13. Hetero-*Diels-Alder* Additions of α,β-Unsaturated-Acyl Cyanides

Part 3[1])

Syntheses of 3-Bromo-2-ethoxy-3,4-dihydro-2*H*-pyran-6-carbonitriles, and about Their Transformation to 2-Ethoxy-2*H*-pyrans

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Cycloadditions of the α,β-unsaturated-acyl cyanides **1**–**3** with (*Z*)-or (*E*)-1-bromo-2-ethoxyethene (**4**) may be performed at moderate temperatures and provide in good yields the 3-bromo-2-ethoxy-3,4-dihydro-2*H*-pyran-6-carbonitriles **5**–**7**, respectively (*Scheme 1*). Diastereoisomeric pairs of products result at room temperature merely from the '*endo*'- and '*exo*'-transition states; more complex mixtures appear above 60° as a consequence of (*Z*)/(*E*)-isomerization of **4**. The relative stability of the anomers of **5** and **6** is explored by treatment with $BF_3 \cdot Et_2O$. Acid alcoholysis (MeOH or EtOH) of **5** leads to acetals **9a**, **b** of 4-bromo-5-oxopentanoate. Alkyl (2*Z*,4*E*)-5-ethoxypenta-2,4-dienoates **12**, **17**, and **20**, are formed in alcoholic alkoxide solutions from **5**, **6**, and **7**, respectively, which is compatible with the intermediacy of 2-alkoxy-2*H*-pyrans and their valence tautomers, α,β-unsaturated-acyl cyanides. Methoxide addition to the CN group competes with dehydrobromination in case of **5**; it leads to 3-bromo-3,4-dihydro-2*H*-pyran-6-carboximidate **13** (*ca.* 50% at −20°) which can be hydrolyzed to the methyl carboxylate **14**. DBU (1,8-diazabicyclo[5,4,0]undec-7-ene) in benzene converts **5** to 6-ethoxy-2-oxohexa-3,5-dienenitrile (**11**), the ring-opening product of an obviously unstable 2-ethoxy-2*H*-pyran; the same reagent dehydrobrominates **6** to 2-ethoxy-4-methyl-2*H*-pyran-6-carbonitrile (**15**). HBr Elimination from **7** takes place with great ease in presence of pyridine, or even during chromatography on alumina, and leads to the stable ethyl 6-cyano-2-ethoxy-2*H*-pyran-4-carboxylate (**18**); this dimerizes at room temperature to give a 1:3 mixture of tricyclic adducts '*endo*'-**21** and '*exo*'-**21**. The structure of the latter is established by an X-ray crystallographic analysis.

1. Introduction. – α,β-Unsaturated carbonyl compounds, *i.e.* 1-oxabutadienes, have been used as dienic components in hetero-*Diels-Alder* additions of inversed electron demand to build 3,4-dihydro-2*H*-pyrans [1]. Their reaction with enol ethers as dienophiles lends itself for the synthesis of carbohydrate derivatives [2]. However, to avoid the required excessive heating [1], facilitating conditions have been seeked such as elevated pressure [3] or catalysis with *Lewis* acids [4].

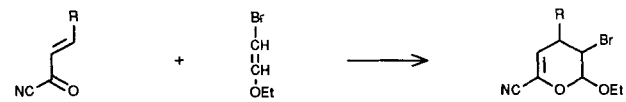
Otherwise, 1-oxabutadienes with electron-attracting substituents on C(3) [5] or on C(2) [6] react with greater ease. We found this to be the case of a CN group on the carbonyl C-atom in α,β-unsaturated-acyl cyanides which react even at room temperature and highly stereospecifically with ethyl vinyl ether [7] or with *N*-methylated uracils [8]. Similar enhanced reactivity was reported recently for 2-cyano-1-azadienes [9]. We present in the following cycloadditions of α,β-unsaturated-acyl cyanides with 1-bromo-2-ethoxy-

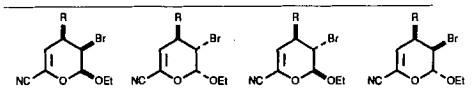
[1]) Part 1: [7], part 2: [8].

ethenes as dienophiles providing 3-bromo-2-ethoxy-3,4-dihydro-2*H*-pyran-6-carbonitriles as potential precursors to 2*H*-pyrans.

2. Results and Discussion. – *The Cycloadditions.* The dienic components, acryloyl cyanides **1**–**3** (see *Scheme 1*), are prepared from the corresponding acyl chlorides by reaction with CuCN and NaI, as mentioned in [7]. The dienophile 1-bromo-2-ethoxyethene (**4**) is obtained as a (*Z*)/(*E*)-mixture (*ca.* 87:13) on HBr elimination from 1,2-dibromo-1-ethoxyethane [10] under thermodynamic control [11], and the pure stereoisomers are isolated by fractional distillation. The dienes are mixed with the

Scheme 1. *Formation of Diastereoisomeric Cycloadducts and Their Anomerization*



Cycloadditions (conditions)	Products (yields [%])	Product distribution[a])				Anomerizations of products by BF_3/Et_2O	
							
		cc	*ct*	*tc*	*tt*		
1 + (*Z*)-**4** (r.t., 48 h)	**5** (50)	100% *c*[b])		–			
1 + (*Z*)-**4** (80°, 19 h)	**5** (85)	93% *c*[b])		7% *t*[b])		*c*-**5** ⇄	*t*-**5**
1 + (*E*)-**4** (r.t., 16 h)	**5** (82)	–		100% *t*[b])		35%	65%
2 + (*Z*)-**4** (60°, 17 h)	**6** (48)	74.8%	3.9%	13.5%	7.8%		
2 + (*Z*)-**4** (60°, 72 h)	**6** (85)	71.0%	6.0%	15.0%	8.0%	*cc*-**6** ⇄	*tt*-**6**
2 + (*Z*)-**4** (80°, 7 h)	**6** (62)	78.0%[c])	6.0%[c])	10.0%[c])	6.0%[c])	6%	94%
2 + (*Z*)-**4** (80°, 10 h)	**6** (80)	74.3%[c])	5.7%[c])	12.5%[c])	7.5%[c])		
2 + (*E*)-**4** (r.t., 240 h)	**6** (98)	–	–	68.0%	32.0%	*ct*-**6** ⇄	*tc*-**6**
3 + (*Z*)-**4** (r.t., 120 h)	**7** (88)	95.0%	5.0%	–	–	57%	43%
3 + (*E*)-**4** (r.t., 15 h)	**7** (97)	–	–	63.0%	37.0%		

[a]) See *Footnote 2.* [b]) For R = H: *c* = *cc* = *ct* and *t* = *tc* = *tt.* [c]) In ^{13}C-NMR tubes.

dienophiles in MeCN as solvent or neat, at room or moderate temperatures (60–80°), and the products **5**–**7** are purified by distillation or flash chromatography; they are characterized by ^{1}H- (*Table 1*) and ^{13}C-NMR, TLC, and GC. Diastereoisomers can be discriminated in mixtures by ^{1}H-NMR, and assignments are confirmed by mutual decoupling and NOE experiments.

At room temperature, the times necessary to obtain optimal yields of the cycloadducts may be rather long, particularly in reactions with (*Z*)-**4** (*Scheme 1*); diene **2** does not react notably in this case. Cycloadditions with (*E*)-**4** take place more readily as generally observed [1]: in a competition experiment, (*E*)-**4** reacts nearly 6 times faster with **1** than does (*Z*)-**4**. At room temperature, each of the reactions of **1** with (*Z*)-**4** or (*E*)-**4** gives rise to one product, *c*-**5**[2]) or *t*-**5**, respectively. Yet, **2** and **3** afford mixtures as expected to be formed *via* the *endo*- and the *exo*-transition states, respectively: **2** and (*E*)-**4** give *tc*/*tt*-**6** 68:32, **3** and (*Z*)-**4** give *cc*/*ct*-**7** 95:5[2]), **3** and (*E*)-**4** give *tc*/*tt*-**7** 63:37.

[2]) The sequence-rule-preferred (*CIP*) substituent at the lowest-numbered substituted ring atom (C(2)) is the reference for relative configurations (*c* or *t*) in the dihydro-2*H*-pyran ring.

Table 1. *^{1}H-NMR Chemical Shifts* δ [ppm] *and Coupling Constants* J [Hz] *of 3-Bromo-2-ethoxy-2*H*-pyrans in* $CDCl_3$

