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Stereochemical study of 1,3-*N*,*X*-heterocycles derived from α-aminoacids and formaldehyde. Structural evidence for the existence of the anomeric effect

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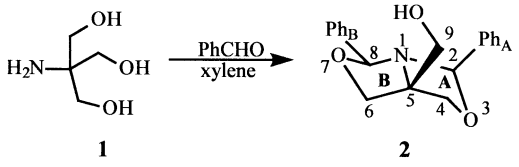
Abstract—We have shown that condensation of L-cysteine methyl ester (**8**) and L-threonine methyl ester (**11**) with formaldehyde provides a convenient and efficient access to novel heterocyclic 2:3 adducts. Depending on the amino acid, the condensation leads to either the *N*,*N*′-methylenebis(thiazolidine) (**10**, L-cys) or -(oxazolidine) (**13**, L-thr) derivative or to its bicyclo[4.4.1]undecane isomer (**5**, L-ser) as the major product of the reaction. The structure of **10**, **12** and **13**, was unambiguously confirmed by diffraction analysis and/or NMR spectroscopy. The latter proved to be a powerful tool to discriminate between the two possible isomers. X-Ray data emphasized the contribution of stereoelectronic effects to the structure of the above compounds. © 2002 Elsevier Science Ltd. All rights reserved.

1. Introduction

The anomeric effect (and its generalized manifestations) is well recognized as an important contributor to ground-state conformational analysis of heteroatoms-containing systems. However, although it has been extensively studied[1–9] (especially by NMR spectroscopy, X-ray diffraction analysis and theoretical calculation), most of the efforts were directed toward five- and six-membered rings derived from carbohydrates. So far, very little attention has been paid to non-carbohydrate heterocycles containing N–C–O, N–C–S or N–C–N sequences, especially when these are incorporated by two in systems larger than the common five- and six-membered rings. This paper aims to demonstrate that anomeric effect applies to this type of situation.

Oxazolidine or thiazolidine derivatives were selected as temporary protecting groups of tris(hydroxymethyl)-aminomethane (TRIS), L-serine (L-ser), L-threonine (L-thr) and L-cysteine (L-cys). When TRIS (**1**) was reacted with benzaldehyde, a 1:2 adduct was obtained which was assigned the structure *cis*-2,8-diphenyl-5-hydroxymethyl-1-aza-3,7-dioxabicyclo[3.3.0]octane (**2**) (Scheme 1), on the basis of nuclear magnetic resonance spectroscopy and X-ray crystallography.[10] The crystal structure of **2** showed that both oxazolidine rings A and B were puckered. The E_3 envelope form of ring A was prone to electron delocalization from the antiperiplanar lone-pair orbital on nitrogen to the σ^* antibonding orbital of the C-2–O-3 acceptor bond.



1 **2**

Scheme 1.

On the other hand, the condensation of L-serine methyl ester hydrochloride (**3**) with paraformaldehyde (**4**) in dichloromethane, in the presence of triethylamine, afforded two novel isomeric 2:3 adducts **5** and **6** (Scheme 2). The structure of the major isomer **5** was established by ^{1}H and ^{13}C NMR spectroscopy and further confirmed by X-ray diffraction analysis[11] to be [1*S*,2*S*,6*S*,7*S*]-1,6-diaza-4,9-dioxa-2,7-dimethoxycarbonylbicyclo[4.4.1]undecane.

The crystal structure of compound **5** revealed (i) the existence of two identical seven-membered rings, each containing a N–C–O and a N–C–N group, (ii) the antiperiplanar geometry of *n*N–C–O and (iii) the manifestation of a strong anomeric effect occurring in both N–C–O

Keywords: anomeric effect; 1,3-*N*,*X*-heterocycles; α-aminoacids; crystal structure.

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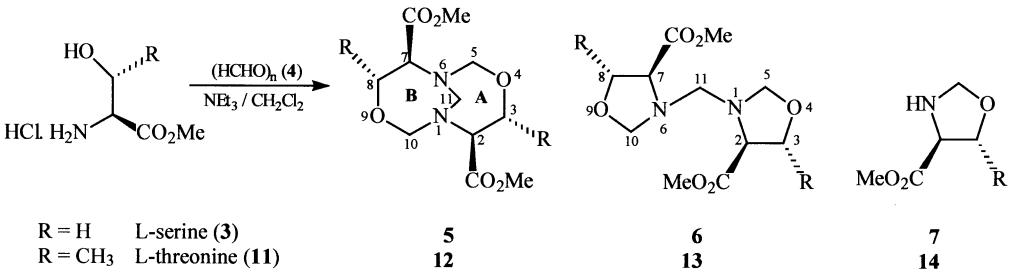


Scheme 2.

