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Stereoselective Sequential Photochemical Cycloaddition - Iminium Ion - Propargylsilane Cyclization. Synthesis of Quinolizidines and Pyrido[1,2-a]azepines

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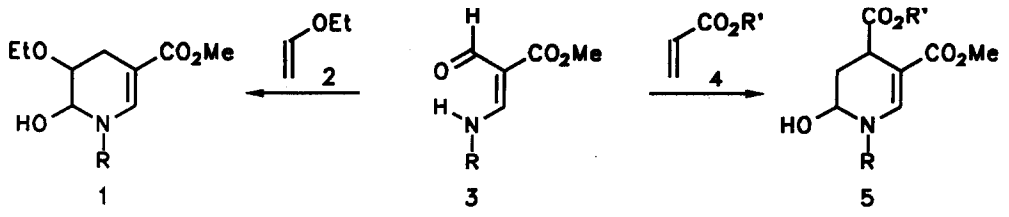
Abstract: - *Photochemical cycloaddition of the enaminecarbaldehydes* ***15*** *and* ***16*** *with the acrylic acid derivatives* ***20a-c*** *gave the 2-hydroxytetrahydropyridines* ***21a-c*** *and* ***24a-c****, respectively which cyclize on treatment with trifluoroacetic acid or Lewis acids to furnish the quinolizidines* ***22a-c*** *and pyrido[1,2-a]azepines* ***25a-c****, respectively in good yields and with high 1,3-induced diastereoselectivity. Indolizidines* ***27*** *cannot be prepared by this method.*

A major interest in organic chemistry is the development of new synthetic methods which are not only highly selective but also highly efficient and which do not depend upon toxic reagents or solvents[1]. A promising approach to this issue is the development of new sequential transformations. In this respect we invented the *tandem*-Knoevenagel *hetero*-Diels-Alder reaction,[1] the *tandem*-Knoevenagel-ene reaction,[2] the tandem-Knoevenagel-allylsilane cyclization[3] and the iminium-aza-ene transformation[4] which allow the diastereo- and enantioselective synthesis of a multitude of different heterocycles and also carbocyclic derivatives in a simple fashion. In this paper we describe a new type of sequential transformation which consists of a photochemical cycloaddition of an enaminecarbaldehyde to give an iminium salt that reacts intramolecularly with a propargylsilane moiety. The method allows the stereoselective synthesis of quinolizidines and pyrido[1,2-a]azepines.

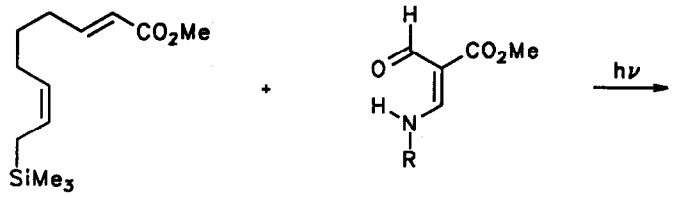
Recently, we have shown that enaminecarbaldehydes **3**[5] undergo a photochemical cycloaddition with alkenes on irradiation using a high pressure mercury lamp to give 2-hydroxytetrahydropyridines.[6] It can be assumed that **3** reacts from the triplet state[7] to give a cyclobutane first, which opens and cyclizes again. In

the reaction electron-deficient as well as electron-rich alkenes may be used. The reaction is highly regioselective, thus, with enol ethers **2** only the 3-substituted compounds **1**, and with electron-deficient alkenes such as acrylates **4** only the 4-substituted tetrahydropyridines **5**, are obtained. Compounds of type **5** easily undergo elimination of water on treatment with acids to give the pharmacologically valuable 1,4-dihydropyridines[8] presumably via an iminium salt.