	c-**5**	*t*-**5**	*cc*-**6**	*ct*-**6**	*tc*-**6**	*tt*-**6**	*cc*-**7**	*ct*-**7**	*tc*-**7**	*tt*-**7**
H_α–C(2)	–	–	5.06	–	5.10	–	4.96	–	5.18	–
H_β–C(2)	5.15	5.15	–	5.16	–	5.24	–	5.18	–	5.25
H_α–C(3)	–	4.10	4.26	–	–	4.08	4.01	–	–	4.42
H_β–C(3)	4.10	–	–	3.73	3.83	–	–	4.38	4.69	–
H_α–C(4)	2.77	3.02	2.84	2.81	2.77	2.97	4.57	3.74	3.41	3.97
H_β–C(4)	2.62	2.49	–	–	–	–	–	–	–	–
H–C(5)	5.71	5.71	5.56	5.64	5.62	5.46	5.85	5.71	5.90	6.00
MeCH_2O–C(2)	1.28	1.22	1.29	1.28	1.26	1.23	1.31	1.28	1.28	1.23
MeC*H_2*O–C(2)	3.92	3.89	3.97	3.91	3.93	3.91	4.06	3.93	3.81	3.91
	3.74	3.68	3.68	3.72	3.67	3.68	3.74	3.73	3.61	3.71
Me–C(4)	–	–	1.28	1.24	1.28	1.20	–	–	–	–
MeCH_2OOC	–	–	–	–	–	–	1.32	1.32	1.16	1.31
MeC*H_2*OOC	–	–	–	–	–	–	4.31	4.26	4.21	4.30
	–	–	–	–	–	–	4.23	–	4.16	4.22
$^2J(4\alpha,4\beta)$	18.1	19.7	–	–	–	–	–	–	–	–
$^3J(2\alpha,3\alpha)$	–	–	1.8	–	–	–	1.0	–	–	–
$^3J(2\alpha,3\beta)$	–	–	–	–	5.2	–	–	–	2.5	–
$^3J(2\beta,3\alpha)$	–	2.5	–	–	–	2.0	–	–	–	1.8
$^3J(2\beta,3\beta)$	2.2	–	–	2.2	–	–	–	2.2	–	–
$^3J(3\alpha,4\alpha)$	–	2.3	5.7	–	–	4.4	4.8	–	–	4.4
$^3J(3\alpha,4\beta)$	–	5.5	–	–	–	–	–	–	–	–
$^3J(3\beta,4\alpha)$	11.0	–	–	11.0	5.4	–	–	9.7	1.9	–
$^3J(3\beta,4\beta)$	6.4	–	–	–	–	–	–	–	–	–
$^3J(4\alpha,5)$	2.9	2.5	3.6	2.5	3.9	2.0	2.5	3.2	5.2	2.2
$^3J(4\beta,5)$	5.3	5.3	–	–	–	–	–	–	–	–
$^4J(2\alpha,4\alpha)$	–	–	0.8	–	0.5	–	1.0	–	–	–
$^4J(2\beta,4\beta)$	0.6	0.8	–	–	–	–	–	–	–	–
$^4J(3\alpha,5)$	–	–	0.6	–	–	2.0	1.9	–	–	2.2
$^4J(3\beta,5)$	–	1.5	–	–	0.3	–	–	–	1.5	–
$^3J(4\alpha,$Me–C(4))	–	–	7.1	7.0	7.1	7.1	–	–	–	–
$^2J_{AB}$ of MeC*H_2*O–C(2)	9.9	9.3	9.8	10.0	9.6	9.8	9.7	9.8	9.8	9.9
$^3J($*Me*CH_2O–C(2))	7.1	7.1	7.1	7.0	7.1	7.1	7.0	7.1	7.1	7.1
$^3J($*Me*C*H_2*OOC)	–	–	–	–	–	–	7.1	7.1	7.1	7.1
$^2J_{AB}$ of MeC*H_2*OOC	–	–	–	–	–	–	11.0	–	11.0	11.0

Unexpected diastereoisomers show up under the influence of heat above 60°. The reaction of **1** with (*Z*)-**4** at 80° leads to a mixture *c*/*t*-**5** 93:7, and the product mixture resulting from **2** and (*Z*)-**4** consists of four components, *cc*-**6** (71–78%), *ct*-**6** (4–6%), *tc*-**6** (12–15%), and *tt*-**6** (7–8%). This complication is explained by isomerization of the dienophile: a sample of (*Z*)-**4**, heated to 60° in a tube of common glass becomes slowly a (*Z*)/(*E*)-mixture (83:17). The linear advancement of this process (*e.g.* 2%/h; ^{1}H-NMR or GC monitoring) suggests heterogeneous catalysis on the glass surface. Thus *t*-**5** found in the reactions of **1** with (*Z*)-**4** stems from the presence of (*E*)-**4**, formed by isomerization, and the four reaction products obtained from **2** are composed of two '*endo-exo*' pairs, *cc*/*tt*-**6** (*ca.* 95:5) formed with (*Z*)-**4**, and *ct*/*tc*-**6** (*ca.* 65:35) formed with (*E*)-**4**; the ratio of the two pairs (*cc*-**6** + *tt*-**6**)/(*ct*-**6** + *tc*-**6**), *ca.* 80:20, depends on the formation of readily reacting (*E*)-**4**. Anomerization of the adducts **5** and **6** under the same conditions takes

place slower than that of the dienophile, hence, it does not account for the unusual high proportion of *tc*-**6** found in the cycloaddition of **2** with (*Z*)-**4**.

Conformational Equilibria. The 2-alkoxy-3,4-dihydro-2*H*-pyrans should adopt preponderantly a half-chair conformation with the anomeric alkoxy group in the stereoelectronically favored axial orientation [12]. This conformation, represented in *Fig. 1* as ${}_2H^3$, is confirmed in the ^{1}H-NMR spectra of *c*-**5**, *ct*-**6**, and *ct*-**7** by large coupling constants ($^3J = 11$ Hz) of the vicinal anti-periplanar H_β–C(3) and H_α–C(4); weak W-couplings ($^4J = 0.8$ Hz) between H_α–C(2) and H_α–C(4) also agree with this conclusion. In case of *t*-**5**, *tt*-**6**, and *tt*-**7**, the absence of large ^3J couplings in the spectra corroborates the same conformation; in addition, long-range couplings (^4J *ca.* 2 Hz) between H_α–C(3) and H–C(5) can be explained reasonably by the proposed conformation (couplings obviously absent in the spectra of *c*-**5**, *ct*-**6**, and *ct*-**7**). It is remarkable that in this preferred conformation of *t*-**5**, *tt*-**6**, and *tt*-**7** both, the EtO group and Br-atom, assume axial orientations[3]).

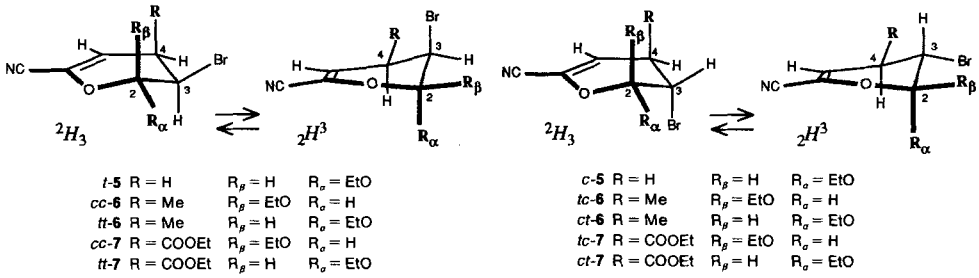


Fig. 1. *Half-chair conformations of 3-bromo-2-ethoxy-3,4-dihydro-2*H*-pyran-6-carbonitriles*

The spectra of the *cc*- and *tc*-isomers of **6** and **7** do not allow a definite conclusion. According to [12], *cc*-**6** should rather be in a conformation like ${}_2H^3$ in *Fig. 1* with both EtO–C(2) and Me–C(4) equatorial to avoid the steric 1:3 interaction; moreover, equatorial Me–C(4) is said to outweigh the benefit of the anomeric effect of the axial EtO group. A twist conformation, however, could be adequate in this case, as supported by weak ^4J couplings between H_β–C(3) and H–C(5).

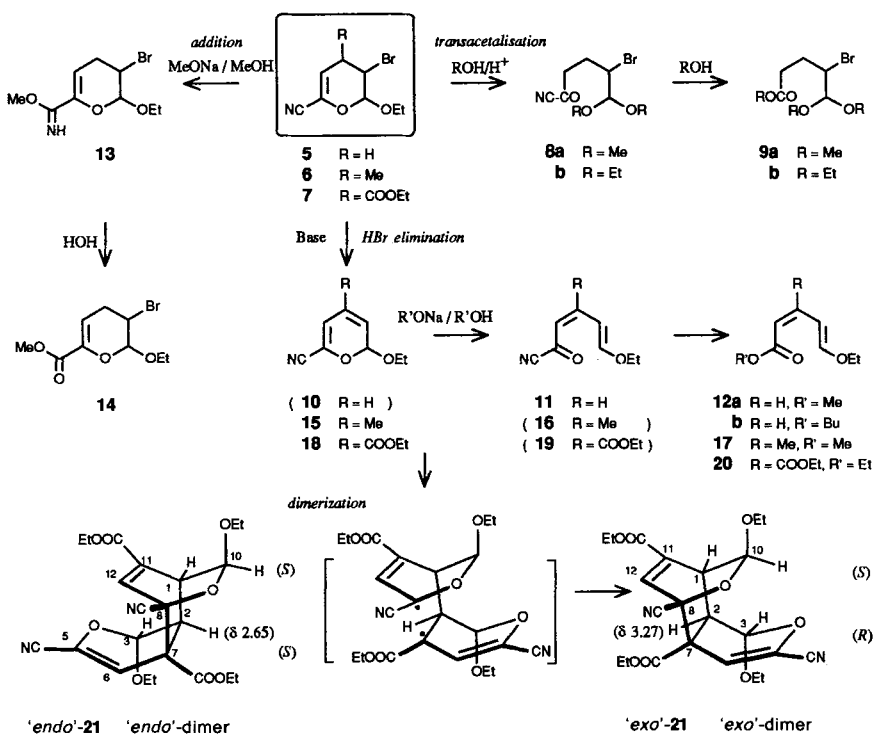
In the spectra of *c*-**5** and *t*-**5** the pseudoaxial of the allylic protons, H_α–C(4) (see *Fig. 1*), is found at lower field than the pseudoequatorial H_β–C(4), as in case of the non-brominated analogue reported in [7] (H_α at 2.31 and H_β at 2.08 ppm); they exhibit remarkably big geminal coupling (*J ca.* 19–20 Hz). In bromodihydropyrans, both allylic protons are deshielded under the influence of the vicinal Br-atom by *ca.* 0.4–0.7 ppm (in *c*-**5**, H_α at 0.46 and H_β at 0.54 ppm; in *t*-**5**, H_α at 0.71 and H_β at 0.41 ppm); this effect is more important for the pseudoaxial H_α–C(4) antiperiplanar to Br–C(3). The deshielding due to the vicinal Br-atom of the pseudoaxial allylic proton, arbitrarily represented as H_α–C(4) in all formula, appears to be related to the conformational equilibrium of *c*-**5** and *t*-**5**, and of the four stereoisomers of **6** and of **7** (the shift differences between bromopyrans and the corresponding non-brominated analogues are for *cc*-**6** 0.34, *tt*-**6** 0.40, *tc*-**6** 0.27, and *ct*-**6** 0.24; for *cc*-**7** 0.88 *tt*-**7** 0.52, *tc*-**7** 0.28, and *ct*-**7** 0.29).

[3]) A preference for conformations with diaxial substituents in cyclohexenes was derived earlier from IR studies in case of 4,5-dichlorocyclohexene [13].