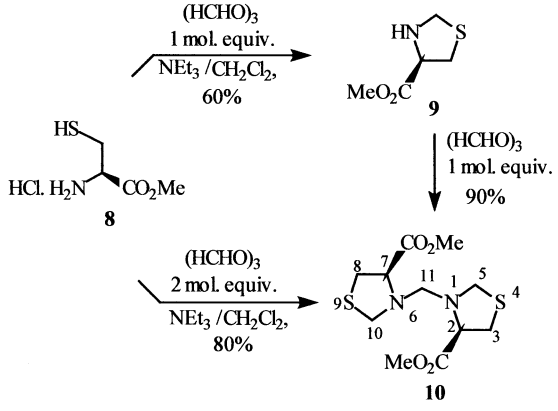
groupings, as corroborated by bond distances and bond angles.

2. Results and discussion

A priori, the seven-membered ring forming process mentioned above could agree with Baldwin's rules[12,13] which state that a 7-*endo-trig* cyclization is favored over a 5-*endo-trig* process when the nucleophile is a first-row element, which is the case of serine. However, since the normally disfavored 5-*endo-trig* process is facilitated when sulfur (a second-row element) is involved, we suspected that the reaction of L-cysteine methylester (**8**) with formaldehyde could afford the thio-analogs of compounds **6** and **7**. Indeed, the reaction produced either the methoxycarbonylthiazolidine **9** or the *N*,*N*′-methylene-bis(thiazolidine) derivative **10** depending on molecular ratio (see Scheme 3). Based on ^{13}C and ^{1}H NMR spectra, the identification of compound **9** (oil, *m*/*z* 147) was straightforward.

The 2:3 adduct which had never been reported before was expected to be compound **10**. This hypothesis was strongly supported by the fact that **10** (*m*/*z* 306) was obtained by the two convergent routes reported in Scheme 3 and also because of strong similarities (in terms of signal patterns, chemical shifts and coupling constants) between the proton and carbon-13 NMR spectra of **10** and **9**. X-Ray diffraction analysis definitely confirmed the structure of compound **10** (Fig. 1(a)).

The reaction of L-threonine methyl ester (**11**) with formaldehyde was also investigated. We surmised that **11** might behave similarly to serine methyl ester. In fact, whatever the molar ratio of reactants, the reaction led to a mixture of two isomeric 2:3 adducts which were separated on column chromatography. The minor (15–20%) compound (**12**) was obtained in crystalline state and assigned the structure [1*S*,2*S*,3*R*,6*S*,7*S*,8*R*]-1,6-diaza-4,9-dioxa-2,7-dimethoxycarbonyl-3,8-dimethylbicyclo[4.4.1]undecane on the basis



Scheme 3.

