomer **8**, **10** (T-1) or to *anti-anti* isomer **8**, **10** (T-2). The same problem is the assignment of a structure to cycloadduct **6** isolated from the cycloaddition of 3′-hydroxy-N-methylnitrone to the *syn-syn* isomer **6** (C-2) or the *syn-anti* isomer **6** (C-1).

The stereoselectivity of the intermolecular cycloaddition of an acyclic nitrone to an alkene is difficult to predict, and it would appear to be susceptible to minor structural changes in either component [10]. The chiral 2,2-dimethyl-1,3-dioxolan-4-yl nitrone showed only modest diastereoface selectivity in its addition to methyl crotonate [11]. However, the more hindered tetramethyl-1,3-dioxolan-4-yl nitrone was more selective. As anticipated from earlier studies [9], the *anti* C-3, C-4′ cycloadducts (in our cases there should occur *anti-anti* and *syn-anti* adducts) were produced stereoselectively or predominated at least. De Shong and coworkers showed that the cycloaddition of α,β-dialkoxy substituted nitrones with vinylene



Endo Transition State



Exo Transition State

Scheme 3

carbonate display moderate selectivity for the diastereomer having C-3, C-4′ *anti* relationship [12].

Dipolar cycloaddition of α-alkoxy substituted nitrones had been shown to occur preferentially via Felkin-Anh [13–15] transition state in which the developing carbon-carbon bond avoided steric interaction with the bulky group [12]. Accordingly, in our case the conformations A and B can be expected (Fig. 1).

All the nitrones used were isolated before cycloaddition, and were shown by ^{1}H-NMR NOE data to be the *Z*-isomers **1**–**3** (formula scheme). The isomeric *E*-nitrones could not be detected, but as it has been postulated that isomerization of *Z*-nitrones to the more reactive nitrones can precede cycloaddition [16]; it is not possible to exclude that either *Z*- and *E*-nitrones are involved in cycloadditions. The *anti*-isoxazolidines **7**, **8** and **10** arise from cycloaddition of *Z*-nitrone through an *endo* transition state, or from the *E*-nitrone in an *exo*-mode. Conversely the *syn*-isoxazolidines **6** could be formed by the *Z*-nitrone reacting in the *exo*-fashion or the *E*-nitrone in an *endo*-mode (Scheme 3).

Accordingly, the cycloadditions via transition state A (Fig. 1) would afford *syn-syn* products (C-2) through the *exo*-attack and *anti-syn* products (T-1) through the *endo*-attack. Conversely the cycloaddition via transition state B would furnish *syn-anti* cycloadducts (C-1) through the *exo*-attack and *anti-anti* adducts (T-2) through the *endo*-attack.

In order to rationalize the above cycloadditions we have carried out some quantum mechanical calculations. Geometries of nitrones were totally optimized by the semiempirical AM1 method [17]. The relative stability of products with *anti-syn* (T-1), *anti-anti* (T-2), *syn-anti* (C-1) and *syn-syn* (C-2) configuration have been assessed by molecular mechanics (MM2) calculations [18]. Subsequent AM1 calculations showed the *Z*-hydroxynitrone **1** to be more stable by 14.8 kJ/mol than the corresponding *E*-derivative, a fact that can be accounted for mainly on steric considerations. In the case of acetoxynitrone **2** both forms are almost equally stable, with a small preference of the *E*-derivative (ca. 5 kJ/mol) (Table 4). Inspection of frontier orbital energies shows that the interaction of **1**–**3** – N-phenylmaleimide is governed by the HOMO dipole. The calculated relative energies in kJ/mol are expressed as energy differences, the energy of the most stable structure being the reference (Figs. 2 and 3).

R = OH	T-1 = 9.6	T-2 = 1.0	C-1 = 0.0	C-2 = 40.5
R = $OCOCH_3$	T-1 = 5.5	T-2 = 0.0	C-1 = 0.2	C-2 = 13.8

Table 4. Energies of frontier orbitals, MO coefficients, and atomic charges at carbon and oxygen for dipoles *X*-OH and *X*-OCO*Me*, calculated using AM1

Molecule	E (eV)		HOMO		LUMO		charges	
	MOMO	LUMO	C	O	C	O	C	O
X-OH *trans*	−9.27	0.18	0.63	−0.65	0.63	0.38	−0.26	−0.49
X-OH *cis*	−8.90	0.53	0.67	−0.65	0.58	0.40	−0.24	−0.45
X-OCO*Me trans*	−9.22	0.22	0.64	−0.64	0.61	0.39	−0.27	−0.47
X-OCO*Me cis*	−9.14	0.31	0.68	−0.65	0.57	0.40	−0.31	−0.44

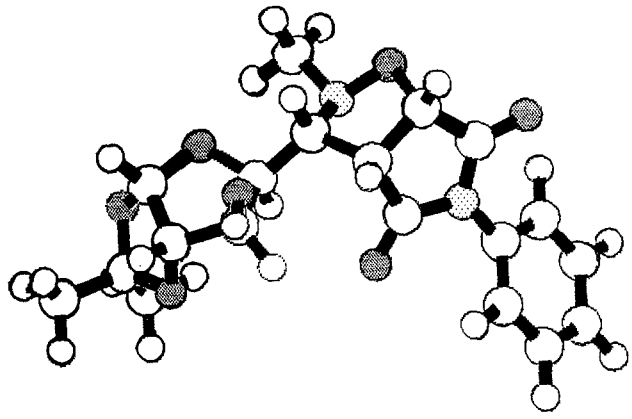


Fig. 2. Optimized geometry for the cycloadduct *syn-anti* **6** (MM2)