Isomerizations with BF_3. To explore the relative stabilities of the adducts, we have forced anomerization by a treatment with $BF_3 \cdot OEt_2$ (*Scheme 1*). The mixture *c*/*t*-**5** 35:65 obtained from *c*-**5** indicates *t*-**5** to be the more stable isomer; this reflects the advantage to have in the prevalent conformation ($_2H^3$ in *Fig. 1*) the EtO group and Br-atom axial. The sterically hindered *cc*-**6** is almost completely isomerized to *tt*-**6**; considering the prevalent $_2H^3$ conformation represented in *Fig. 1*, we note in this most spectacular case not just steric relief but cooperating effects of axial EtO–C(2), axial Br–C(3), and equatorial Me–C(4) favoring this isomer. In case of anomerization of *tc*-**6**, there is a modest advantage in favor of *ct*-**6**. Noteworthy in this case compared to the previous one is the fact that steric relief from 1:3 interaction is not the main motive, neither is it equatorial Me–C(4) in *ct*-**6** (in the preferred $_2H^3$ conformation, *Fig. 1*); it becomes clear that here the equatorial Br-atom does not stabilize as much as the axial Br-atom does in the case of the previously mentioned *tt*-**6**.

*About the Formation of 2-Alkoxy-2*H*-pyrans.* Several conditions have been explored to promote dehydrobromination of the 3-bromo-3,4-dihydro-2*H*-pyrans. Upon treatment of *c*-**5** with acidic MeOH or EtOH, the alkyl 5,5-dialkoxy-4-bromopentanoates **9a** or **9b**, respectively, are obtained (*Scheme 2*). In the first step, the non-isolable acyclic acetals **8** are formed by transacetalization; these contain an acyl-cyanide group which is readily cleaved by the alcohol, with liberation of HCN, to give the corresponding esters **9**.

Scheme 2. *Transformations of 3-Bromo-2-ethoxy-3,4-dihydro-2*H*-pyran-6-carbonitriles*



Dehydrobromination takes place under basic conditions, but the reaction may not necessarily provide a 2-ethoxy-2*H*-pyran. It is known that 2*H*-pyrans undergo thermally or photochemically electrocyclic valence tautomerization to a dienone system, and structural assignments proved often difficult [14]. Effectively, 2-ethoxy-2*H*-pyran **10** is unavailable from *c*-**5** on attempted HBr elimination. When *c*-**5** is treated with NaOMe in MeOH a mixture of methyl (2*Z*,4*E*)-5-ethoxypenta-2,4-dienoate (**12a**) and 3-bromo-2-ethoxy-3,4-dihydro-2*H*-pyran-6-carboximidate (**13**) results. The products **12a** and **13** are separated by chromatography and their structures elucidated by ^{1}H-NMR. Carboximidate **13** can be hydrolyzed readily to give methyl carboxylate **14**. The part of **13** in the product mixture increases linearily with lowering temperature (from 17% at 30° to 53% at −30°); the slower rate can be made up with a higher reagent concentration. The varying proportions of **12a** and **13** appear to be related to the temperature-dependent conformational equilibrium of *c*-**5**; since antiperiplanar HBr elimination could take place only in a half-chair with an axial Br-atom ($^2H_3$, *Fig. 1*) which in this case is the minor component with an equatorial EtO group. Alkoxide additions to the CN group have not been observed in other cases; the reaction of NaOBu with *c*-**5** merely leads to the ester **12b**. Also, when *c*-**5** is treated with 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) in MeOH, pure **12a** is obtained.

The reactions of NaOMe or NaOEt with the substituted bromo-dihydropyrans **6** and **7** afford the corresponding diene esters **17** and **20**, respectively. Whereas the (2*Z*,4*E*)-configuration of **12** can be inferred from the coupling constants, that of **17** is established by a NOE experiment. This particular configuration is relevant for the reaction mechanism. It is known that the thermal interconversion of 2*H*-pyrans leads to open-chain dienones of (*Z*,*E*)-configuration [15]. This allows us to conclude that the primary intermediates of alkaline alcoholysis of **5**–**7** are the 2-ethoxy-2*H*-pyrans **10**, **15**, and **18**, respectively, which tautomerize to the acyl cyanides **11**, **16**, and **19**, respectively, and these react in return with alkoxide to give the esters **12**, **17**, and **20** with loss of the CN group. The (2*Z*,4*E*)-acid of **12** was obtained in another case of electrocyclic reaction [16], but synthetic approaches to this type of compounds lead to other stereoisomers [17].

Evidence for the intermediacy of 2-ethoxy-2*H*-pyrans in HBr elimination is obtained under non-nucleophilic basic conditions. One example is the reaction of *c*-**5** with DBU in deuterobenzene leading to 6-ethoxy-2-oxohexa-3,5-dienenitrile (**11**), the valence tautomer of obviously unstable **10** which can be identified in solution by ^{1}H-NMR. More convincing is the reaction of *tt*-**6** with DBU in C_6D_6 which delivers within a few min pure 2-ethoxy-2*H*-pyran **15**, identified by ^{1}H-NMR and UV (λ_{max} 277 nm (hexane), 279 nm (MeOH)). The 2-ethoxy-2*H*-pyran **15** undergoes in MeOH slow transformation to **17** which can be followed by ^{1}H-NMR, unlike to the above mentioned fast conversions in presence of NaOMe when the intermediary 2*H*-pyran is not observable. This finding is revealing, since it may now be rationalized that here the valence-tautomer equilibrium between **15** and **16** is in favor of the obviously more stable 4-alkyl-2*H*-pyran (at least > 98%); the transformation of **16** to **17** is conditioned by the rate of alcoholysis, slow in MeOH, and fast with the more nucleophilic NaOMe[4]).

Dehydrobromination occurs with particular ease in case of 3-bromo-3,4-dihydro-2*H*-pyran **7** on treatment with pyridine in an inert solvent or even during chromatography or

[4]) The faster reaction of NaOMe corroborates the finding that acyl cyanides hydrolyze faster at higher p*H*'s [18].

filtration on alumina; the structure of the product, 2-ethoxy-2*H*-pyran **18** is documented by the UV spectrum (λ_{max} 290 nm (hexane)) and ^{1}H- and ^{13}C-NMR data. Treatment of **18** with NaOEt, however, leads to ester **20**; as explained above, this transformation gives evidence for an equilibrium between 2*H*-pyran **18** and ring-opening product **19** which is removed by fast reaction with NaOEt.

The 2-ethoxy-2*H*-pyran **18** is relatively stable in solution at low temperature. In neat form at room temperature, it dimerizes to give the partially crystalline mixture of 25% '*endo*'-**21** and 75% '*exo*'-**21**. Some of this product is obtained also besides **18** during chromatography of **7** on silica gel. The prevalent '*exo*'-adduct '*exo*'-**21** crystallizes from EtOH and its tricyclic structure is established by X-ray crystallography (*Fig. 2*; structure data in *Table 2*). The structure of the minor '*endo*'-**21** can be inferred from a comparison of the ^{1}H- and ^{13}C-NMR spectra with that of '*exo*'-**21** since the essential shift difference is that of the *m* of the angular *H*–C(2) (at 2.65 in '*endo*'-**21** and 3.27 ppm in '*exo*'-**21**) under the influence of anisotropy of the COOEt group at C(11).

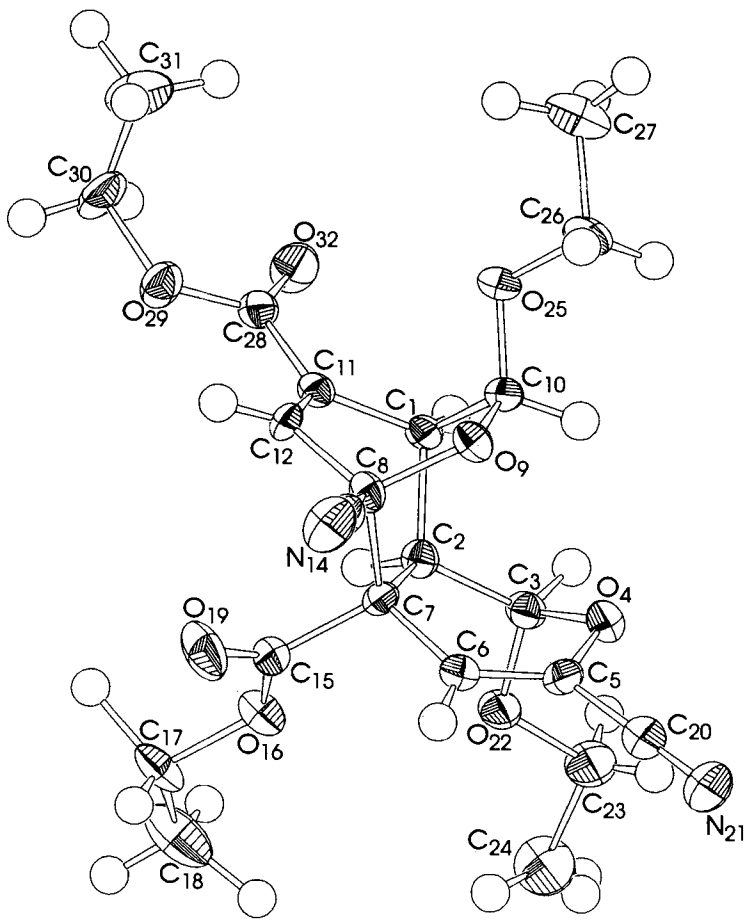


Fig. 2. *X-Ray crystal structure of the prevalent dimer* 'exo'-**21**. ORTEP Plot.