1 3 5

Iminium salts are also valuable intermediates in the C-C-bond formation.[4,9] Thus, in the presence of aromatic rings[10] or allysilane moieties,[11] the hydroxytetrahydropyridines form a C-C-bond on treatment with acids. In this respect, **7**, which is obtained by photochemical cycloaddition of **3** and **6**, leads to the annulated piperidine **8** as a single diastereomer. In the described example, the allylsilane moiety is part of the employed alkene, however, the cyclization terminator may also be part of the enaminecarbaldehyde which allows the construction of new heterocycles of the quinolizidine and pyrido[1,2-a]azepines, depending upon the length of the tether. For this reason the enaminecarbaldehydes **15** and **16**, with a propargylsilane moiety, were synthesized and the photochemical cycloaddition with various alkenes followed by cyclization with Lewis acids was investigated.



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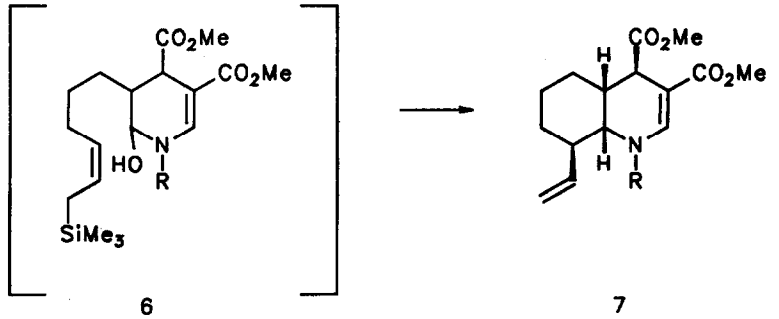

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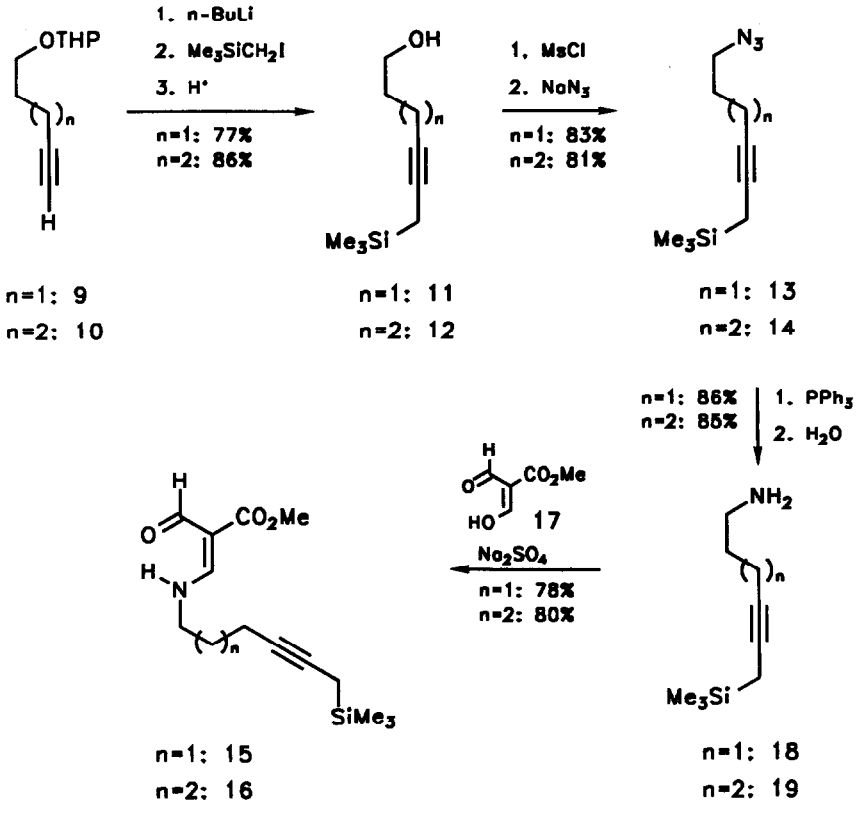
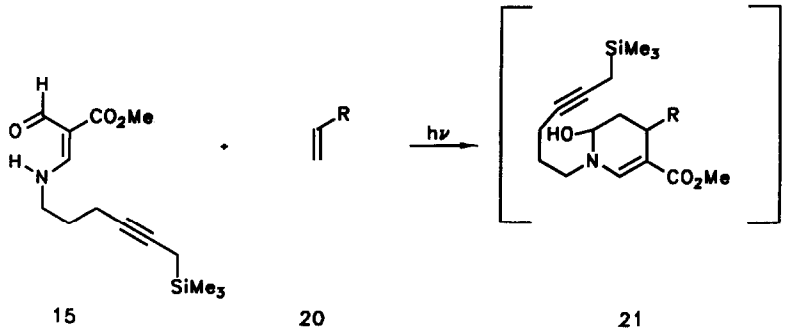
For the preparation of the enaminecarbaldehydes **15** and **16**, methyl diformylacetate[12] **17** was condensed with the amines **18** and **19**, respectively, which were obtained according to scheme 1 in 54% and 59% overall yield starting from the readily available protected alkynols[13] **9** and **10**. Alkylations of **9** and **10** with iodomethyltrimethylsilane[14] using standard conditions gave the alcohols **11** and **12** after acid catalyzed removal of the protecting group. Conversion of the hydroxy function in **11** and **12** into an amino group was performed via the well known sequence of mesylation, replacement with sodium azide and subsequent reduction with triphenylphosphine.[15] The condensation of diformylacetate **17** with the primary amines **18** and **19** proceeds well and mildly in the presence of sodium sulfate as a water removing agent at room temperature within a few hours.