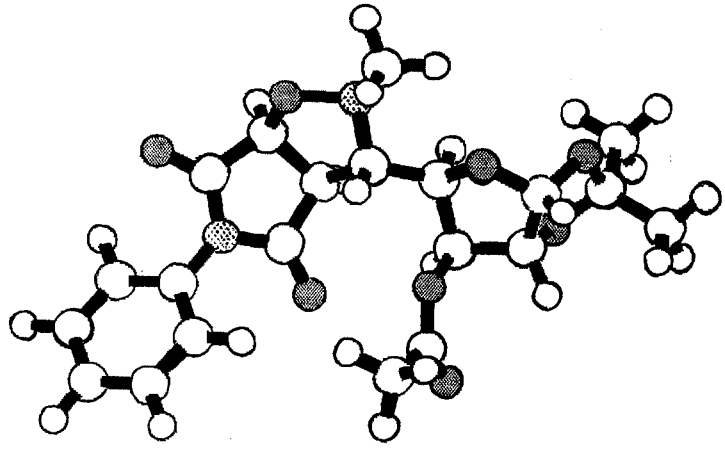


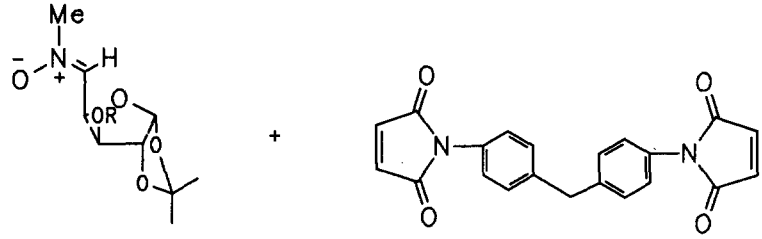
Fig. 3. Optimized geometry for the cycloadduct *anti-anti* **8** (MM2)

The quantum mechanical calculations are complicated, since the products are very flexible and can have many local minima through rotation around the bond between pentose – condensed isoxazolidine.

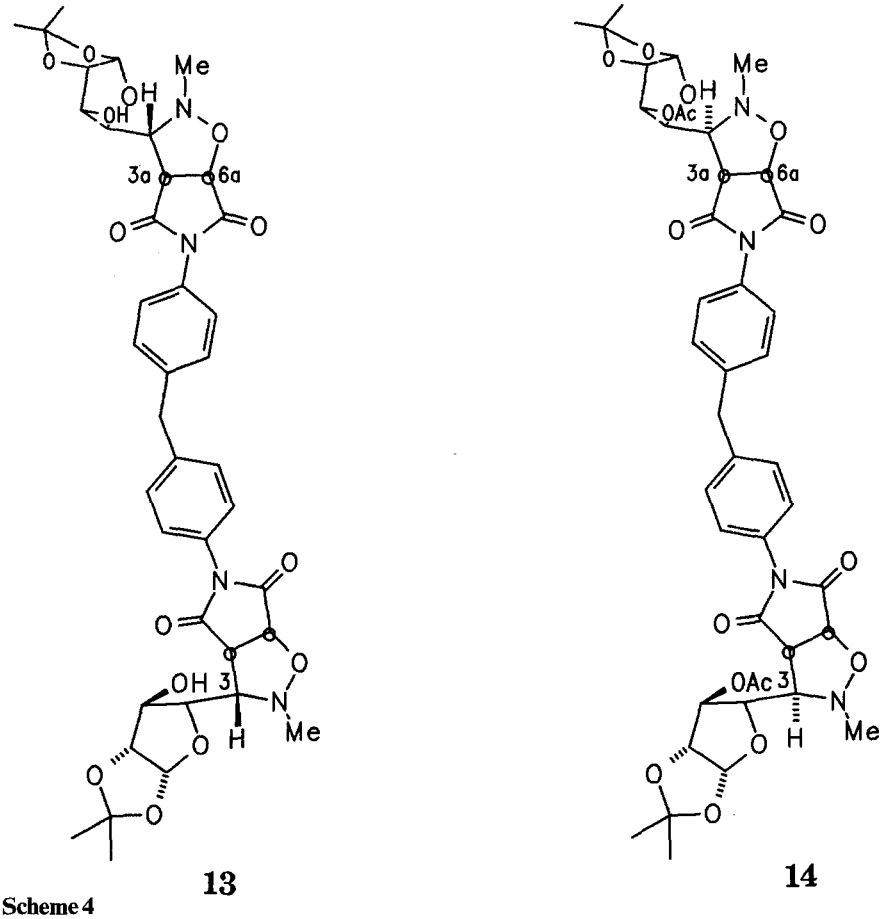
Thus, 3′-hydroxy-N-methylnitrone (**1**) gave the *syn-anti* cycloadducts **6** via *exo* attack (conformation B), since the formation of *syn-syn* (C-2) adducts is not possible according to the MM2 results. Molecular models suggest that an attack via mode B is the least sterically demanding, and may explain the selective formation of the *syn-anti* (C-1) in the case of the hydroxynitrones and the *anti-anti* (T-2) in the case of acetoxynitrones. For conformation A severe steric interactions occur between the incoming N-arylmaleimide and sugar moiety and also for conformation A unfavourable interactions between the nitrone oxygen and the substituent on the C-3′ carbon are present. We propose that the aforementioned nitrones undergo (via conformation B favoured on steric grounds) the *endo* attack which is sterically preferred, since the repulsion between N-aryl-maleimide and the sugar moiety are avoided for the 3′-acetoxynitrones, and if they suffer an *exo* attack, this is ster-

eoelectronically preferred through the hydrogen bond between the pentose hydroxyl group and one of the carbonyl groups of the N-arylmaleinimide.

NMR analysis of the crude mixture showed the presence of the second isomer *anti-syn* (T-1) in the cycloadditions of 3′-acetoxynitrones and *syn-syn* (C-2) in the case of 3′-hydroxynitrone, but both less than 10%. These compounds were not possible to be isolated from the major products. Cycloaddition of nitrones **1** and **2** and bis-maleinimide **12** proceeded analogously and results in stereoselective formation of *syn*-adducts **13** to the nitrone **1** and *anti* adducts **14** for the nitrone **2** (Scheme 4).