Table 2. *Structure Determination of* 'exo'-**21**

Crystal Data		Standard reflections	3 measured every 97 reflections
Empirical formula	$C_{22}H_{26}N_2O_8$		
Color; habit	transparent-colorless platelets	Index ranges	$-27 \leq h \leq 24$, $-9 \leq k \leq 9$, $-13 \leq l \leq 16$
Crystal size [mm]	*N/A*		
Crystal system	monoclinic	Reflections collected	5540
Space group	*C2/c*	Independent reflections	2132 ($R_{int} = 3.19\%$)
Unit cell dimensions	$a = 28.24(4)$ Å	Observed reflections	1254 ($F > 6.0\sigma(F)$)
	$b = 10.13(3)$ Å	Absorption correction	*N/A*
	$c = 17.54(3)$ Å		
	$\beta = 116.14(11)°$	*Solution and Refinement*	
Volume	4503(16) Å^3		
Z	8	System used	*Siemens* SHELXTL PLUS (PC version)
Formula weight	446.4		
Density (calc.)	1.317 Mg/m^3	Solution	direct methods
Absorption coefficient	0.101 mm^{-1}	Refinement method	full-matrix least-squares
F(000)	1888	Quantity minimized	$\Sigma w(F_o - F_c)^2$
		Absolute structure	*N/A*
Data Collection		Extinction correction	$\chi = 0.000179(13)$, where $F^* = F[1 + 0.002\chi F^2/\sin(2\theta)]^{-1/4}$
Diffractometer used	*Siemens R3m/V*		
Radiation	MoK_α ($\lambda = 0.71073$ Å)		
Temperature [K]	566	H-Atoms	riding model, fixed isotropic *U*
Monochromator	highly oriented graphite crystal		
		Weighting scheme	$w^{-1} = \sigma^2(F)$
2θ Range	2.0–40.0°	Number of parameters refined	362
Scan type	2θ–θ		
Scan speed	variable; 3.00 to 15.00 °/min in ω	Final *R* indices (obs. data)	$R = 3.76\%$, $wR = 3.17\%$
Scan range (ω)	1.40° plus K_α-separation	Goodness-of-fit	1.93
Background measurement	stationary crystal and stationary counter at beginning and end of scan, each for 50.0% of total scan time	Largest and mean Δ/σ	0.002, 0.000
		Data-to-parameter ratio	3.5:1
		Largest difference peak	0.17 eÅ^{-3}
		Largest difference hole	−0.17 eÅ^{-3}

The regiospecificity of dimer formation can be rationalized readily considering the *Diels-Alder* addition as biradicaloid [19][5]): as shown in *Scheme 2*, the most stabilized intermediate would ensue from an initial bond formation between C(3) of the diene and C(3) of the dienophile[6]). For sterical reasons, to avoid interaction of the two EtO groups, the '*endo*'-transition state provides the (*RS,RS*)-racemate, and the '*exo*' transition state the (*RS,SR*)-racemate; the reason for the preference of the '*exo*'-adduct is not obvious. Probably other 'dimeric products' of unknown structure mentioned in [14] may be issued of the same type of reaction. *Conrads* and *Mattay* [20] obtained a 3-methyl homologue of **18** by a hetero-*Diels-Alder* addition of **3** with 1-methoxypropa-1,2-diene and subsequent double-bond rearrangement of the adduct; interestingly, a dimerization of this 2*H*-pyran derivative was not observed.

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[5]) The term diradicaloid reaction was suggested by *M.J.S. Dewar* in [19d].

[6]) We thank Prof. *Pierre Vogel* for a helpful discussion.

Experimental Part

General. Starting materials were purchased from *Fluka AG*. The 2-oxobut-3-enenitrile (**1**), 2-oxopent-3-enenitrile (**2**), and ethyl 4-cyano-4-oxobut-2-enoate (**3**) were prepared following known procedures [7] [8]. The (*Z*)- and (*E*)-1-bromo-2-ethoxyethene ((*Z*)- and (*E*)-**4**, resp.) were obtained by distillation of mixtures [10] [11] using a *Fischer*-'Spaltrohr' column (*Büchi*). Column chromatography: silica gel *60* (200–400 mesh ASTM, *Merck 9385*); FC = flash chromatography. TLC: aluminium sheets precoated with silica gel *60* F_{254}, 0.2 mm *Merck 5554*. GC: Capillary column (*HP* cross-linked methyl silicone, 25 m); program: 4 min isocratic 50° (pro 50) or 100° (pro 100), gradient 16°/min to 250°; retention times t_R; *Hewlett-Packard 5730A*. UV Spectra: λ_{max} (ε) in nm; *Hewlett-Packard* diode array *8450* spectrometer. IR Spectra: in cm^{-1}; *Perkin-Elmer-1420* spectrometer. ^1H- and ^{13}C-NMR Spectra: chemical shifts δ in ppm rel. to $SiMe_4$ (= 0 ppm) as an internal standard *J* in Hz; *Bruker-WH-250* and *-WH-360* spectrometers. NOE: indication of irradiated H→affected H's (%). MS: EI (electron impact) or CI (chemical ionization; in NH_3), *m/z* (intensities in % of base peak); *Nermag-R-10-10C* spectrometer.

*3-Bromo-2-ethoxy-3,4-dihydro-2*H*-pyran-6-carbonitriles* (**5**). *Procedure for* c-**5**. *cis*-Bromovinyl ether (*Z*)-**4** (1.51 g, 10 mmol) and *ca.* 0.3M **1** in MeCN (60 ml, 18 mmol) prepared following [8] were left at r.t. for 48 h to give *c*-**5** as only product (1.16 g, 50%). GC (pro 50): t_R 11.1. IR (neat): 3075*w*, 2232*m*, 1645*s*, 1376*m*, 1942*vs*, 847*s*. ^1H-NMR (C_6D_6): 4.73 (*dd*, *J* = 5.4, 2.9, H_β–C(5)); 4.53 (*d*, *J* = 2.4, H–C(2)); 3.41, 3.12 (*dq* (*AB*), *J* = 10.0, 7.1, $MeCH_2O$); 3.24 (*ddd*, *J* = 11.4, 6.1, 2.4, H_β–C(3)); 2.26 (*ddd*, *J* = 18.0, 11.4, 2.9, H_α–C(4)); 1.66 (*ddd*, *J* = 18.0, 6.1, 5.4, H_β–C(4)); 0.88 (*t*, *J* = 7.1, $MeCH_2O$). ^{13}C-NMR $CDCl_3$): 125.3 (*s*, C(6)); 116.6 (*d*, C(5)); 113.9 (*s*, CN); 97.5 (*d*, C(2)); 65.3 (*t*, $MeCH_2O$); 27.7 (*d*, C(4)); 41.2 (*d*, C(3)); 14.5 (*q*, $MeCH_2O$). EI-MS: 233/231 (18/17, M^+), 188/186 (12/12), 152/150 (100/52), 107 (9), 106 (46), 97 (71), 96 (26), 81 (3), 69 (38), 68 (28).

Procedure for t-**5**. *trans*-Bromovinyl ether (*E*)-**4** (1.51 g, 10 mmol) and *ca.* 0.3M **1** in MeCN (40 ml, 12 mmol) prepared following [8] were left at r.t. for 16 h. The solvent was evaporated and the residue bulb-to-bulb distilled (130°/0.01 Torr): *t*-**5** (1.90 g, 82% of added (*E*)-**4**). GC (pro 50): t_R 11.6. IR (neat): 3080*m*, 2232*s*, 1648*s*, 1375*s*, 1038*s*, 928*s*, 840*s*. ^1H-NMR (C_6D_6): 4.86 (*ddd*, *J* = 5.4, 2.5, 1.2, H–C(5)); 4.57 (*dd*, *J* = 2.6, 0.4, H_β–C(2)); 3.36 (*dddd*, *J* = 5.5, 3.0, 2.6, 1.2, H_α–C(3)); 3.34, 3.07 (*dq* (*AB*), *J* = 10.0, 7.1, $MeCH_2O$); 2.23 (*ddd*, *J* = 19.7, 5.4, 3.0, H_α–C(4)); 1.67 (*dddd*, *J* = 19.7, 5.5, 2.5, 0.4, H_β–C(4)); 0.79 (*t*, *J* = 7.1, $MeCH_2O$). ^{13}C-NMR ($CDCl_3$): 124.5 (*s*, C(6)); 114.2 (*d*, C(5)); 114.0 (*s*, CN); 97.7 (*d*, C(2)); 64.8 (*t*, $MeCH_2O$); 26.4 (*d*, C(4)); 39.6 (*d*, C(3)); 14.6 (*q*, $MeCH_2O$). EI-MS: 233/231 (19/15, M^+), 188/186 (27/23), 152/150 (100/64), 107 (14), 106 (69), 97 (27), 81 (4), 69 (30), 68 (31).

Heating 0.3M **1** in MeCN (60 ml, 18 mmol) and (*Z*)-**4** (1.51 g, 10 mmol) for 19 h under reflux gave *c*/*t*-**5** 93:7 (1.98 g, 85%), as evaluated by ^1H-NMR from the 2*m* of H–C(4) (2.77 and 2.62 for *c*-**5**, 3.02 and 2.49 for *t*-**5**).

*3-Bromo-2-ethoxy-3,4-dihydro-4-methyl-2*H*-pyran-6-carbonitriles* (**6**). *Procedure for* cc-**6** *and* ct-**6**. A mixture of **2** (10 mmol) and (*Z*)-**4** (13 mmol) was heated 72 h at 60° in an oil bath. The product (2.10 g, 85%), purified by bulb-to-bulb distillation (120°/0.01 Torr), was a mixture of *cc*-, *ct*-, *tc*-, and *tt*-**6** 71:6:15:8 (ratios by ^1H-NMR: *cc*-**6** 5.06, *ct*-**6** 5.16, *tc*-**6** 5.10, *tt*-**6** 5.24). The diastereoisomers were separated by FC (CH_2Cl_2/hexane 1:1). R_f (CH_2Cl_2/hexane 1:1) and t_R (GC pro 100).

cc-**6**: R_f 0.39, t_R 8.48. IR (neat): 3064*m*, 2232*s*, 1640*vs*, 1375*vs*, 1140*vs*, 1010*vs*, 960*s*, 876*s*. ^{13}C-NMR ($CDCl_3$): 125.6 (*s*, C(6)); 120.1 (*d*, C(5)); 113.8 (*s*, CN); 99.5 (*d*, C(2)); 65.8 (*t*, $MeCH_2O$); 32.5 (*d*, C(4)); 50.0 (*d*, C(3)); 17.4 (*q*, Me–C(4)); 14.7 (*q*, $MeCH_2O$). EI-MS: 247/245 (2/3, M^+), 202/200 (4/3), 166 (69), 152/150 (98/100), 124 (83), 122 (87), 111 (23), 106 (20), 82 (29), 69 (44), 68 (14).

ct-**6**: R_f 0.56, t_R 7.81. This product was isolated after repeated FC (silica gel) of the product mixture. IR (neat): 3065*w*, 2232*m*, 1643*s*, 1380*s*, 1155*vs*, 1060*vs*, 960*vs*, 875*s*. ^{13}C-NMR ($CDCl_3$): 124.8 (*s*, C(6)); 121.6 (*d*, C(5)); 114.0 (*s*, CN); 98.2 (*d*, C(2)); 65.6 (*t*, $MeCH_2O$); 32.2 (*d*, C(4)); 50.6 (*d*, C(3)); 17.9 (*q*, *Me*–C(4)); 14.8 (*q*, $MeCH_2O$). EI-MS: 247/245 (6/7, M^+), 202/200 (4/3), 166 (23), 152/150 (56/60), 124 (71), 122 (100), 120 (48), 111 (31), 106 (17), 99 (40), 82 (18), 69 (38), 68 (13).