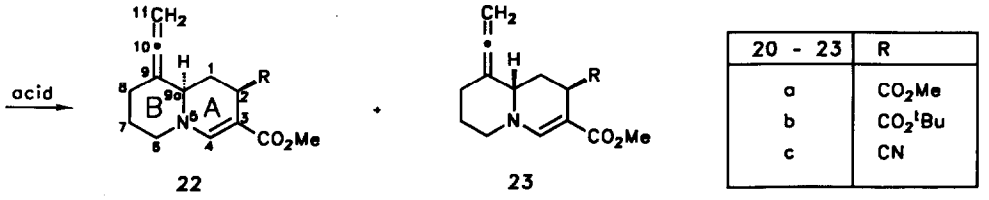
Scheme 1. Synthesis of enaminecarbaldehydes **15** and **16**

For the photochemical cycloadditions of the enaminecarbaldehydes **15** and **16**, the electron-deficient alkenes, methyl acrylate **20a**, *tert*-butyl acrylate **20b**, and acrylonitrile **20c** were used. Thus, irradiation of a solution of **15** and a 50-fold excess of the alkenes **20a-c** in dichloromethane at -15 to -25°C with a mercury high-pressure lamp in a pyrex ring reactor[16] ($\lambda > 280$ nm) gave the 2-hydroxytetrahydropyridines **21a**, **21b** and **21c**, respectively in almost quantitative yields. Prior to the treatment of acids the excess alkenes have to be removed since polymerization takes place. After all volatiles were distilled off in vacuo, the residue was

dissolved in dichloromethane (1.5 ml/mmol), cooled to -78°C and different Lewis acids were added (1.1 equivalents, Table 1). Cyclization was usually complete after 1-2 h, whereupon after quenching with water and work up the products were purified by chromatography on silica gel. The diastereoselectivity of the cyclization was determined by gas chromatography of the crude product mixture. In all cases the quinolizidines **22a**, **22b** and **22c**, respectively, were isolated as main products in good overall yield. The second possible diastereomers **23a-c** were found in less than 7.2 to 1.1% depending upon the substrate and the Lewis acid used; the minor compounds could not be obtained in a pure form, but were identified by GC-MS spectroscopy, showing nearly identical fragmentation patterns as the main products. The best promoter for the cyclization was trimethylsilyl trifluoromethanesulfonate, although the selectivity was higher using boron trifluoride etherate (Table 1). The cyclization can also be achieved within 2-5 min by employing trifluoroacetic acid at room temperature; however, the acid has to be used as solvent, since otherwise (4 equiv., -78°C, CH_2Cl_2) only dehydration takes place to give the corresponding 1,4-dihydropyridines.