1, 2 **12**



13 **14**

Scheme 4

Thus the cycloaddition of the C-glycosylnitrones to N-arylmaleimides would appear to proceed with useful stereoselectivity, but the nature of the stereoselectivity is dependent upon the precise functionality present in the nitrone. We have demonstrated how small a structural change in the nitrone needs to be to effect a significant change in the stereoselectivity of the cycloaddition.

Experimental Part

Melting points were determined on a Kofler hot plate apparatus and are uncorrected. ^{1}H-NMR spectra were recorded on a Varian VXR 300 or a TESLA BS 487 C (80 MHz) and ^{13}C-NMR spectra on a Varian VXR 300 spectrometer (*TMS* as internal standard, $CDCl_3$, δ-values in ppm, *J* in Hz). The nitrones **1**–**3** were prepared from the corresponding aldehydes **4** and **5** [7] by treatment with N-methylhydroxylamine or N-phenylhydroxylamine.

C-(1,2-O-Isopropylidene-α-D-xylo-tetrofuranos-4-yl)-N-methylnitrone (**1**)

Yield: 96%, m. p. 150°C. $C_9H_{15}NO_5$ (217.2) calc.: C 49.76, H 6.91, N 6.45; found: C 50.01, H 6.63, N 6.55. $[\alpha]_D$ −170° (*c* 1.0, chloroform). ^{1}H-NMR: 1.32 (s, 3 H, CH_3), 1.49 (s, 3 H, CH_3), 3.72 (s, 3 H, N-CH_3), 4.56 (d, 1 H, H-2, J_{1-2} = 3.6 Hz), 4.75 (d, 1 H, H-3, J_{3-4} = 3.0 Hz), 5.12 (m, 1 H, H-4), 5.98 (d, 1 H, H-1), 7.03 (d, 1 H, H-5, J_{4-5} = 3.9 Hz). ^{13}C-NMR: 26.54 (q, CH_3), 27.27 (q, CH_3), 52.26 (q, N-CH_3), 75.08 (d, C-3), 79.22 (d, C-2), 85.99 (d, C-4), 105.15 (d, C-1), 112.40 (s, CMe_2), 141.63 (d, C-5).

C-(1,2-O-Isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-N-methylnitrone (**2**)

Yield: 96%, m. p. 158–160°C. $C_{11}H_{17}NO_6$ (259.2) calc.: C 50.96, H 6.56, N 5.40; found: C 50.93, H 6.63, N 5.30. $[\alpha]_D$ −220° (*c* 1.2, chloroform). ^{1}H-NMR: 1.31 (s, 3 H, CH_3), 1.53 (s, 3 H, CH_3), 2.06 (s, 3 H, $COCH_3$), 3.73 (s, 3 H, N-CH_3), 4.57 (d, 1 H, H-2, J_{1-2} = 3.9 Hz), 5.38 (dd, 1 H, H-4, J_{3-4} = 3.3 Hz, J_{4-5} = 5.1 Hz), 5.53 (d, 1 H, H-3), 5.93 (d, 1 H, H-1), 6.82 (d, 1 H, H-5). ^{13}C-NMR: 21.01 (q, $COCH_3$), 26.53 (q, CH_3), 27.03 (q, CH_3), 52.76 (q, N-CH_3), 75.59 (d, C-3), 76.79 (d, C-2), 83.47 (d, C-4), 104.83 (d, C-1), 112.92 (s, CMe_2), 135.09 (d, C-5), 169.68 (s, C=O).

C-(1,2-O-Isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-N-phenylnitrone (**3**)

Yield: 83%, m. p. 118–120°C. $C_{16}H_{19}NO_6$ (321.3) calc.: C 59.81, H 5.96, N 4.35; found: C 60.15, H 6.20, N 4.78. H-NMR: 1.31 (s, 3 H, CH_3), 1.50 (s, 3 H, CH_3), 2.00 (s, 3 H, $COCH_3$), 4.65 (d, 1 H, H-2, J_{1-2} = 3.6 Hz), 5.30 (dd, H-4, 1 H, J_{3-4} = 3.0 Hz, J_{4-5} = 5.0 Hz), 5.45 (d, 1 H, H-3), 6.02 (d, 1 H, H-1), 7.20 (d, 1 H, H-5), 7.48-7.80 (m, 5 H, aromat. H).

2-Methyl-(or phenyl)-3-glycosyl-5-aryl-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazoles **6**, **8**, **10** *(Tables 1–3)*

C-Glycosylnitrone **1**–**3** (2.3 mmol) and corresponding N-arylmaleimide (2.3 mmol) in dry toluene (50 ml), were heated under reflux for 0.5–1 h (*TLC*). Concentration under reduced pressure and chromatography using chloroform gave corresponding cycloadducts after purification by crystallization from chloroform-petrolether.

2-Methyl-3-(1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-5-phenyl-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]isoxazole (**6a**)

^{1}-NMR: 1.33 (s, 3 H, CH_3), 1.51 (s, 3 H, CH_3), 2.93 (s, 3 H, N-CH_3), 3.40 (m, 1 H, H-3), 3.71 (dd, 1 H, H-3a, J_{3a-6a} = 7.2 Hz, J_{3-3a} = 7.2 Hz), 4.24 (dd, 1 H, H-4′, $J_{3'-4'}$ = 2.4 Hz), 4.39 (d, 1 H, H-3′), 4.55 (d, 1 H, H-2′, $J_{1'-2'}$ = 3.6 Hz), 4.95 (d, 1 H, H-6a), 5.98 (d, 1 H, H-1′), 7.16–7.50 (m, 5 H, aromat. H).