Procedure for tc-**6** *and* tt-**6**. A mixture of **2** (10 mmol) and (*E*)-**4** (10 mmol) was left for 10 days at r.t. Bulb-to-bulb distillation gave 68:32 (2.40 g, 98%), as evaluated by ^1H-NMR (1-H *m*'s of *tc*-**6** at 5.62, 5.10, and 2.77, and of *tt*-**6** at 5.46, 5.24, 2.97). The diastereoisomers were separated by FC (CH_2Cl_2/hexane 1:1).

tc-**6**: R_f 0.45, t_R 8.14. IR (neat): 3070*w*, 2230*m*, 1645*vs*, 1378*s*, 1148*vs*, 975*vs*, 862*vs*. ^{13}C-NMR ($CDCl_3$): 125.4 (*s*, C(6)); 119.8 (*d*, C(5)); 113.9 (*s*, CN); 100.8 (*d*, C(2)); 65.4 (*t*, $MeCH_2O$); 36.9 (*d*, C(4)); 49.2 (*d*, C(3)); 19.3 (*q*, *Me*–C(4)); 14.8 (*q*, $MeCH_2O$). EI-MS: 247/245 (6/6, M^+), 232/230 (4/5), 202/200 (5/5), 166 (24), 152/150 (58/61), 124 (75), 122 (100), 120 (48), 110 (27), 106 (21), 99 (35), 95 (6), 82 (18), 69 (38), 68 (12).

tt-**6**: R_f 0.50, t_R 8.48. IR (neat): 3068*w*, 2232*s*, 1642*vs*, 1383*s*, 1120*vs*, 978*vs*, 862*vs*. ^{13}C-NMR ($CDCl_3$): 124.6 (*s*, C(6)); 119.7 (*d*, C(5)); 114.3 (*s*, CN); 99.3 (*d*, C(2)); 65.2 (*t*, $MeCH_2O$); 27.5 (*d*, C(4)); 49.2 (*d*, C(3)); 17.3 (*q*,

Me–C(4)); 14.9 (*q*, *Me*CH_2O). EI-MS: 247/245 (6/6, M^+), 232/230 (4/5), 202/200 (16/19), 166 (71), 152/150 (100/88), 124 (68), 122 (71), 121 (10), 120 (71), 106 (38), 96 (8), 95 (7), 83 (26), 82 (25), 69 (41), 68 (12).

*Ethyl 3-Bromo-6-cyano-2-ethoxy-3,4-dihydro-2*H*-pyran-4-carboxylates* (**7**). *Procedure for* cc-**7** *and* ct-**7**. A mixture of **3** (1.53 g, 10 mmol) and (*Z*)-**4** (1.52 g, 10 mmol) was left at r.t. for 5 days. Bulb-to-bulb distillation (140°/0.01 Torr) afforded *cc*/*ct*-**7** 95:5 (2.68 g, 88%), as evaluated by ^{1}H-NMR (*m*'s at 5.85 and 4.96 of *cc*-**7**, and at 5.71 and 5.18 of *ct*-**7**). IR (neat): 3088*m*, 2236*m*, 1728*vs*, 1640*s*, 1370*vs*, 1270*vs*, 1160*vs*, 1050*vs*, 860*s*, 767*s*. EI-MS: 306/304 (4/4, $[M + 1]^+$), 305/303 (5/5, M^+), 260/258 (4/4), 232/230 (37/38), 224 (59), 153 (5), 152/150 (65/89), 124 (72), 123 (35), 122 (100), 106 (59), 97 (32), 96 (15), 95 (46), 94 (46), 69 (24), 68 (75), 67 (33).

cc-**7**: ^{13}C-NMR ($CDCl_3$): 166.6 (*s*, *C*OOEt); 127.1 (*s*, C(6)); 111.0 (*d*, C(5)); 112.9 (*s*, CN); 98.6 (*d*, C(2)); 65.5 (*t*, Me*C*H_2O–C(2)); 61.6 (*t*, Me*C*H_2OOC); 44.3 (*d*, C(4)); 44.6 (*d*, C(3)); 14.3 (*q*, *Me*CH_2O–C(2)); 13.5 (*q*, *Me*CH_2OOC).

ct-**7**: ^{13}C-NMR ($CDCl_3$): 166.6 (*s*, *C*OOEt); 127.3 (*s*, C(6)); 113.3 (*d*, C(5)); 113.0 (*s*, CN); 97.7 (*d*, C(2)); 65.6 (*t*, Me*C*H_2O–C(2)); 61.9 (*t*, Me*C*H_2OOC); 44.7 (*d*, C(4)); 41.9 (*d*, C(3)); 14.4 (*q*, *Me*CH_2O–C(2)); 13.7 (*q*, *Me*CH_2OOC).

Procedure for tc-**7** *and* tt-**7**. A mixture of **3** (10 mmol) and (*E*)-**4** (10 mmol) was left at r.t. for 15 h. Bulb-to-bulb distillation (140°/0.01 Torr) afforded *tc*/*tt*-**7** 63:37 (2.95 g, 97%). IR (neat): 3085*m*, 2232*m*, 1735*vs*, 1647*vs*, 1378*s*, 1367*s*, 1280*vs*, 1200*vs*, 1110*vs*, 1040*vs*, 980*s*, 840*s*, 770. EI-MS: 305/303 (5/5, M^+), 260/258 (6/7), 232/230 (27/27), 224 (38), 178 (40), 152/150 (62/71), 124 (50), 123 (20), 122 (87), 113 (26), 106 (100), 97 (36), 96 (12), 95 (46), 94 (40), 69 (12), 68 (39), 67 (15). CI-MS: 323/321 (63/65, $[M + NH_4]^+$), 178 (100).

tc-**7**: ^{13}C-NMR ($CDCl_3$): 167.4 (*s*, *C*OOEt); 124.8 (*s*, C(6)); 112.1 (*d*, C(5)); 113.6 (*s*, CN); 97.5 (*d*, C(2)); 64.9 (*t*, Me*C*H_2O–C(2)); 61.7 (*t*, Me*C*H_2OOC); 43.9 (*d*, C(4)); 39.6 (*d*, C(3)); 14.5 (*q*, *Me*CH_2O–C(2)); 13.8 (*q*, *Me*CH_2OOC).

tt-**7**: ^{13}C-NMR ($CDCl_3$): 167.4 (*s*, *C*OOEt); 125.0 (*s*, C(6)); 111.8 (*d*, C(5)); 113.6 (*s*, CN); 98.3 (*d*, C(2)); 65.2 (*t*, Me*C*H_2O–C(2)); 61.9 (*t*, Me*C*H_2O–C(2)); 40.8 (*d*, C(4)); 39.6 (*d*, C(3)); 14.2 (*q*, *Me*CH_2O–C(2)); 13.8 (*q*, *Me*CH_2OOC).

Isomerizations of (*Z*)-**4** *in Glass Tubes*. Pure neat (*Z*)-**4** was heated to 60° in a normal glass tube (*AR-Glass*®). The ratio (*Z*)/(*E*)-**4** was determined by GC. The percentage of (*E*)-**4** progressed linearily by *ca.* 2%/h until a final equilibrium (*Z*)/(*E*)-**4** 83:17 was reached.

Isomerizations of cc-**6** *in Glass Tubes*. Neat *cc*-**6** was heated and the formation of *tt*-**6** quantified by ^{1}H-NMR ($CDCl_3$), using the ratio of the sums of integrations of 2 1-H *m*'s at 5.56 and 5.06 for *cc*-**6** and at 5.46 and 5.24 for *tt*-**6**. The linear increase of the part of *tt*-**6** in 3 independent experiments was as follows: *a*) heated in a normal glass tube at 60° in the dark: 0.09%/h; *b*) heated at 60° in the dark in a glass tube which was treated before with conc. H_2SO_4, rinsed with H_2O, and dried: 0.17%/h; *c*) heated in a normal glass tube at 65° in daylight: 1.9%/h.

Isomerizations by $BF_3 \cdot Et_2O$. Solns. of the dihydropyrans in Et_2O with some drops of $BF_3 \cdot Et_2O$ were left in dark at r.t. for 24 h. The mixtures were evaporated and dissolved in $CDCl_3$ for ^{1}H-NMR inspection. The ratios of products were established from integrations of characteristic signals as mentioned.

c-**5** and *t*-**5**: Starting with 0.6 g of *c*/*t*-**5** 93:7 in Et_2O (6 ml) and 12 drops of $BF_3 \cdot Et_2O$, the following mixtures were obtained: after 9 h *c*/*t*-**5** 36:64 and after 24 h *c*/*t*-**5** 34.5:65.5, as evaluated by ^{1}H-NMR (*m*'s of H–C(4) of *t*-**5** at 3.02 (H_α) and 2.49 (H_β), of *c*-**5** at 2.77 (H_α) and 2.62 (H_β)). Identical conditions applied to pure *t*-**5** gave the same product mixtures.

cc-**6** and *tt*-**6**: Pure *cc*-**6** in Et_2O (2 ml) and $BF_3 \cdot Et_2O$ (4 drops) left for 24 h gave *cc*/*tt*-**6** 6:94, as evaluated by ^{1}H-NMR (H–C(2) at 5.06 and 5.24, resp.).

tc-**6** and *ct*-**6**. A mixture *tc*/*ct*-**6** 88:12 (0.2 g in 2 ml of Et_2O) and $BF_3 \cdot Et_2O$ (4 drops) after 24 h contained *tc*/*ct*-**6** 43:57, as evaluated by ^{1}H-NMR (H–C(2) at 5.10 and 5.16, resp.).