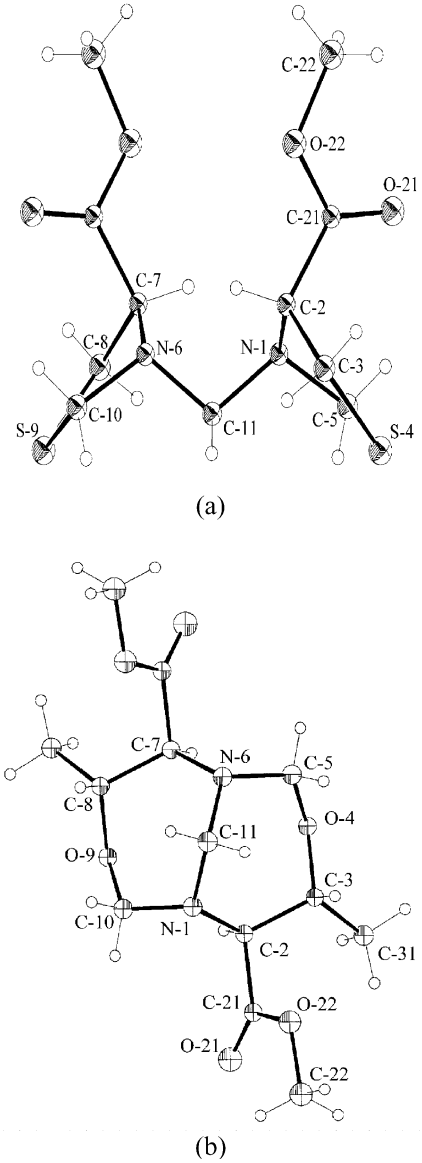


Figure 1. ORTEP view of compounds **10** (a) and **12** (b) with atoms numbering. The thermal ellipsoids are drawn at the 30% probability level.

of a single-crystal diffraction analysis (see Fig. 1(b)). The *N*,*N*′-methylenebis(oxazolidine) structure of the major component **13** (mp 32–33°C) was established by (i) proton and carbon-13 NMR spectroscopy, (ii) the facile isomerization of **12** to **13** and vice versa (see latter on). However, as for serine[11] the oxazolidine **14** was never detected in the reaction mixture.

2.1. Crystal structure of compounds 10 and 12. Stereoelectronic effects

All crystal data for both compounds are presented in Section 4.2 (see Section 4). It must be noted that the e.s.d.s for bond lengths are ≤0.003 Å and bond angles ≤0.2°.

2.1.1. Compound 10. X-Ray crystal structure and atoms labeling are shown in Fig. 1(a). The *R* configuration of the α-carbon of L-cysteine is preserved at C-2 (C-7), whereas N-1 (N-6) also displays the *R* configuration. In the solid state, **10** exhibits a rigorous (crystallographic) two-fold axis of symmetry. This axis lies in the plane N-1–C-11–N-6 passing through C-11 and bisecting the bond angle N-1–C-11–N-6.

The three-dimensional representation of **10** (Fig. 1(a)) clearly shows the E_N envelope conformation adopted by both five-membered rings. Nitrogen atoms were found 0.506 Å below the plane defined by the remaining four atoms. The dihedral angle between this plane and the envelope tip (36°35) indicates that both five-membered rings are puckered. This envelope conformation may be explained as a way to minimize inter- and intra-thiazolidine ring non-bonding interactions. Indeed, molecular modeling showed that the dihedral angle between the ester group and the pseudo axial bond at C-3 increases to approximately 150°. In addition, rotation occurring at the inter-thiazolidine (or oxazolidine) linkage plays an important role in relieving unfavorable interactions, including those involving nitrogen lone-pairs. On the basis of torsion angles, nitrogen lone pairs were shown to be roughly orthogonal.

Stereoelectronic effects. The most significant crystal data in relation with the possible contribution of the anomeric effect to the structure of compound **10** are the following:

(a) A significant contraction of C-5–N-1 bond is observed: 1.450 Å compared to 1.469 and 1.470 Å for, respectively (N-1–C-2) and (N-1–C-11). Although less pronounced (Δd 0.020 Å) than in serine/threonine derivatives **5** (Δd 0.033–0.039 Å) and **12** (see below), this contraction seems to indicate that anomeric effect occurs in the sequence N-1–C-5–S-4. This hypothesis is corroborated by the concomitant increase of the C-5–S-4 bond (1.843 Å) which is longer than the reference C-3–S-4 bond (1.808 Å). Such observations imply that, most likely, electron delocalization from *n*(N) to C-5–S-4 σ^* antibonding orbital occurs. However, the differences in bond shortening between compound **10** and compound **5** may reflect a less efficient overlapping in **10**. This could be due to the less electron-acceptor character of the C–S bond compared to its C–O analog and possibly to an imperfect antiperiplanar conformation between the nitrogen lone-pair and the C-5–S-4 acceptor bond. Indeed, the three-dimensional structure of **10** reveals a significant deviation from theoretical alignment. On the basis of difference in electronegativity between nitrogen (χ=3.0) and sulfur (χ=2.5) one could have envisage electron delocalization to occur from *n*(S-4) to the σ^* antibonding orbital of the C-5–N-1 bond. Crystallographic data definitely rules out such an eventuality.
(b) As already observed,[11,14,15] anomeric effect seems to be absent in the N-1–C-11–N-6 aminal motif. The C–N bond distance is identical to standard Csp^3–Nsp^3 bond length, i.e. 1.469 Å.