^{13}C-NMR: 21.45 (q, N-CH_3), 26.18 (q, CH_3), 26.83 (q, CH_3), 53.63 (d, C-3a), 69.71 (d, C-3), 75.21 (d, C-6a), 76.03 (d, C-3′), 77.24 (d, C-4′), 84.48 (d, C-2′), 105.56 (d, H-1′), 111.92 (s, C*Me*$_2$), 125.29, 126.07, 126.13, 128.96, 129.40, 130.76, 131.04, 137.87 (aromat. C), 175.97 (s, C=O), 176.54 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-5-(2,6-dimethylphenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]isoxazole (**6b**)

^{1}H-NMR: 1.33 (s, 3H, CH_3), 1.51 (s, 3H, CH_3), 2.09 (s, 3H, CH_3), 2.12 (s, 3H, CH_3), 2.97 (s, 3H, N-CH_3), 3.23 (m, 1H, H-3), 3.71 (dd, 1H, H-3a, J_{3a-6a}=7.2 Hz), 4.27 (dd, 1H, H-4′, $J_{3'-4'}$=2.5 Hz), 4.42 (d, 1H, H-3′), 4.55 (d, 1H, H-2′, $J_{1'-2'}$=3.6 Hz), 4.98 (d, 1H, H-6a), 5.98 (d, 1H, H-1′), 7.15–7.26 (m, 3H, aromat. H). ^{13}C-NMR: 17.49 (q, CH_3), 17.75 (q, CH_3), 26.20 (q, CH_3), 26.83 (q, CH_3), 53.80 (d, C-3a), 70.07 (d, C-3), 75.44 (d, C-6a), 75.99 (d, C-3′), 77.24 (C-4′), 84.20 (C-2′), 105.76 (d, C-1′), 111.97 (s, C*Me*$_2$), 128.50, 128.69, 128.89, 130.12, 134.34, 135.49, 135.75, 135.79 (aromat. C), 175. 90 (s, C=O), 176.80 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-5-(2-ethyl-6-methylphenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]isoxazole (**6c**)

^{1}H-NMR: 1.14 (t, 3H, CH_3), 1.32 (s, 3H, CH_3), 1.51 (s, 3H, CH_3), 2.10 (s, 3H, CH_3), 2.39 (q, 2H, CH_2), 2.97 (s, 3H, N-CH_3), 3.22 (m, 1H, H-3), 3.70 (dd, 1H, H-3a, J_{3a-6a}=7.2 Hz, J_{3-3a}=7.2 Hz), 4.27 (dd, 1H, H-4′, $J_{3'-4'}$=2.4 Hz), 4.30 (d, 1H, H-3′), 4.55 (d, 1H, H-2′, $J_{1'-2'}$=3.0 Hz), 4.98 (d, 1H, H-6a), 5.98 (d, 1H, H-1′), 7.16–7.33 (m, 3H, aromat. H). ^{13}C-NMR: 14.39 (q, CH_3), 14.48 (q, CH_3), 17.53 (q, CH_3), 17.76 (q, CH_3), 20.40 (q, N-CH_3), 24.29 (t, CH_2), 24.36 (t, CH_2), 26.20 (q, CH_3), 26.83 (q, CH_3), 53.81 (d, C-3a), 70.66 (d, C-3), 75.44 (d, C-6a), 75.98 (d, C-3′), 77.24 (d, C-4′), 84.20 (d, C-2′), 105.97 (d, C-1′), 111.97 (s, C*Me*$_2$), 126.88, 127.17, 128.85, 130.36, 134.31, 135.49, 135.72, 141.28, 141.57 (aromat. C), 177.14 (s, C=O), 177.21 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-5-(2,6-diethylphenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**6d**)

^{1}H-NMR: 1.13 (t, 6H, 2·CH_3), 1.32 (s, 3H, CH_3), 1.51 (s, 3H, CH_3), 2.39 (q, 4H, 2×CH_2), 2.97 (s, 3H, N-CH_3), 3.23 (m, 1H, H3), 3.71 (dd, 1H, H-3a, J_{3a-6a}=6.9 Hz, J_{3-3a}=6.9 Hz), 4.28 (dd, 1H, H4′, $J_{3'-4'}$=2.5 Hz), 4.41 (d, 1H, H-3′), 4.54 (d, 1H, H-2′, $J_{1'-2'}$=3.6 Hz), 4.97 (d, 1H, H-6a), 5.98 (d, 1H, H-1′), 7.19–7.41 (m, 3H, aromat. H). ^{13}C-NMR: 14.31 (q, CH_3), 14.44 (q, CH_3), 24.26 (t, CH_2), 24.33 (t, CH_2), 26.19 (q, CH_3), 26.83 (q, CH_3), 53.80 (d, C-3a), 70.05 (d, C-3), 75.41 (d, C-6a), 75.96 (d, C-3′), 77.26 (d, C-4′), 84.20 (d, C-2′), 105.77 (d, C-1′), 111.95 (s, C*Me*$_2$), 126.82, 127.10, 127.19, 127.61, 130.38, 130.55, 141.23, 141.33, 141.50 (aromat. C), 177.14 (s, C=O), 177.53 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-5-(3,5-dichlorophenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**6e**)

^{1}H-NMR (in *DMSO-d*$_6$): 1.25 (s, 3H, CH_3), 1.41 (s, 3H, CH_3), 2.67 (s, 3H, N-CH_3), 3.92–4.01 (m, 3H, H-3, H-3a, H-4′), 4.47 (d, 1H, H-2′, $J_{1'-2'}$=3.0 Hz), 5.11 (d, 1H, H-6a, J_{3a-6a}=7.8 Hz), 5.58 (d, 1H, H-3, $J_{3'-4'}$=4.5 Hz), 5.88 (d, 1H, H-1′), 7.44 (s, 2H, aromat. H), 7.77 (s, 1H, aromat. H). ^{13}C-NMR (in *DMSO-d*$_6$): 25.99 (q, CH_3), 26.69 (q, CH_3), 52.60 (d, C-3a), 66.73 (d, C-3), 66.77 (d, C-6a), 73.13 (d, C-3′), 78.03 (d, C-4′), 85.28 (d, C-2′), 104.71 (d, C-1′), 110.71 (s, C*Me*$_2$), 125.35, 128.51, 133.92, 134.31 (aromat. C), 174.26 (s, C=O), 175.14 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-5-(4-chlorophenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**6f**)