Acid Methanolysis of c-**5**. Acetyl chloride (1.03 ml) was added to MeOH (3 ml) at –40° under N_2. To this was slowly added *c*-**5** (1.16 g, 5 mmol) in hexane (85 ml). After 24 h at r.t., brine (10 ml) was added and the product extracted with CH_2Cl_2 (3 × 20 ml). The org. layer was washed with H_2O, dried (Na_2SO_4), and evaporated and the oil (1.10 g, 86%) purified by FC (AcOEt/hexane 1:6): *methyl-4-bromo-5,5-dimethoxypentanoate* (0.83 g, 65%; **9a**). Oil. R_f 0.31. GC (pro 50): t_R 9.5. IR (neat): 1735*vs*, 1440*s*, 1258*s*, 1200*s*, 1120*s*, 1070*s*. ^{1}H-NMR ($CDCl_3$): 4.40 (*d*, *J* = 5.5, H–C(5)); 4.07 (*ddd*, *J* = 10.3, 5.5, 3.2, H–C(4)); 3.69 (*s*, MeO); 3.45, 3.44 (2*s*, 2 MeO–C(5)); 2.63 (*ddd*, *J* = 16.8, 8.5, 5.7) and 2.52 (*ddd*, *J* = 16.8, 8.0, 7.2, CH_2(2)); 2.35 (*dddd*, *J* = 15.0, 8.5, 7.2, 3.2) and 2.01 (*dddd*, *J* = 15.0, 10.3, 8.0, 5.7, CH_2(3)). ^{13}C-NMR ($CDCl_3$): 172.8 (*s*, *C*OOMe); 105.7 (*d*, C(5)); 54.9 (*q*, MeO); 54.7 (*q*, MeO); 53.1 (*d*, C(4)); 51.4 (*q*, MeO); 31.3 (*t*, C(2)); 27.9 (*t*, C(3)).

Acid Ethanolysis of c-**5**. A mixture of *c*-**5** (0.70 g, 3 mmol) and toluene-4-sulfonic acid monohydrate (0.1 g) in EtOH (10 ml) was refluxed for 72 h. After evaporation, the residue was purified by FC (AcOEt/hexane 1:6): *ethyl*

4-bromo-5,5-diethoxypentanoate (0.64 g, 72%; **9b**). Colorless oil. R_f 0.35. IR (neat): 1728*s*, 1440*m*, 1370*m*, 1250*m*, 1180*m*, 1050*s*. ^{1}H-NMR ($CDCl_3$): 4.54 (*d*, *J* = 5.5, H–C(5)); 4.13 (*q*, *J* = 7.1, MeCH_2OOC); 4.07 (*ddd*, *J* = 10.4, 5.5, 3.0, H–C(4)); 3.74, 3.71 (2*dq*, *J* = 9.3, 7.1, 1 MeCH_2O–C(5)); 3.60, 3.59 (2*dq*, *J* = 9.3, 7.1, 1 MeCH_2O–C(5)); 2.62 (*ddd*, *J* = 16.7, 8.7, 5.7, H_A–C(2)); 2.49 (*ddd*, *J* = 16.7, 8.3, 7.0, H_B–C(2)); 2.36 (*dddd*, *J* = 14.5, 8.7, 7.0, 3.0, H_A–C(3)); 2.02 (*dddd*, *J* = 14.5, 10.4, 8.3, 5.7, H_B–C(3)); 1.26 (*t*, *J* = 7.1, *Me*CH_2OOC); 1.23 (*t*, *J* = 7.1, 2 *Me*CH_2O–C(5)). ^{13}C-NMR ($CDCl_3$): 172.5 (*s*, *C*OOEt); 103.8 (*d*, C(5)); 63.4 (*t*, CH_2O); 63.1 (*t*, CH_2O); 60.1 (*t*, CH_2O); 54.2 (*d*, C(4)); 31.8 (*t*, C(2)); 27.8 (*t*, C(3)); 14.9 (*q*, 2 *Me*CH_2O); 14.0 (*q*, *Me*CH_2OCO). EI-MS: 253 (12), 251 (11), 207 (4), 203 (4), 179 (8), 177 (7), 165 (3), 163 (3), 151 (2), 149 (2), 124 (2), 122 (2), 115 (2), 104 (6), 103 (100), 97 (8), 85 (9), 75 (58), 73 (3), 69 (6), 57 (10), 55 (10).

Alkaline Methanolysis of **c-5**. A soln. of *c*-**5** (0.46 g, 2 mmol) in dry MeOH (5 ml) and 1M NaOMe (4 ml, 4 mmol) were mixed at different temp. When all *c*-**5** had disappeared, the product was extracted with brine (10 ml) and Et_2O (3 × 20 ml). The Et_2O extract was dried (Na_2SO_4) and evaporated and the residue analyzed by ^{1}N-NMR (ratios **12a**/**13**): 1 h at 30° 83:17; 1 h at 20° 80:20; 2 h at 10° 73:27; 6.5 h at 0° 65:35; 24 h at −10° 59:41; 4 d at −20° 50:50; 9 d at −30° 47:53.

Assays with other *c*-**5**/NaOMe ratios: *a*) 1:4 or 1:10, 24 h at −20°, gave the same composition **12a**/**13** 44:56; *b*) 1:10, 10 h at −30°, gave **12a**/**13** 46:54 (65% yield).

Methyl (2Z,4E)-5-Ethoxypenta-2,4-dienoate (**12a**). R_f (hexane/AcOEt 1:6) 0.61: GC (pro 50): t_R 11.7. UV (MeOH): 287 (10600). IR (film): 3090*w*, 3030*w*, 1710*vs*, 1620*vs*, 1440*s*, 1190*vs*, 1190*vs*, 1170*vs*, 945*s*, 815*s*. ^{1}H-NMR ($CDCl_3$): 6.95 (*dd*, *J* = 13.0, 9.7, H–C(4)); 6.88 (*dd*, *J* = 13.0, 1.0, H–C(5)); 6.51 (*ddd*, *J* = 11.0, 9.7, 1.0, H–C(3)); 5.44 (*d*, *J* = 11.0, H–C(2)); 3.95 (*q*, *J* = 7.0, MeCH_2O); 3.71 (*s*, MeO); 1.34 (*t*, *J* = 7.0, *Me*CH_2O). ^{13}C-NMR ($CDCl_3$): 167.4 (*s*, *C*OOMe); 158.7 (*d*, C(5)); 143.5 (*d*, C(3)); 110.8 (*d*, C(4)); 103.7 (*d*, C(2)); 65.6 (*t*, Me*C*H_2O); 50.5 (*q*, MeO); 14.2 (*q*, *Me*CH_2O). In another preparation of **12a**, DBU (0.20 g, 1.3 mmol) was added to a soln. of *c*-**5** (0.23 g, 1 mmol) in MeOH (5 ml). After 1 h at r.t., the soln. was filtered through a pad of SiO_2; the CH_2Cl_2 eluate contained **12a** (0.15 g, 96%).

*Methyl 3-Bromo-2-ethoxy-3,4-dihydro-2*H*-pyran-6-carboximidate* (**13**). R_f (hexane/AcOEt 1:6) 0.23. GC (pro 50): t_R 17.9. GC (pro 100): t_R 10.8. UV (hexane): 223 (8300). IR (neat): 3320*s*, 1668*s*, 1617*vs*, 1440*vs*, 1375*s*, 1350*s*, 1075*vs*, 990*vs*, 910*vs*, 847*vs*, 795*s*, 730*s*. ^{1}H-NMR ($CDCl_3$): 7.83 (br. *s*, NH); 5.70 (*dd*, *J* = 5.2, 3.0, H–C(5)); 5.19 (*d*, *J* = 2.2, H_α–C(2)); 4.13 (*ddd*, *J* = 10.8, 6.3, 2.2, H_α–C(3)); 3.88, 3.72 (2*dq*, *J* = 9.5, 7.1, MeCH_2O); 3.81 (*s*, MeO); 2.77 (*ddd*, *J* = 18.0, 10.8, 3.0, H_β–C(4)); 2.60 (*ddd*, *J* = 18.0, 6.3, 5.2, H_α–C(4)); 1.26 (*t*, *J* = 7.0, *Me*CH_2O). ^{13}C-NMR ($CDCl_3$): 163.0 (*s*, C=NH); 138.4 (*s*, C(6)); 104.0 (*d*, C(5)); 97.1 (*d*, C(2)); 64.7 (*t*, Me*C*H_2O); 52.9 (*q*, MeO); 42.9 (*d*, C(3)); 27.3 (*t*, C(4)); 14.5 (*q*, *Me*CH_2O). CI-MS: 264/266 (100/98, $[M + H]^+$), 184 (85), 150/152 (8/8), 138 (9), 112/114 (4/4), 97 (12), 89 (7).

Butyl 5-Ethoxypenta-2,4-dienoate (**12b**). A soln. of BuONa (0.008M) in BuOH (from BuOH (12 ml) and Na (0.18 g)) was added to *c*-**5** (0.93 g, 4 mmol) in BuOH (6 ml). After 30 min at r.t., brine (5 ml) was added, the mixture extracted with Et_2O (3 × 40 ml), the extract dried (Na_2SO_4) and evaporated, and the residue dissolved in AcOEt and filtered through silica gel: **12b** (0.77 g, 97%). Colorless oil. IR (neat): 1725*vs*, 1620*vs*, 1460*vs*, 1245*vs*, 1175*vs*, 1100*s*, 1065*vs*, 1020*s*, 978*s*. ^{1}H-NMR ($CDCl_3$): 6.94 (*dd*, *J* = 13.0, 9.7, H–C(4)); 6,87 (*dd*, *J* = 13.0, 1.2, H–C(5)); 6.5 (*ddd*, *J* = 11.0, 9.7, 1.2, H–C(3)); 5.44 (*d*, *J* = 11.0, H–C(2)); 4.11 (*t*, *J* = 6.5, Me$(CH_2)_2$CH_2O); 3.94 (*q*, *J* = 7.0, MeCH_2O); 1.65, 1.41 (2*m*, Me(C$H_2)_2$CH_2O); 1.34 (*t*, *J* = 7.0, *Me*CH_2O); 0.95 (*t*, *J* = 7.3, *Me*$(CH_2)_3$O). ^{13}C-NMR ($CDCl_3$): 166.7 (*s*, *C*OOBu); 158.3 (*d*, C(5)); 142.9 (*d*,C(3)); 111.0 (*d*, C(4)); 103.5 (*d*, C(2)); 65.2, 62.8 (2*t*, 2 CH_2O); 30.4 (*t*, CH_2); 18.7 (*t*, CH_2); 13.9, 13.2 (2*q*, 2 Me).