15 20 21



22 23

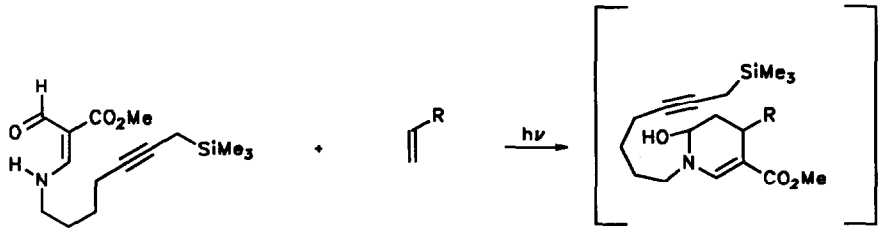
20 - 23	R
a	CO_2Me
b	$CO_2{}^tBu$
c	CN

In a similar way as **15**, also the enaminecarbaldehyde **16** can be used in the sequence. Irradiation of **16** and **20a-c** gave the 2-hydroxytetrahydropyridines **24a-c**, which led to **25a-c** as the main products upon treatment with trifluoroacetic acid or Lewis acids. The other possible diastereomers **26a-c** were formed again in only minor quantities (Table 2).

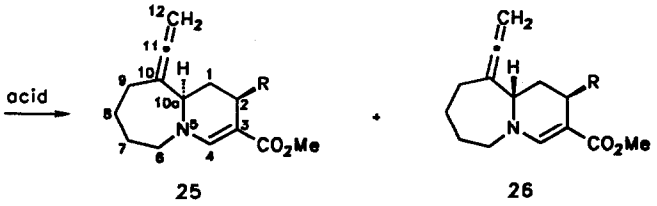
Table 1. Sequential Photochemical Cycloaddition - Iminium Ion Cyclization of **15** and **20a-c**

Substrates	Lewis Acid	Solvent	Isolated overall yields (%)	Product ratio[a] **22 : 23**
15 + 20a	---	CF_3COOH	55	11.3 : 1
15 + 20a	TMSOTf	CH_2Cl_2	65	13.9 : 1
15 + 20a	$BF_3 \cdot Et_2O$	CH_2Cl_2	61	27.8 : 1
15 + 20a	$SnCl_4$	CH_2Cl_2	58	12.8 : 1
15 + 20a	$TiCl_4$	CH_2Cl_2	43	23.4 : 1
15 + 20b	---	CF_3COOH	65	44.9 : 1
15 + 20b	TMSOTf	CH_2Cl_2	73	35.5 : 1
15 + 20b	$BF_3 \cdot Et_2O$	CH_2Cl_2	60	63.8 : 1
15 + 20b	$SnCl_4$	CH_2Cl_2	57	43.5 : 1
15 + 20b	$TiCl_4$	CH_2Cl_2	49	59.0 : 1
15 + 20c	---	CF_3COOH	55	63.0 : 1
15 + 20c	TMSOTf	CH_2Cl_2	56	58.4 : 1
15 + 20c	$BF_3 \cdot Et_2O$	CH_2Cl_2	48	86.3 : 1
15 + 20c	$SnCl_4$	CH_2Cl_2	44	73.8 : 1
15 + 20c	$TiCl_4$	CH_2Cl_2	33	69.8 : 1

[a]Determined by GC.