^{1}H-NMR: 1.35 (s, 3H, CH_3), 1.51 (s, 3H, CH_3), 2.91 (s, 3H, N-CH_3), 3.41 (m, 1H, H-3), 3.73 (dd, 1H, H-3a, J_{3a-6a}=7.2 Hz, J_{3-3a}=7.2 Hz), 4.24 (dd, 1-H, H-4′, $J_{3'-4'}$=2.4 Hz), 4.38 (d, 1H, H-3′), 4.54 (d, 1H, H-2′, $J_{1'-2'}$=3.6 Hz), 4.95 (d, 1H, H-6a), 5.97 (d, 1H, H-1′), 7.24 (d, 2H, aromat. H),

7.45 (d, 2H, aromat. H). ^{13}C-NMR: 26.16 (q, CH_3), 26.81 (q, CH_3), 53.55 (d, C-3a), 69.65 (d, C-3), 76.01 (d, C-6a), 76.23 (d, C-3′), 77.24 (d, C-4′), 84.49 (d, C-2′), 105.52 (d, C-1), 111.95 (s, C*Me*$_2$), 127.29, 127.37, 129.60, 135.22 (aromat. C), 176.00 (s, C=O), 176.20 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-5-(4-fluorophenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**6g**)

^{1}H-NMR: 1.32 (s, 3H, CH_3), 1.51 (s, 3H, N-CH_3), 2.92 (s, 3H, N-CH_3), 3.41 (m, 1H, H-3), 3.73 (dd, 1H, H-3a, J_{3a-6a}=7.2 Hz, J_{3-3a}=7.2 Hz), 4.24 (dd, 1H, H-4′, $J_{3'-4'}$=2.4 Hz), 4.39 (d, 1H, H-3′), 4.55 (d, 1H, H-2′, $J_{1'-2'}$=3.6 Hz), 4.96 (d, 1H, H-6a), 5.98 (d, 1H, H-1′), 7.14−7.31 (m, 4H, aromat. H). ^{13}C-NMR: 26.16 (q, CH_3), 26.81 (q, CH_3), 53.57 (d, C-3a), 69.72 (d, C-3), 75.20 (d, C-6a), 76.03 (d, C-3′), 77.24 (d, C-4′), 84.47 (d, C-2′), 105.54 (d, C-1′), 111.95 (s, C*Me*$_2$), 116.35, 127.97, 128.14, 160.87 (aromat. C), 175.89 (s, C=O), 176.43 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-5-(4-bromophenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**6h**)

^{1}H-NMR: 1.33 (s, 3H, CH_3), 1.51 (s, 3H, CH_3), 2.91 (s, 3H, N-CH_3), 3.41 (m, 1H, H-3), 3.72 (dd, 1H, H-3a, J_{3a-6a}=7.5 Hz, J_{3-3a}=7.5 Hz), 4.24 (dd, 1H, H-4′, $J_{3'-4'}$=2.0 Hz), 4.38 (d, 1H, H-3′), 4.55 (d, 1H, H-2′, $J_{1'-2'}$=3.6 Hz), 4.95 (d, 1H, H-6a), 5.98 (d, 1H, H-1′), 7.18 (d, 2H, aromat. H), 7.61 (d, 2H, aromat. H). ^{13}C-NMR: 21.45 (q, N-CH_3), 26.17 (q, CH_3), 26.82 (q, CH_3), 53.58 (d, C-3a), 69.71 (d, C-3), 75.20 (d, C-6a), 76.02 (d, C-3′), 77.24 (d, C-4′), 84.48 (d, C-2′), 105.53 (d, C-1′), 111.95 (s, C*Me*$_2$), 123.29, 128.21, 129.03, 132.36 (aromat. C), 175.61 (s, C=O), 176.13 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-5-(3,4-dichlorophenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**6i**)

^{1}H-NMR: 1.33 (s, 3H, CH_3), 1.51 (s, 3H, CH_3), 2.91 (s, 3H, N-CH_3), 3.45 (m, 1H, H-3), 3.74 (dd, 1H, H-3a, J_{3a-6a}=7.2 Hz, J_{3-3a}=7.2 Hz), 4.26 (dd, 1H, H-4′, $J_{3'-4'}$=1.8 Hz), 4.38 (d, 1H, H-3′), 4.55 (d, 1H, H-2′, $J_{1'-2'}$=3.6 Hz), 4.96 (d, 1H, H-6a), 5.98 (d, 1H, H-1′), 7.18−7.58 (m, 3H, aromat. H). ^{13}C-NMR: 26.16 (q, CH_3), 26.81 (q, CH_3), 53.56 (d, C-3a), 69.71 (d, C-3), 75.22 (d, C-6a), 76.03 (d, C-3′), 77.23 (d, C-4′), 84.50 (d, C-2′), 105.51 (d, C-1′), 111.98 (s, C*Me*$_2$), 125.28, 127.99, 129.93, 130.99, 133.35, 133.68 (aromat. C), 175.33 (s, C=O), 175.82 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-5-phenyl-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**8a**)

^{1}H-NMR: 1.32 (s, 3H, CH_3), 1.54 (s, 3H, CH_3), 2.20 (s, 3H, $COCH_3$), 2.85 (s, 3H, CH_3), 3.42 (d, 1H, H-3a, J_{3a-6a}=7.8 Hz), 3.72 (d, 1H, H-3, $J_{3-4'}$=8.4 Hz), 4.50−4.54 (m, 2H, H-2′, H-4′), 4.83 (d, 1H, H-6a), 5.44 (d, 1H, H-3′, $J_{3'-4'}$=2.7 Hz), 5.97 (d, 1H, H-1′, $J_{1'-2'}$=3.6 Hz), 7.12−7.29 (m, 5H, aromat. H). ^{13}C-NMR: 20.98 (q, N-CH_3), 26.27 (q, CH_3), 26.73 (q, CH_3), 51.93 (d, C-3a), 68.12 (d, C-3), 75.67 (d, C-6a), 76.41 (d, C-3′), 77.30 (d, C-2′), 82.85 (d, C-4′), 105.44 (d, C-1′), 112.55 (s, C*Me*$_2$), 116.21, 127.92, 128.00, 134.28 (aromat. C), 164.05 (s, C=O), 170.41 (s, C=O), 174.10 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-5-(2,6-dimethylphenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**8b**)