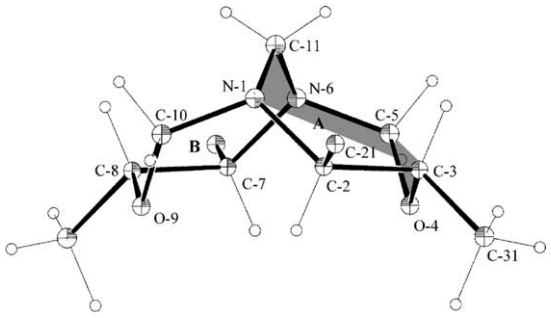


Figure 2. Perspective view of the X-ray crystal structure of **12**.

2.1.2. Compound 12. Bond distances and bond angles are listed in Section 4.2. The structure and atom labeling are shown in Figs. 1(b) and 2.

Configuration of the α-(*S*) and β-(*R*) carbons of L-threonine is preserved at C-2 (C-7) and C-3 (C-8). In the solid state **12** exhibits also a rigorous (crystallographic) two-fold axis of symmetry. Conformation of the seven-membered ring A for instance is chair-like. Indeed, atom O-4 is 0.676 Å away from the P1 plane which is defined by atoms N-1, C-3, C-5, N-6 while atom C-11 is 0.679 Å away from the same plane. The dihedral angle between P1 and P2 (defined by atoms C-3, O-4, C-5) is equal to 60°5 while P1 forms a 66°5 dihedral angles with P3 being defined by atoms N-1, C-11, N-6. Data above show that the sequence N-1–C-3–O-4–C-5–N-6–C-11 describes an almost perfect $^{11}C_4$ chair conformation (see Fig. 2). This conformation accounts for the specific features of the ^{1}H NMR spectrum that will be discussed later on.

Stereoelectronic effects. The contribution of stereoelectronic effects to the three-dimensional structure of **12** can be inferred from the following crystal features:

(a) The N-1–C-10 bond (1.428 Å) is unquestionably shorter than either N-1–C-2 or N-1–C-11, respectively, 1.474 and 1.465 Å.
(b) The significant contraction of N-1–C-10 (N-6–C-5) bond (Δd 0.039–0.046 Å, i.e. 14×e.s.d. on the average) reveals delocalization of the unshared pair of electrons on nitrogen atom to the C–O σ^* antibonding orbital in both N–C–O groupings. The antiperiplanar geometry of the *n*N–C–O sequence favors overlapping of *n*(N) and σ^* orbitals. Torsion angles involving bridgehead nitrogen atoms (66°5 and 72°9) show that the C-5–O-4 bond bisects fairly well the C-11–N-6–C-7 bond angle, as

does O-9–C-10 with respect to the C-11–N-1–C-2 bond angle.

(c) Bridgehead nitrogen atoms have gained some sp^2 character as illustrated by the significant widening of N-1 bond angles. Of special interest is the sum of these: 345°7 compared with sp^3 standard value 328°5. This value should be compared to the one measured in compound **10** (331°5) as well as those reported by Lemoine et al. for acyclic *N*,*N*′-methylenebis[(*S*)-5-phenyloxazolidine] (325°5 and 324°4)[16] and by Engel et al. for *N*,*N*′-methylenebis[4-methyl-5-phenyloxazolidine] (324° and 328°6).[17]

(d) None of the above data can reasonably support the hypothesis of a stereoelectronic effect occurring in the N–C–N aminal group as already observed.[11,14,15]

2.2. Structure in solution

2.2.1. NMR study. Rough NMR data were unable to discriminate between the two possible structures for the 2:3 adducts. A priori, data could fit both isomers. However, in compound **5** for instance, careful analysis of ^1H signals and spectra simulations revealed the existence of two long-range coupling constants between H-5e (H-10e) and H-11_B (H-11_A) as well as between H-5e (H-10e) and H-3e (H-8e), respectively (see Table 1), supporting the existence of a rigid W-conformation for the appropriate bond sequences. These observations were in accordance with the chair-like conformation observed in its solid state for both seven-membered rings A and B. They also attested that chair conformation was maintained in solution.