*Methyl 3-Bromo-2-ethoxy-3,4-dihydro-2*H*-pyran-6-carboxylate* (**14**). To a soln. of **13** (0.8 g) in Et_2O (10 ml) was added 1N HCl (8 ml) and the mixture stirred for 1 h. The org. layer, adjusted to 20 ml, was washed with sat. $NaHCO_3$ soln. and brine and evaporated: **14** (0.7 g, 88%). Colorless oil. R_f (hexane/AcOEt 2:1) 0.61. GC (pro 100): t_R 10.6. UV (MeOH): 247. IR (neat): 1725*s*, 1645*s*, 1260*s*, 1105*s*, 1045*s*, 985*s*, 850*s*, 813*s*, 755*s*. ^{1}H-NMR ($CDCl_3$): 6.09 (*dd*, *J* = 5.4, 2.9, H–C(5)); 5.24 (*dd*, *J* = 2.3, 0.5, H–C(2)); 4.12 (*ddd*, *J* = 11.4, 6.4, 2.3, H–C(3)); 3.91, 3.74 (2*dq*, *J* = 9.9, 7.1, MeCH_2O); 3.81 (*s*, MeO); 2.81 (*ddd*, *J* = 18.2, 11.4, 2.9, H_α–C(4)); 2.62 (*dddd*, *J* = 18.2, 6.4, 5.4, 0.5, H_β–C(4)); 1.26 (*t*, *J* = 7.1, *Me*CH_2O). ^{13}C-NMR ($CDCl_3$): 162.1 (*s*, *C*OOMe); 139.4 (*s*, C(6)); 110.9 (*d*, C(5)); 96.8 (*d*, C(2)); 64.5 (*t*, Me*C*H_2O); 51.7 (*q*, MeO); 42.4 (*d*, C(3)); 27.4 (*t*, C(4)); 14.4 (*q*, *Me*CH_2O). EI-MS: 266/264 (1/1, M^+), 185 (7), 152/150 (6/5), 139 (8), 125 (21), 124 (11), 122 (15), 97 (38), 85 (16), 81 (12), 69 (32), 59 (63), 57 (22), 55 (100), 53 (25).

(E,E)-6-Ethoxy-2-oxohexa-3,5-dienenitrile (**11**). DBU (14 mg, 0.09 mmol) was added at r.t. to a soln. of *c*-**5** (17 mg, 0.07 mmol) in abs. C_6D_6 (0.5 ml). The product **11** (*ca.* 30%) was identified besides *c*-**5** (*ca.* 70%) by ^{1}H-NMR (C_6D_6): 7.46 (*dd*, *J* = 15.3, 12.0, H–C(4)); 6.32 (*d*, *J* = 12.3, H–C(6)); 5.87 (*d*, *J* = 15.3, H–C(3)); 5.38 (*dd*, *J* = 12.3, 12.0, H–C(5)); 3.19 (*q*, *J* = 7.0, MeCH_2O); 1.02 (*t*, *J* = 7.0, *Me*CH_2O).

*2-Ethoxy-4-methyl-2*H*-pyran-6-carbonitrile* (**15**). DBU (16.9 mg, 0.11 mmol) was added at r.t. to a soln. of *tt*-**6** (25.6 mg, 0.104 mmol) in abs. C_6D_6 (1 ml; →precipitate). The reaction was complete within 10 min as visualized by ^{1}H-NMR. The soln. was filtered through a pad of SiO_2. UV (MeOH): 279. UV (hexane): 277. ^{1}H-NMR ($CDCl_3$): 6.08 (*d*, *J* = 1.2, H–C(5)); 5.57 (*m*, H–C(2), H–C(3)); 3.92, 3.64 (2*dq*, *J* = 9.8, 7.0, MeCH_2O); 1.89 (*d*, *J* = 0.5, Me–C(4)); 1.24 (*t*, *J* = 7.0, *Me*CH_2O). ^{1}H-NMR (C_6D_6): 5.29 (br. *d*, *J* = 1.4, H–C(5)); 5.03 (br. *d*, *J* = 4.0, H–C(2)); 4.98 (*ddq*, *'sept'*, *J* = 4.0, *ca.* 1.4, *ca.* 1.4, H–C(3)); 3.54, 3.11 (2*dq*, *J* = 9.8, 7.0, MeCH_2O); 1.21 (*d*, *J* = 1.4, Me–C(4)); 0.92 (*t*, *J* = 7.0, *Me*CH_2O); decoupling: H–C(5)→H–C(3)(very br. *d*, *J* = 4.0), H–C(2)(*d*, *J* = 4.0); H–C(3)→H–C(5)(*s*), Me–C(4)(*s*); Me–C(4)→H–C(5)(sharp *d*, *J* = 1.4), H–C(3)(sharp *dd*, *J* = 4.0, 1.4). ^{13}C-NMR ($CDCl_3$): 131.6 (C(4) or C(6)); 125.8 (C(6) or C(4)); 117.6 (C(5)); 116.5 (C(3)); 96.4 (C(2)); 64.2 (MeCH$_2$O); 20.0 (*Me*–C(4)); 15.1 (*Me*CH$_2$O). EI-MS: 165 (7, M^+), 149 (27), 137 (9), 120 (84), 111 (36), 109 (27), 98 (27), 97 (46), 95 (28), 83 (47), 81 (36), 72 (55), 71 (45), 69 (88), 59 (100), 57 (70), 55 (63).

*Methyl (2*Z*,4*E*)-5-Ethoxy-3-methylpenta-2,4-dienoate* (**17**). *a*) A soln. of **15** in CD_3OD was left at r.t. According to ^{1}H-NMR monitoring conversion to **17** was 64% after 4 h and complete after 14 h. *b*) MeONa (0.108 g, 2 mmol) was added to a soln. of *cc*-**6** (0.247 g, 1 mmol) in Et_2O (5 ml). After 4 h at r.t., brine (10 ml) was added and the product extracted with Et_2O (2 × 15 ml). The Et_2O layer was washed with H_2O, dried (Na_2SO_4), and evaporated and the residue (0.14 g, 82%) purified by prep. TLC (hexane/AcOEt 4:1). R_f 0.34. UV (MeOH): 288. IR (neat): 3100*w*, 1710*vs*, 1620*vs*, 1600*s*, 1385*s*, 1240*vs*, 1195*vs*, 1155*vs*, 1052*s*, 945*m*. ^{1}H-NMR ($CDCl_3$): 7.21 (*d*, *J* = 13.1, H–C(5)); 7.02 (*d*, *J* = 13.1, H–C(4)); 5.43 (br. *q*, *J* = 1.2, H–C(2)); 3.94 (*q*, *J* = 7.0, MeCH_2O); 3.69 (*s*, MeO); 1.97 (*d*, *J* = 1.2, Me–C(3)); 1.33 (*t*, *J* = 7.0, *Me*CH$_2$O). NOE ($CDCl_3$): Me–C(3)→H–C(2) (4.8%), H–C(4) (6.1%), H–C(5) (1%); H–C(2)→Me–C(3) (14.5%). ^{13}C-NMR ($CDCl_3$): 167.2 (*s*, CO); 154.4 (*d*, C(5)); 150.9 (*s*, C(3)); 111.9 (*d*, C(4)); 104.3 (*d*, C(2)); 65.1 (*t*, MeCH$_2$O); 50.5 (*q*, MeO); 20.7 (*q*, *Me*–C(2)); 14.3 (*q*, *Me*CH$_2$O).

*Ethyl 6-Cyano-2-ethoxy-2*H*-pyran-4-carboxylate* (**18**). *a*) Pyridine (10 drops) was added to a soln. of *cc*/*ct*-**7** (0.31 g, 1 mmol) in Et_2O (10 ml). After 1 h at r.t., the mixture was filtered to remove the precipitated pyridinium bromide which was washed with Et_2O. The filtrate was evaporated at *ca.* 0°. The residue, redissolved in hexane, was filtered again and the filtrate evaporated: **18** (0.22 g). The analogous experiment with *tt*/*tc*-**7** led to the same result. *b*) FC of *cc*/*ct*-**7** (or *tt*/*tc*-**7**; 5 mmol) with CH_2Cl_2 (short column (2 × 10 cm) of neutral, acid, or basic alumina) led to oily **18** (1.11 g, quant.), after evaporation at 0°. On standing at r.t., **18** dimerized, but it was stable for longer periods of time when stored in the freezer. UV (hexane): 290 (3550). IR (film): 3070*m*, 2230*s*, 1725*vs*, 1645*s*, 1580*s*, 1370*s*, 1270*vs*, 1180*vs*, 1110*vs*, 1080*vs*, 1040*vs*, 990*vs*, 910*m*, 835*s*, 752*s*. ^{1}H-NMR ($CDCl_3$): 6.72 (*d*, *J* = 1.5, H–C(5)); 6.68 (*dd*, *J* = 4.0, 1.5, H–C(3)); 5.77 (*d*, *J* = 4.0, H–C(2)); 4.32 (*q*, *J* = 7.0, MeCH_2OOC); 3.98, 3.72 (2*dq*, *J* = 9.4, 7.1, MeCH_2O–C(2)); 1.34 (*t*, *J* = 7.0, *Me*CH$_2$OOC); 1.27 (*t*, *J* = 7.1, *Me*CH$_2$O–C(2)). ^{13}C-NMR ($CDCl_3$): 162.6 (*s*, COOEt); 126.8 (*s*, C(6)); 126.4 (*s*, C(4)); 125.2 (*d*, C(5)); 113.5 (*s*, CN); 111.9 (*d*, C(3)); 95.5 (*d*, C(2)); 64.9 (*t*, CH$_2$O); 61.6 (*t*, CH$_2$O); 14.9 (*q*, Me); 13.9 (*q*, Me). CI-MS: 224 (13, $[M + H]^+$), 223 (33, M^+), 197 (11), 195 (11), 194 (24), 178 (100), 166 (9), 151 (8), 150 (32), 138 (10), 122 (17), 121 (26), 113 (6), 112 (12), 105 (28), 103 (9), 99 (12), 95 (37), 84 (7), 83 (12).