^{1}H-NMR: 2.10 (s, 3H, CH_3), 2.17 (s, 3H, CH_3), 2.90 (s, 3H, N-CH_3), 3.37 (d, 1H, H-3a, J_{3a-6a}=7.2 Hz), 3.70 (d, 1H, H-3, $J_{3-4'}$=8.1 Hz), 4.49 (d, 1H, H-2′, $J_{1'-2'}$=3.9 Hz), 4.58 (dd, 1H, H-4′, $J_{3'-4'}$=3.0 Hz), 4.83 (d, 1H, H-6a), 5.43 (d, 1H, H-3′), 5.98 (d, 1H, H-1′), 7.10−7.26 (m, 3H, aromat. H). ^{13}C-NMR: 17.57 (q, CH_3), 17.79 (q, CH_3), 20.89 (q, N-CH_3), 26.23 (q, CH_3), 26.80 (q,

CH_3), 52.35 (d, C-3a), 67.73 (d, C-3), 75.61 (d, C-6a), 76.63 (d, C-3), 77.26 (d, C-2'), 82.64 (d, C-4'), 105.46 (d, C-1'), 112.49 (s, C*Me*$_2$), 128.45, 128.69, 129.62, 134.33, 135.39 (aromat. C), 163.95 (s, C=O), 170.37 (s, C=O), 173.65 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-5-(2-ethyl-6-methylphenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**8c**)

^{1}H-NMR: 1.09 (t, 3H, CH_3), 1.32 (s, 3H, CH_3), 1.54 (s, 3H, CH_3), 2.05 (6, 3H, CH_3), 2.10 (s, 3H, CH_3), 2.17 (s, 3H, $COCH_3$), 2.38 (q, 2H, CH_2), 2.90 (s, 3H, N-CH_3), 3.37 (d, 1H, H-3a, J_{3a-6a}=7.2 Hz), 3.70 (d, 1H, H-3, $J_{3-4'}$=9.0 Hz), 4.09 (d, 1H, H-2', $J_{1'-2'}$=3.6 Hz), 4.58 (dd, 1H, H-4', $J_{3'-4'}$=3.0 Hz), 4.83 (d, 1H, H-6a), 5.43 (d, 1H, H-3'), 5.96 (d, 1H, H-1'), 7.11−7.35 (m, 3H, aromat. H). ^{13}C-NMR: 14.48 (q, CH_3), 14.72 (q, CH_3), 17.60 (q, CH_3), 17.80 (q, CH_3), 20.88 (q, N-CH_3), 24.35 (t, CH_2), 24.51 (t, CH_2), 26.23 (q, CH_3), 26.80 (q, CH_3), 52.32 (d, C-3a), 67.85 (d, C-3), 75.56 (d, C-6a), 76.64 (d, C-3'), 77.26 (d, C-2'), 82.64 (d, C-4'), 105.46 (d, C-1'), 112.49 (s, C*Me*$_2$), 126.56, 127.20, 128.48, 128.67, 129.09, 129.91, 134.31, 135.41, 136.20, 141.11, 142.12 (aromat. C), 170.38 (s, C=O), 174.05 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-5-(2,6-diethylphenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**8d**)

^{1}H-NMR: 1.09 (t, 6H, 2×CH_3), 1.32 (s, 3H, CH_3), 1.54 (s, 3H, CH_3), 2.16 (s, 3H, $COCH_3$), 2.37 (q, 4H, 2×CH_2), 2. 91 (s, 3H, N-CH_3), 3.37 (d, 1H, H-3a, J_{3a-6a}=7.2 Hz), 3.70 (d, 1H, H-3, $J_{3-4'}$=8.4 Hz), 4.49 (d, 1H, H-2', $J_{1'-2'}$=3.9 Hz), 4.58 (dd, 1H, H-4', $J_{3'-4'}$=2.4 Hz), 4.83 (d, 1H, H-6a), 5.43 (d, 1H, H-3'), 5.96 (d, 1H, H-1'), 7.16−7.36 (m, 3H, aromat. H). ^{13}C-NMR: 14.16 (q, CH_3), 14.69 (q, CH_3), 20.88 (q, N-CH_3), 24.33 (t, CH_2), 24.49 (t, CH_2), 26.22 (q, CH_3), 26.79 (q, CH_3), 52.35 (d, C-3a), 67.83 (d, C-3), 75.40 (d, C-6a), 76.63 (d, C-3'), 76.72 (d, C-2'), 82.64 (d, C-4'), 105.47 (d, C-1'), 112.49 (s, C*Me*$_2$), 126.55, 127.16, 127.52, 130.10, 141.06, 142.09 (aromat. C), 170.38 (s, C=O), 174.39 (s, C=O).

2-Methyl-3-(1,2-O-isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-5-(4-fluorophenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]isoxazole (**8g**)

^{1}H-NMR: 1.32 (s, 3H, CH_3), 1.54 (s, 3H, CH_3), 2.20 (s, 3H, $COCH_3$), 2.86 (s, 3H, N-CH_3), 3.40 (d, 1H, H-3a, J_{3a-6a}=7.5 Hz), 3.71 (d, 1H, H-3, $J_{3-4'}$=8.0 Hz), 4.50−4.51 (m, 2H, H-2', H-4'), 4.82 (d, 1H, H-6a), 5.43 (d, 1H, H-3', $J_{3'-4'}$=3.0 Hz), 5.97 (d, 1H, -1', $J_{1'-2'}$=3.6 Hz), 7.26−7.50 (m, 4H aromat H). ^{13}C-NMR: 21.25 (q, N-CH_3), 26.57 (q, CH_3), 27.12 (q, CH_3), 52.36 (d, C-3a), 68.19 (d, C-3), 76.13 (C-6a), 76.86 (d, C-3'), 77.39 (d, C-2'), 83.91 (d, C-4'), 105.70 (d, C-1'), 112.81 (s, C*Me*$_2$), 126.23, 129.28, 129.58, 131.67 (aromat. C), 170.68 (s, C=O), 174.40 (s, C=O).