NMR spectra of compound **10** were compared with those of compound **5** (see Table 1). The salient features that emerged from the comparison were the following: (i) the signal for the methylene protons at C-11 (δ 3.28) was considerably different from the equivalent signal in compound **5** (δ 4.56), (ii) neither long-range coupling between H-5e (H-3e) and H-11_B (H-11_A) nor those between H-8e (H-10e) and H-5e (H-3e) was detected in **10**, (iii) however, long-range coupling was observed between H-5e and H-2 (0.5 Hz), (iv) in the ^{13}C NMR spectra, the most significant difference arose from the chemical shift of carbon-11 which was much more deshielded in compound **10** (δ 73.09) than in compound **5** (δ 68.08).

The above observations allow to foresee successful identification of both classes of compounds on the basis of NMR spectroscopy alone. This eventuality was unambiguously confirmed by the careful examination of NMR spectra of **12** and **13** (Table 1) which underlined the following peculiarities:

1. Significant chemical shift differences were observed for C-11 ($\Delta\delta$ 8.5), CH_2-11 ($\Delta\delta$ 0.82) and methyl groups at C-3 and C-8 ($\Delta\delta$ 0.22).
2. Long-range coupling ($J_{5e,11B}=J_{10e,11A}=2.0$ Hz) was observed in compound **12** whereas it was absent in **13**. Interestingly, the E_N envelope conformation (see Fig. 1(a) and discussion below) of the five-membered rings appears to be preserved in solution in both *N*,*N*′-methylenebis derivatives **10** and **13**, as attested by the coupling between protons 5eq and 2eq (*J*, 0.5 Hz). Indeed, crystal data and molecular models reveal that such E_N conformation is prone to long-range coupling as a consequence of the appropriate sequence displaying a clear W-rigid arrangement.
3. Finally, noticeable differences were observed in ^3J coupling constants: $J_{2,3}=9.8$ Hz in **12** versus 6.6 Hz in **13**.

Table 1. ^1H and ^{13}C NMR data for compound **5**, **10**, **12** and **13** in $CDCl_3$ (δ ppm, *J* Hz)

Compounds	**5**	**10**	**12**	**13**
Protons[a]		δ		
H-2 (H-7)	4.00	4.40	3.59	3.51
H-5_{eq} (H-10_{eq})	4.43	4.28	4.44	4.58
H-5_{ax} (H-10_{ax})	4.26	4.24	4.19	4.46
H-3_{eq} (H-8_{eq})	4.24	3.29	–	–
H-3_{ax} (H-8_{ax})	3.92	3.14	4.06	3.99
H-11_A, H-11_B[b]	4.56	3.28	4.54	3.72
CH_3	–	–	1.23	1.48
OCH_3	3.74	3.74	3.73	3.75
J (Hz)				
$2,3_{eq}=7,8_{eq}$	3.0	3.5	9.8	6.6
$2,3_{ax}=7,8_{ax}$	9.8	7.6	–	–
$3,CH_3$	–	–	6.2	6.2
5_{ax}, $5_{eq}=10_{eq}$, 10_{ax}	−11.4	−9.9	−11.8	6.2
5_{eq}, $11_{B=}10_{eq}$, 11_A	1.6	0	2.0[b]	0
5_{eq}, $2=10_{eq}$, 7	0	0.5	0	0.5
5_{eq}, $3_{eq}=10_{eq}$, 8_{eq}	0.6	0	0	0
Carbons[a]				
C=O	172.0	171.45	171.06	172.47
C-5, C-10	87.44	57.32	87.94	85.38
C-3, C-8	70.03	32.60	76.45	76.83
C-2, C-7	64.58	67.01	70.20	69.26
C-11	68.08	73.09	68.17	76.61
OCH_3	52.28	52.35	52.51	52.07
CH_3	–	–	20.42	20.09

$CDCl_3$ solution (solvent at 7.280 ppm vs TMS).

[a] See Schemes 2 and 3 and Fig. 1 for atoms numbering.

[b] H-11_A and H-11_B represent proton-11 directed above ring A and ring B, respectively (compounds **5** and **12**).