16 20 24



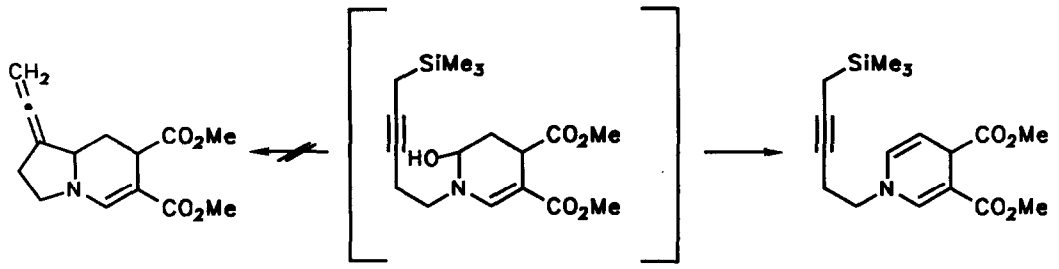
20,24-26	R
a	CO_2Me
b	$CO_2{}^tBu$
c	CN

Table 2. Sequential Photochemical Cycloaddition - Iminium Ion Cyclization of **16** and **20a-c**

Substrates	Lewis Acid	Solvent	Isolated overall yields (%)	Product ratio[a] **25 : 26**
16 + 20a	---	CF_3COOH	64	11.6 : 1
16 + 20a	TMSOTf	CH_2Cl_2	66	12.9 : 1
16 + 20a	$BF_3 \cdot Et_2O$	CH_2Cl_2	60	26.6 : 1
16 + 20a	$SnCl_4$	CH_2Cl_2	56	13.4 : 1
16 + 20a	$TiCl_4$	CH_2Cl_2	42	21.2 : 1
16 + 20b	---	CF_3COOH	70	19.2 : 1
16 + 20b	TMSOTf	CH_2Cl_2	73	25.1 : 1
16 + 20b	$BF_3 \cdot Et_2O$	CH_2Cl_2	68	32.2 : 1
16 + 20b	$SnCl_4$	CH_2Cl_2	61	16.7 : 1
16 + 20b	$TiCl_4$	CH_2Cl_2	41	25.5 : 1
16 + 20c	---	CF_3COOH	53	31.3 : 1
16 + 20c	TMSOTf	CH_2Cl_2	48	45.6 : 1
16 + 20c	$BF_3 \cdot Et_2O$	CH_2Cl_2	41	69.3 : 1
16 + 20c	$SnCl_4$	CH_2Cl_2	40	43.8 : 1
16 + 20c	$TiCl_4$	CH_2Cl_2	30	53.9 : 1

[a] Determined by GC.

Interestingly, the preparation of indolizidines **27** was not possible using this method. Thus, treatment of the 2-hydroxytetrahydropyridine **28**, which was obtained by photochemical cycloaddition in the usual way, gave mainly the 1,4-dihydropyridine **29** on treatment of acids. In this case the elimination of a proton is faster than the addition to the intermediate iminium ion.



27 28 29

The structure determination of the products **22a-c** and **25a-c** is based mainly on NMR-spectroscopy. Thus ^{1}H-NMR spectra of the diastereomers **22a-c** show characteristic doublets of doublets of doublets for the $H_{ax}C$ (1) with J = 14 - 14.5, J = 10 - 11 and J = 5 - 6 Hz at δ = 1.85 - 1.95 and a similar pattern for the $H_{eq}C$ (1) with J = 14 - 14.5, 2.5 - 4.0 and J = 2.5 - 3.0 Hz at δ = 2.17 - 2.23. The HC (2) resonates at δ = 3.5 - 3.7 as doublets of doublets with J = 5.5 - 6.0 and J = 2.5 - 4.0 Hz and HC (9a) at δ = 3.5 - 3.6 as doublets of doublets of triplets with J = 10 - 11 Hz, J = 2.5 - 4 Hz and J = 3 - 4 Hz; the latter is due to a coupling with the allenic protons. On the sole basis of the NMR data an unambiguous assignment was not possible; therefore two dimensional NOE experiments with **22a** were performed. The $H_{ax}C$ (6) shows NOE effects with $H_{eq}C$ (7), $H_{ax}C$ (8), $H_{eq}C$ (6) and HC (9a) and the $H_{ax}C$ (1) shows NOE effects with $H_{eq}C$ (1), $H_{eq}C$ (2) and HC (9a). These effects could only be observed, if $H_{ax}C$ (1), $H_{ax}C$ (6) and HC (9a) were on the same side of the ring system. Thus, the NMR data of **22a-c** together with the NOE experiments of **22a** clearly show that the substituent at C-2 holds a pseudoaxial orientation; HC (9a) has an axial orientation according to ring B and its relationship is assigned *cis* to HC (2).