2,5-Diphenyl-3-(1,2-O-isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**10a**)

^{1}H-NMR: 1.33 (s, 3H, CH_3), 1.55 (s, 3H, CH_3), 2.14 (s, 3H, $COCH_3$), 4.18 (d, 1H, H-3a, J_{3a-6a}=7.5 Hz), 4.46 (dd, 1H, H-4', $J_{3-4'}$=8.7 Hz), 4.61 (d, 1H, H-2', $J_{1'-2'}$=3.9 Hz), 5.05 (d, 1H, H-3), 5.10 (d, 1H, H-6a), 5.29 (d, 1H, H-3', $J_{3'-4'}$=3.3 Hz), 6.01 (d, 1H, H-1'), 6.36−7.27 (m, 10H, aromat. H). ^{13}C-NMR: 20.96 (q, $COCH_3$), 26.08 (q, CH_3), 26.69 (q, CH_3), 51.53 (d, C-3a), 64.84 (d, C-3), 76.55 (d, C-6a), 77.74 (d, C-3'), 78.09 (d, C-2'), 83.60 (d, C-4'), 104.97 (d, C-1'), 112.44 (s, C*Me*$_2$), 114.00, 123.36, 126.09, 128.90, 128.94, 129.55, 130.79, 148.53 (aromat. C), 169.45 (c, C=O), 172.57 (s, C=O), 174.21 (s, C=O).

2-Phenyl-3-(1,2-O-isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-5-(2,6-dimethylphenyl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**10b**)

^{1}H-NMR: 1.32 (s, 3H, CH_3), 1.54 (s, 3H, CH_3), 2.02 (s, 3H, $COCH_3$), 2.18 (s, 3H, CH_3), 2.23 (s, 3H, CH_3), 4.32 (d, 1H, H-3a, J_{3a-6a}=7.8 Hz), 4.44 (dd, 1H, H-4', $J_{3-4'}$=7.8 Hz, $J_{3'-4'}$=3.0 Hz),

4.59 (d, 1 H, H-2′, $J_{1'-2'}$ = 3.9 Hz), 5.18 (d, 1 H, H-3), 5.20 (d, 1 H, H-6 a), 5.53 (d, 1 H, H-3′), 5.98 (d, 1 H, H-1′), 6.88 – 7.26 (m, 8 H, aromat. H). ^{13}C-NMR: 17.83 (q, CH_3), 17.86 (q, CH_3), 21.01 (q, $COCH_3$), 26.17 (q, CH_3), 26.61 (q, CH_3), 51.51 (d, C-3 a), 64.68 (d, C-3), 75.34 (d, C-6 a), 77.23 (d, C-3′), 77.76 (d, C-2′), 83.72 (d, C-4′), 105.15 (d, C-1′), 112.48 (s, C*Me*$_2$), 114.96, 123.45, 128.31, 128.67, 129.46, 129.68, 134.78, 136.46, 136.52, 147.01, 148.58 (aromat. C), 169.65 (s, C=O), 172.43 (s, C=O), 173.91 (s, C=O).

2-Phenyl-3-(1,2-O-isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-5-(3,5-dichlorophenyl)-4,6-dioxo-2,3,3 a,4,6,6 a-hexahydropyrrolo[3,4-d]-isoxazole (**10 e**)

^{1}H-NMR: 1.35 (s, 3 H, CH_3), 1.56 (s, 3 H, CH_3), 2.25 (s, 3 H, $COCH_3$), 3.65 (d, 1 H, H-3 a, J_{3a-6a} = 7.8 Hz), 4.53 (dd, 1 H, H-4′, $J_{3-4'}$ = 9.0 Hz, $J_{3'-4'}$ = 3.3 Hz), 4.63 (d, 1 H, H-2′, $J_{1'-2'}$ = 3.6 Hz), 4.83 (d, 1 H, H-3), 5.08 (d, 1 H, H-6 a), 5.54 (d, 1 H, H-3′), 6.06 (d, 1 H, H-1), 6.26 – 7.28 (m, 8 H, aromat. H). ^{13}C-NMR: 20.87 (q, $COCH_3$), 26.28 (q, CH_3), 26.83 (q, CH_3), 50.99 (d, C-3 a), 67.65 (d, C-3), 75.10 (d, C-6 a), 77.22 (d, C-3′), 78.52 (d, C-2′), 83.78 (d, C-4′), 105.19 (d, C-1′), 112.75 (s, C*Me*$_2$), 114.16, 129.67, 129.42, 129.36, 129.53, 132.21, 135.22, 148.82 (aromat. C), 170.27 (s, C=O), 171.78 (s, C=O), 173.08 (s, C=O).

2-Phenyl-3-(1,2-O-isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-5-(4-fluorophenyl)-4,6-dioxo-2,3,3 a,4,6,6 a-hexahydropyrrolo[3,4-d]-isoxazole (**10 g**)

^{1}H-NMR: 1.33 (s, 3 H, CH_3), 1.55 (s, 3 H, CH_3), 2.14 (s, 3 H, $COCH_3$), 4.19 (d, 1 H, H-3 a, J_{3a-6a} = 7.5 Hz), 4.46 (dd, 1 H, 4′, $J_{3-4'}$ = 8.7 Hz, $J_{3'-4'}$ = 3.3 Hz), 4.61 (d, 1 H, H-2′, $J_{1'-2'}$ = 3.6 Hz), 5.05 (d, 1 H, H-3), 5.10 (d, 1 H, H-6 a), 5.29 (d, 1 H, H-3′), 6.01 (d, 1 H, H-1′), 6.33 – 7.26 (m, 9 H, aromat. H). ^{13}C-NMR: 20.96 (q, $COCH_3$), 26.08 (q, CH_3), 26.69 (q, CH_3), 51.50 (d, C-3 a), 64.87 (d, C-3), 76.54 (d, C-6 a), 77.66 (d, C-3′), 78.08 (d, C-2′), 83.61 (d, C-4′), 104.98 (d, C-1′), 112.48 (s, C*Me*$_2$), 114.02, 116.00, 123.11, 125.29, 127.84, 129.58, 134.23, 160.73 (aromat. C), 169.42 (s, C=O), 172.48 (s, C=O), 174.17 (s, C=O).