2.2.2. Equilibration in solution. The confirmation of structural relationship between **5** and **6** on one hand, **12** and **13** on the other, was obtained through isomerization experiments. Interconversion of **5** to **6** and vice versa in $CDCl_3$ was investigated. At 40°C, ^1H NMR monitoring indicated that the equilibrium was reached within 24 h. Isomerization of **5** was accompanied by the decrease of the signal ascribed to the methylene protons of the aminal bridge (δ 4.56) and by the concomitant increase of the equivalent signal (δ 3.81) in the *N*,*N*′-methylenebis(oxazolidine) derivative **6**. This change parallels the decrease of the OCH_3 signal at δ 3.74 and the increase of the equivalent signal in **6** at δ 3.62. Relative concentrations of **5** and **6** after equilibration were 80:20.

A similar study was performed on $CDCl_3$ solutions of pure compounds **12** and **13**. Interconversion of **12** to **13** and vice versa in $CDCl_3$ was investigated. ^1H NMR monitoring indicated that equilibrium was reached within 5 h at room temperature. The equilibrium mixture was quantitated

using the relative intensity of the following signals: (i) that of the methylene protons of the aminal bridge, (ii) that of the methyl groups at C-3 (C-8), (iii) that of OCH_3. At equilibrium, the molar ratio **12/13** (5:95) was drastically different from that observed with serine. In contrast, under the same conditions, compound **10** remained stable over a long period of time (several weeks). This is in accordance with the higher stability of the 1,3-thiazolidine ring.[18] In conclusion, the above data allow to establish the usefulness of ^{13}C and ^{1}H NMR spectroscopy to identify isomeric heterocyclic 2:3 adducts resulting from the condensation of L-serine, L-threonine and L-cysteine methylester with formaldehyde.

Surprisingly, the condensation of L-threonine methyl ester with formaldehyde produces predominantly the *N*,*N*′-methylenebis(oxazolidine) derivative **13**, a finding that contrasts sharply with the observations concerning serine. Due to the fact that compound **13** was the thermodynamically stable isomer, this unexpected result might be explained in the following ways:

1. In compound **12**, the presence of a methyl at C-3 generates additional non-bonding interactions that are absent in **13**. In this connection, the following points should be made: (i) CH_3 belongs to the chair materialized by the N-1–C-3–O-4–C-5–N-6–C-11 sequence (see Fig. 2), (ii) consequently, it experiences two gauche interactions with, respectively, the N-1 pseudo-equatorial lone pair and the C-2–N-1 bond, (iii) in addition, it displays a further unfavorable gauche interaction with the ester group at C-2 (dihedral angle C-21–C-2–C-3–C-31=43°).
2. The above interactions are either removed or drastically reduced, in compound **13**. Indeed, puckering of the five-membered oxazolidine rings increases the dihedral angle between the methyl and the ester groups to approximately 150° and concomitantly relieves the gauche interaction. The sum of the above non-bonding interactions may reasonably account for the energy difference observed between compounds **12** and **13** and very likely for the specific behavior of L-threonine regarding its condensation with formaldehyde.

3. Summary and conclusion

Elucidation of the structure of compounds **5**, **10**, **12**, **13** by NMR spectroscopy and/or X-ray crystallography unambiguously established the following points: (i) $n(N) \rightarrow \sigma^*$ (C–N) delocalization is absent in the N–C–N aminal group whereas strong anomeric effect is present in both N–C–O groups as corroborated by bond distances and bond angles, (ii) electron delocalization from n(N) to C–S σ^* antibonding orbital occurs also in the sequence N–C–S although to a lesser extent than in its N–C–O counterpart. (iii) conformation of both oxazolidine and thiazolidine five-membered rings of *N*,*N*′-methylenebis derivatives **10** and **13**, and seven-membered ring of bicyclo[4.4.1]undecane derivatives **5** and **12** are preserved in solution as confirmed by NMR data. In that respect, it should be noted that the ^{13}C and ^{1}H NMR chemical shifts of the N–CH_2–N aminal bridge as well as long-range coupling have proved to be very specific probes to discriminate between the two possible isomeric structures.

4. Experimental

4.1. General procedure

To a suspension of L-aminoacid methylester hydrochloride (6.5 mmol) in anhyd. dichloromethane (50 mL) were added triethylamine (7.8 mmol) and paraformaldehyde (6.5 or 13) mmol). After stirring at room temperature for 1–3 days (t.l.c. monitoring), the solvent was evaporated to dryness and the residue, dissolved in diethylether (100 mL), was filtered on sintered glass. The filtrate was dried over anhyd. Na_2SO_4 and evaporated to dryness. The residue was either recrystallized or purified on silica gel column chromatography to afford a solid or an oily material.