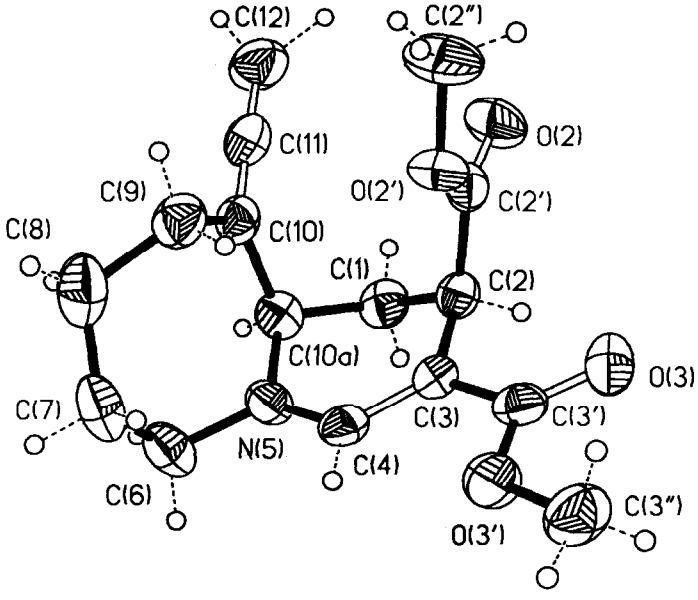


Figure 1. Thermal ellipsoid plot of the molecule **25a** showing the atom numbering

The higher population of the conformation with the pseudoaxial arrangement of the substituent at C-2 is in agreement with our findings with similarly substituted dihydropyrans.[17] The ^{1}H-NMR spectra of **25a-c** are nearly identical to those of **22a-c** with the exception that the coupling constant $J_{2\text{-H, }1\text{-Hax}}$ = 4.5 - 8.0 Hz was larger than that found for the corresponding quinolizidines **22a-c**. To conform the configuration of **25a-c** an X-ray structure analysis of **25a** was performed. As expected, the thermal ellipsoid plot shows a pseudoaxial orientation of the ester group at C-2 and a half-chair conformation of the tetrahydropyridine moiety (Figure 1).

DISCUSSION

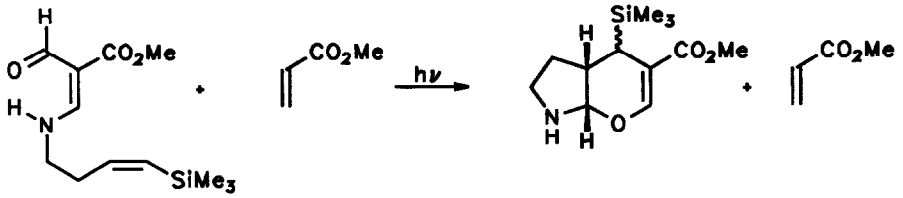
The C-C bond formation via iminium salts is a general principle in biosynthesis[18] and also a widely used method in preparative organic chemistry.[4,9] In the electrophilic cyclization of iminium salts allyl,[19]- vinyl[20]- and propargylsilanes[21] are most suitable as terminators though simple alkenes[4] and alkynes[22] may also be employed. The iminium salts are usually obtained from appropriate amines or carbamates and formaldehyde or other reactive aldehydes and ketones. In addition, reduction of imides followed by elimination of water, decarboxylation of α-amino acids, elimination of cyanide from α-aminonitriles or alcohols from N,O-acetals and cleavage of aminals can be used. In the described sequential photochemical cycloaddition - iminium ion formation - progargylsilane cyclization, a new synthesis of iminium ions is described. In a photochemical [2 + 2] cycloaddition of enaminecarbaldehydes and alkenes, tetrahydropyridines containing an α–aminoalcohol moiety are prepared, which form iminium salts on treatment with acids.