2-Phenyl-3-(1,2-O-isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-5-(4-bromophenyl)-4,6-dioxo-2,3,3 a,4,6,6 a-hexahydropyrrolo[3,4-d]-isoxazole (**10 h**)

^{1}H-NMR: 1.33 (s, 3 H, CH_3), 1.55 (s, 3 H, CH_3), 2.14 (s, 3 H, $COCH_3$), 4.18 (d, 1 H, H-3 a, J_{3a-6a} = 7.5 Hz), 4.46 (dd, 1 H, H-4′, $J_{3-4'}$ = 8.7 Hz, $J_{3'-4'}$ = 3.3 Hz), 4.61 (d, 1 H, H-2′, $J_{1'-2'}$ = 3.6 Hz), 5.04 (d, 1 H, H-3), 5.10 (d, 1 H, H-6 a), 5.29 (d, 1 H, H-3′), 6.01 (d, 1 H, H-1′), 6.25 – 7.40 (m, 9 H, aromat. H). ^{13}C-NMR: 20.95 (q, $COCH_3$), 26.07 (q, CH_3), 26.68 (q, CH_3), 51.53 (d, C-3 a), 64.87 (d, C-3), 76.51 (d, C-6 a), 77.68 (d, C-3′), 78.05 (d, C-2′), 83.59 (d, C-4′), 104.97 (d, C-1′), 112.47 (s, C*Me*$_2$), 114.01, 122.98, 123.41, 127.82, 129.69, 132.10, 132.45, 148.47 (aromat. C), 169.42 (s, C=O), 172.24 (s, C=O), 173.93 (s, C=O).

5,5′-(Methylenedi-4,1-phenylene)bis-2-methyl-3-(1,2-O-isopropylidene-α-D-xylo-tetrofuranos-4-yl)-4,6-dioxo-2,3,3 a,4,6,6 a-hexahydropyrrolo[3,4-d]-isoxazole (**13**)

Yield: 76%, m. p. 160 – 162°C. $C_{39}H_{44}N_4O_4$ (792.7) calc.: C 59.08, H 5.59, N 7.06; found: C 58.89, H 5.35, N 6.76. $[\alpha]_D$ −284° (*c* 1.3, chloroform). ^{1}H-NMR: 1.32 (s, 3 H, CH_3), 1.51 (s, 3 H, CH_3), 2.91 (s, 3 H, N-CH_3), 3.40 (m, 1 H, H-3), 3.73 (dd, 1 H, H-3 a, J_{3a-6a} = 7.5 Hz), 4.04 (s, 2 H, CH_2), 4.24 (dd, 1 H, H-4′, $J_{3'-4'}$ = 5.1 Hz), 4.39 (d, 1 H, H-3′), 4.55 (d, 1 H, H-2′, $J_{1'-2'}$ = 3.6 Hz), 4.95 (d, 1 H, H-6 a), 5.97 (d, 1 H, H-1′), 7.19 (m, 8 H, aromat. H). ^{13}C-NMR: 26.17 (q, CH_3), 26.82 (q, CH_3), 41.11 (t, CH_2), 53.59 (d, C-3 a), 69.70 (d, C-3), 75.17 (d, C-6 a), 76.01 (d, C-3′), 77.47 (d, C-4′), 84.48 (d, C-2′), 105.55 (d, C-1′), 111.92 (s, C*Me*$_2$), 126.12, 126.24, 129.75, 129. 93, 134.22, 141.63 (aromat. C), 176.02 (s, C=O), 176. 56 (s, C=O).

5,5'-(Methylenedi-4,1-phenylene)bis-2-methyl-3-(1,2-O-isopropylidene-3-acetoxy-α-D-xylo-tetrofuranos-4-yl)-4,6-dioxo-2,3,3a,4,6,6a-hexahydropyrrolo[3,4-d]-isoxazole (**14**)

Yield: 70%, m.p. 165°C. $C_{43}H_{48}N_4O_{16}$ (876.8) calc.: C 58.89, H 5.51, N 6.39; found: C 58.46, H 5.80, N 6.74. $[\alpha]_D$ +28 (*c* 0.7, chloroform). ^{1}H-NMR: 1.31 (s, 3H, CH_3), 1.53 (s, 3H, CH_3), 2.19 (s, 3H, $COCH_3$), 2.85 (s, 3H, N-CH_3), 3.29 (d, 1H, H-3a, J_{3a-6a} = 7.8 Hz), 3.58 (d, 1H, H-3, $J_{3-4'}$ = 8.7 Hz), 3.90 (s, 2H, CH_2), 4.37–4.41 (m, 2H, H-2', H-4'), 4.71 (d, 1H, H-6a), 5.31 (d, 1H, H-3', $J_{3'-4'}$ = 3.0 Hz), 5.85 (d, 1H, H-1, $J_{1'-2'}$ = 3.6 Hz), 7.07–7.16 (m, 8H, aromat. H). ^{13}C-NMR: 21.14 (q, $COCH_3$), 21.27 (q, N-CH_3), 26.58 (q, CH_3), 27.13 (q, CH_3), 41.44 (t, CH_2), 52.34 (d, C-3a), 68.49 (d, C-3), 76.67 (d, C-6a), 76.99 (d, C-3'), 77.62 (d, C-2'), 83.18 (d, C-4'), 105. 70 (d, C-1'), 112. 80 (s, CMe_2), 126. 50, 128.69, 130.12, 134.53, 140.46, 140.69, 141.54, 141.77 (aromat. C), 169.89 (s, C=O), 174.42 (s, C=O), 175.57 (s, C=O).

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Received November 4, 1991. Accepted January 18, 1992