4.1.1. [1*S*,2*S*,6*S*,7*S*]-1,6-Diaza-4,9-dioxa-2,7-dimethoxycarbonylbicyclo[4.4.1]undecane (5). 90%; mp 91–92°C; $[\alpha]_D^{20}=+54.5$ (*c* 1.0, $CHCl_3$); FAB^+ MS (NBA) *m*/*z* 275 $[M+H]^+$, 144; ^{1}H and ^{13}C NMR data see Table 1. Anal. calcd for $C_{11}H_{18}O_6N_2$ (274): C, 48.17; H, 6.56; N, 10.22; O, 35.03 Found: C, 48.10; H, 6.64; N, 10.27; O, 35.61.

4.1.2. 2(*R*)-2-Methoxycarbonylthiazolidine (9). 60%; FAB^+ MS (NBA) *m*/*z* 148 $[M+H]^+$, 160 $[M+Na]^+$; ^{1}H NMR (200.13 MHz, $CDCl_3$, *J* (Hz)): 2.50 (br. s, 1H, NH), 2.90 and 3.27 (*AB*X, 2H, 2H-3, *J*=7.7 Hz), 3.80 (s, 3H, CH_3O), 3.88 (AB*X*, 1H, H-2, *J*=7.5 Hz), 4.14 and 4.40 (AB, 2H, 2H-5, *J*=9.6 Hz); ^{13}C NMR (100.60 MHz, $CDCl_3$, *J* (Hz)): 37.37 (C-3), 52.94 (CH_3O), 54.82 (C-5), 65.60 (C-2), 172.21 (C=O).

4.1.3. *N*,*N*′-Methylenebis[(2*R*)-2-methoxycarbonylthiazolidine] 10. 80%; mp 36–37°C; $[\alpha]_D^{20}=-175.8$ (*c* 1.0, $CHCl_3$); FAB^+ MS (NBA) *m*/*z* 305 $[M-H]^+$, 160; ^{1}H and ^{13}C NMR data see Table 1. Anal. calcd for $C_{11}H_{18}O_4N_2S_2$ (306): C, 43.13; H, 5.88; N, 9.15; O, 20.91; S, 20.91. Found: C, 43.02; H, 5.92; N, 9.24; O, 21.21; S, 21.58.

4.1.4. [1*S*,2*S*,3*R*,6*S*,7*S*,8*R*]-1,6-Diaza-4,9-dioxa-2,7-dimethoxycarbonyl-3,8-dimethylbicyclo[4.4.1]undecane (12). 66%; mp 104–106°C; $[\alpha]_D^{20}=-28.1$ (*c* 1.0, $CHCl_3$); FAB^+ MS (NBA) *m*/*z* 303 $[M+H]^+$, 158; ^{1}H and ^{13}C NMR data see Table 1. Anal. calcd for $C_{13}H_{22}O_6N_2$ (302): C, 51.65; H, 7.28; N, 9.27; O, 31.78. Found: C, 51.60; H, 7.39; N, 9.34; O, 31.76.

4.1.5. *N*,*N*′-Methylenebis[(2*S*,3*R*)-2-methoxycarbonyl-3-methyloxazolidine] (13). 10%; mp 31–32°C; $[\alpha]_D^{20}=-72.5$ (*c* 1.0, $CHCl_3$); FAB^+ MS (NBA) *m*/*z* 303 $[M+H]^+$, 158; ^{1}H and ^{13}C NMR data see Table 1. Anal. calcd for $C_{13}H_{22}O_6N_2$ (302): C, 51.65; H, 7.28; N, 9.27; O, 31.78. Found: C, 51.63; H, 7.25; N, 9.14; O, 31.94.

4.2. Supplementary material

Full crystallographic data (tables of crystallographic details, non-hydrogen coordinates, bond distances and bond angles, anisotropic thermal parameters, hydrogen coordinates and isotropic thermal parameters) have been deposited with the

Cambridge Crystallographic Data Centre (CCDC no. 158098 and 158097 for compounds **10** and **12**, respectively). This material is available on request from The Director, CCDC, 12 Union Road, Cambridge CB21EZ, UK (tel.: +44-1223-336408; fax: +44-1223-336033; e-mail: deposit@ccdc.cam.ac.uk or http://www/ccdc.cam.ac.uk).

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