In sequential transformations the reactivity of the different functional groups has to be adjusted quite carefully. Though we have shown that in the intermolecular photochemical cycloaddition of enaminecarbaldehydes, alkenes with electron-withdrawing groups are much more reactive than allyl- and vinylsilanes,[11] the picture changes completely using enaminecarbaldehydes such as **30** with a vinylsilane moiety. Even employing a 100-fold excess of methyl acrylate, **31** was obtained as the only compound via an intramolecular cycloaddition. Similar intramolecular cycloadditions using enaminoketones to give cyclobutanes have recently been described by Winkler.[23] In our sequential approach we therefore used a propargylsilane moiety as a terminator for the electrophilic cyclization which does not undergo a photochemical cycloaddition.

In the final cyclization step, two diastereomers may be obtained. Though the inducing centre of chirality is in the 3-position to the newly formed stereogenic centre, the induction is quite high (Table 1 and 2). It can be assumed that the electrophilic cyclization proceeds under kinetic control, since the pure products do not isomerize under reaction conditions. There is no dramatic effect on the stereochemical outcome by using either Brønsted or Lewis acids, modifying the size or character of the substituent at C-5 or changing the tether to give either the six- or seven-membered ring azacyclic series. In both series the highest selectivity was obtained with the compounds bearing a cyano group at C-4 using boron trifluoride etherate. As expected, fluoride does not promote the reaction. On the basis of these observations we conclude that the function of the acid is to generate the iminium ion from the aminoalcohol moiety only and the formation of metal complexes as described for many other transformations[24] is not necessary to explain the obtained

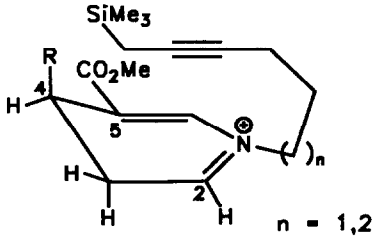
stereoselectivity. We can not exclude, that in the process also 1,4-dihydropyridines are formed intermediately, which are in equilibrium with the iminium salts. Thus, treating the corresponding 1,4-dihydropyridines with Brønsted or Lewis acids gave the azabicyclic compounds, however, in lower yields.

How can we explain the observed stereoselectivity? We assume that the reactive conformation is governed by minimizing steric and dipole-dipole interactions of the ester moiety at C-5 and the substituent at C-4 pushing the latter group into a pseudoaxial orientation, though 1,2-allylic strain is usually small relative to 1,3-allylic strain.[17,25]



30 20a 31 20a

The attack of the propargylsilane group at the iminium moiety via **32** must now take place along a trajectory of about 109° *syn* to the substituent at C-4 to allow an energetically favoured transition structure.[26] This assumption would nicely fit in with the observed preferred formation of **22a-c** and **25a-c** with a *trans*-arrangement of the substituent at C-4 and the bridgehead hydrogen.



32

Also the failure to prepare pyrrolizidines using this method fits in the picture. Models clearly show that in the case of the shorter tether the appropriate geometry can not be obtained; thus, it is well known that 5-*endo*-trig ring closure reactions are disfavoured.[27] Therefore, as the more favoured reaction, elimination of a proton from the intermediate iminium ion to give the corresponding 1,4-dihydropyridine is observed.