Diethyl 2-(2-Ethoxyethenyl)but-2-enedioate (**20**). NaOEt in EtOH (2 mmol; prepared from 46 mg of Na and 5 ml of EtOH) was added dropwise within 30 min to a soln. of **18** (2 mmol) in Et_2O (10 ml). After 1 h at r.t., Et_2O (50 ml) was added, the soln. washed 2 times with H_2O (20 ml), dried (Na_2SO_4), and evaporated, and the oily residue (0.44 g) purified by FC: 0.39 g (80%) of oily **20**. UV (MeOH): 305 (82000). IR (neat): 3080*m*, 1720*vs*, 1710*vs*, 1615*vs*, 1585*s*, 1385*s*, 1365*s*, 1250*vs*, 1180*vs*, 1135*vs*, 1035*vs*, 945*s*, 870*s*, 855*s*, 783*s*. ^{1}H-NMR ($CDCl_3$): 7.45 (*d*, *J* = 13.0, EtOC*H*=CH); 6.99 (*dd*, *J* = 13.0, 0.6, EtOCH=C*H*); 6.06 (*d*, *J* = 0.6, H–C(2)); 4.28, 4.20 (2*q*, *J* = 7.1, 2 MeCH_2OOC); 3.97 (*q*, *J* = 7.1, MeCH_2O–CH=CH); 1.34, 1.33 (2*t*, *J* = 7.1, 2 *Me*CH$_2$OOC); 1.30 (*t*, *J* = 7.1 *Me*CH$_2$O–CH=CH). ^{13}C-NMR ($CDCl_3$): 166.6, 166.3 (2*s*, 2 COOEt); 157.8 (*d*, EtO*C*H=CH); 143.5 (*s*, C(3)); 116.4 (*d*, EtOCH=*C*H); 100.1 (*d*, C(2)); 65.8, 61.5, 60.2 (3 CH$_2$O); 14.5, 14.2, 14.1 (3 Me). EI-MS: 243 (7, $[M + H]^+$), 242 (44, M^+), 209 (6), 207 (7), 197 (40), 170 (15), 169 (30), 141 (33), 140 (17), 139 (18), 113 (49), 112 (100), 103 (19), 5 (89), 85 (53), 84 (53), 71 (68), 69 (57), 57 (77), 55 (46).

The same product was obtained by similar treatment of *cc*/*ct*-**7**.

Dimerization of **18**. When neat **18** was left at r.t. for 24 h, the partially crystalline product contained 25% of *'endo'*- and of 75% of *'exo'*-**21**. The same product resulted when a mixture of *tt*/*tc*-**7** (or *cc*/*ct*-**7**; 1.70 g) was passed through silica gel with hexane/AcOEt 1:5 (1.15 g, 92%). The prevalent crystalline *'exo'*-**21** was recrystallized from EtOH. The mother liquor contained *'endo'*/*'exo'*-**21** 2:1.

Diethyl 5,8β-Dicyano-3α,10α-diethoxy-4,9-dioxa-1β,2α-tricyclo[6.2.2.0^{2,7}]dodeca-5,11-diene-7α,11-dicarboxylate (*'exo'*-**21**). M.p. 143–144°. IR (KBr): 3085*s*, 2235*s*, 1742*vs*, 1710*vs*, 1655*s*, 1640*s*, 1375*vs*, 1350*s*, 975*vs*, 940*s*, 920*vs*, 860*vs*, 820*s*. ^{1}H-NMR ($CDCl_3$): 7.17 (*d*, *J* = 2.0, H–C(12)); 6.25 (br. *s*, H–C(6)); 5.01 (*d*, *J* = 1.4, H–C(3));

5.09 (*d*, *J* = 2.0, H–C(10)); 4.42, 4.33, 4.32, 4.27 (4*dq*, *J* = 7.1, 11, 2 $MeCH_2OOC$); 3.68(*A*), 3.53(*B*), 3.66(*A*), 3.44(*B*) (4*dq*, *J* = 9.7, 7, 2 $MeCH_2O$); 3.68 (*m*, H–C(1)); 3.27 (*m*, H–C(2)); 1.39, 1.33 (2*t*, each *J* = 7.1, 2 $MeCH_2OOC$); 1.17, 1.10 (2*t*, each *J* = 7, 2 $MeCH_2O$). ^{13}C-NMR ($CDCl_3$): 166.9 (*s*, *C*OOEt); 162.5 (*s*, *C*OOEt); 135.6 (*d*, C(12)); 134.1 (*s*, C(11)); 126.8 (*s*, C(5)); 116.3 (*d*, C(6)); 115.3 (*s*, CN); 113.2 (*s*, CN); 99.3, 98.9 (2*d*, C(3) or C(10)); 71.4 (*s*, C(8)); 64.5, 63.7 (2*t*, 2 $MeCH_2OOC$); 63.2, 61.5 (2*t*, 2 $MeCH_2O$); 52.6 (*s*,C(7)); 40.6, 37.9 (2*d*, C(1) or C(2)); 14.62, 14.57, 13.9, 13.8 (4*t*, 4 Me). EI-MS: 446 (1, M^+), 401 (2), 400 (3), 355 (22), 354 (100), 300 (11), 281 (5), 223 (11), 195 (21), 194 (56), 178 (20), 166 (20), 121 (12), 103 (9), 95 (19). CI-MS: 464 (100, $[M + NH_4]^+$), 447 (12, $[M + H]^+$), 446 (4, M^+), 401 (13), 400 (9), 355 (19), 354 (65), 300 (4), 223 (7), 195 (7), 194 (10), 178 (17), 166 (2), 121 (3), 103 (2), 95 (4).

Structure determination of '*exo*'-**21** by X-ray crystallography: summary of data *Table 2*; all other data (bond length, angles *etc.*) were deposited with the *Cambridge Crystallographic Data Center*.

Diethyl 5,8α-Dicyano-3α,10β-diethoxy-4,9-dioxa-1α,2α-tricyclo[6.2.2.0 ^{2,7}]dodeca-5,11-diene-7α,11-dicarboxylate ('*endo*'-**21**). ^{1}H-NMR ($CDCl_3$): 7.20 (*d*, *J* = 2.0, H–C(12)); 6.34 (br. *s*, H–C(6)); 5.14 (*d*, *J* = 1.4, H–C(3)); 5.13 (*d*, *J* = 2, H–C(10)); 4.5–4.2 (*m*, 2 $MeCH_2OOC$); 3.9–3.4 (*m*, 2 $MeCH_2O$); 3.69 (*m*, H–C(1)); 2.65 (*m*, H–C(2)); 1.39, 1.31 (2*t*, each *J* = 7.1, $MeCH_2OOC$); 1.27, 1.20 (2*t*, each *J* = 7.1, $MeCH_2O$); from decoupling exper.: *J*(H–C(1), H–C(2)) = 2.3, *J*(H–C(1), H–C(10)) = 2.2, *J*(H–C(1), H–C(12)) = 1.9, *J*(H–C(2), H–C(3)) = 1.4, *J*(H–C(2), H–C(6)) = 0.6. ^{13}C-NMR ($CDCl_3$): 168.2 (*s*, *C*OOEt); 162.5 (*s*, *C*OOEt); 136.2 (*s*, C(12)); 135.8 (*s*, C(11)); 127.9 (*s*, C(5)); 117.1 (*d*, C(6)); 115.4 (*s*, CN); 113.6 (*s*, CN); 100,3, 96.0 (2*d*, C(3) or C(10)); 70.7 (*s*, C(8)); 64.9, 64.0 (2*t*, 2 $MeCH_2OOC$); 63.3, 61.7 (2*t*, 2 $MeCH_2O$); 51.3 (*s*, C(7)); 40.6, 38.2 (2*d*, C(1) or C(2)); 14.8, 14.7 (2*q*, 2 $MeCH_2O$); 14.0, 13.8 (2*q*, 2 $MeCH_2OOC$).

*Ethyl 6-Cyano-2-ethoxy-3,4-dihydro-2*H*-pyran-4-carboxylate* ('*t*-**6**' in [7]). Et_3N (10 drops) was added to the soln. of '*c*/*t*-**6**' [7] 95:5 (0.3 g) in EtOH (5 ml). The solvent was removed *in vacuo* after 24 h, and the residue, '*c*/*t*-**6**' [7] 28:72, taken for ^{1}H-NMR ($CDCl_3$): 5.90 (*dd*, *J*(4α,5) = 3.0, *J*(3α,5) = 1.3, H–C(5)); 5.19 (*dd*, *J*(2β,3α) = 3.1, *J*(2β,3β) = 2.5, H_β–C(2)); 4.20 (*q*, *J* = 7.2, $MeCH_2OOC$); 3.88, 3.63 (2*dq*, each *J* = 9.7,7.0, $MeCH_2O$–C(2)); 3.45 (*ddd*, *J*(3β,4α) = 11.0, *J*(3α,4α) = 6.3, *J*(4α,5) = 3.0, H–C(4)); 2.19 (*dddd*, *J*(3α,3β) = 13.9, *J*(3α,4α) = 6.3, *J*(2β,3α) = 3.1, *J*(3α,5) = 1.3, H–C(3)); 2.01 (*ddd*, *J*(3α,3β) = 13.9, *J*(3β,4α) = 11.0, *J*(2β,3β) = 2.5, H–C(3)); 1.29 (*t*, *J* = 7, $MeCH_2OOC$); 1.23 (*t*, *J* = 7, $MeCH_2O$–C(2)). NOE ($CDCl_3$): H–C(5)→H_β–C(2) (1.5%), H_β–C(3) (1.8%), H_α–C(3) (2.4%), H_α–C(4) (7.0%); H_α–C(2)→H_β–C(3) (3.8%), H_α–C(3) (4.3%), H_α–C(4) (2.4%), H–C(5) (0.6%); H_α–C(4)→H_β–C(2) (3.4%), H_β–C(3) (3.2%), H_α–C(4) (6.5%), H–C(5) (9.5%); H_β–C(3)→H_β–C(2) (4.7%), H_α–C(3) (24.2%), H_a–C(4) (2.6%), H–C(5) (1.8%); H_α–C(3)→H_β–C(2) (6.4%), H_β–C(3) (25.2%), H_α–C(4) (8.7%), H–C(5) (2%). Data of '*c*-**6**' were as reported.

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