CONCLUSION

The sequential photochemical cycloaddition - iminium ion formation - propargylsilane cyclization is a new method for the stereoselective formation of quinolizidines and other annulated tetrahydropyridines with

the nitrogen at the bridgehead position. The transformation implies a novel type of sequential pathway which allows to perform the synthesis of these compounds in a highly efficient mode starting from simple substrates. In addition a new procedure for the preparation of the synthetically valuable iminium ions is presented. In the first step a chemoselective intermolecular photochemical cycloaddition with an alkene takes place to give a 2-hydroxytetrahydropyridine. The α–aminoalcohol moiety in this compound is transformed by Brønsted or Lewis acids to form an iminium salt which reacts in an electrophilic cyclization with the present propargylsilane moiety. The high 1,3-induced diastereoselectivity can be explained by a reactive conformation **32** with a pseudoaxial orientation of the substituent at C-4 and stereoelectronically controlled *syn* attack of the propargylsilane moiety. Interestingly, the observed stereochemistry for the main products **22a-c** and **25a-c** stays in contrast with the findings of Spitzner and Wenkert[28] in their synthesis of vallesiachotamine using a related cyclization step. One has to assume that the conformation of the transition structures must be different in both cases, because of the different nature of the substituents at the dihydropyridinium salts, or the cyclization in the synthesis of vallesiachotamine is thermodynamically controlled. The procedure is of general interest, since many different alkenes may be employed; however, there are some restrictions: vinylsilanes and presumably also allylsilanes, though this has not been investigated so far, can not be used, since intramolecular photochemical cycloaddition takes place. Also the synthesis of pyrrolizidines could not be achieved by employing the described sequence, since an appropriate geometry of the transition state is not accessible; therefore, elimination of a proton to give the 1,4-dihydropyridine is faster than the addition.

EXPERIMENTAL

^1H and ^{13}C NMR: Varian VXR-500S, XL-200, VXR-200, and FT-80 A; Bruker AMX 300; multiplicities were determined with APT pulse sequence; assignments with an asterisk are uncertain. - MS: Varian MAT 311A; GC-MS: Varian 3400, Finnigan MAT INCOS 50. - IR: Bruker IFS 25. - UV: Varian Cary 219. - GC: Varian 3700 with Merck-Hitachi D-2000; Machery-Nagel & Co, 0.25 μm, chemically bound SE 30, 0.32 mm x 50 m fused silica. - Elemental analyses were carried out in the analytical laboratory of the university. - X-ray structure determination: A specimen of 0.3x0.3x0.6 mm was investigated at room temperature on a STOE four-circle diffractometer AED2 rev 6.2 with monochromated Mo-Kα radiation. The unit cell constants were determined by refinement of 40 reflections in the range $2\theta = 20° \ldots 30°$: a = 5.925(1), b = 15.014(3); c =17.081(2)Å: 1774 reflection intensities up to $2\theta = 45°$ were measured in profile fitted 2θ–ω scans. The structure was solved in the orthorhombic space group $P2_12_12_1$ by direct methods with Shelxs-86 and the nonhydrogen atoms refined anisotropically by Shelx-76. For 1279 unique observed reflections ($F > 3\sigma(F)$) the final R values were R = 0.040, wR = 0.039, $w^{-1} = \sigma^2(F) + 0.0004F^2$. The hydrogen atoms were positioned geometrically and refined riding on their carbon atoms. Further information such as the anisotropic displacement parameters, hydrogen atom coordinates, the calculated and observed structure factors can be ordered at the Fachinformationszentrum Karlsruhe, Gesellschaft für wissenschaftlich-technische Information mbH, D-7514 Eggenstein-Leopoldshafen 2, by referencing the deposition number CSD 55626 and the authors. - Photochemical transformations were done with a high pressure mercury lamp TQ 718 (500 watt) or TQ 150 (150 watt) from Fa. Heraeus using a pyrex filter. - All solvents were destilled prior to use. - Reagents and materials were obtained from commercial suppliers and

used without further purification. - All reactions were carried out under argon and monitored by TLC (Machery-Nagel Polygram SIL G/UV_{254}). Products were isolated by column or flash chromatography (CC or FC) on SiO_2 (CC: ICN Silica 63-200, 60 A, ICN Biochemicals, Eschwege; FC: Baker 30-60 active). - Solvents used for TLC and column chromatography: solvent A, ether : petroleum ether = 1 : 1; solvent B, ether : petroleum ether = 1 : 2; solvent C, ether : petroleum ether = 1 : 20; solvent D, EtOAc : petroleum ether = 1 : 2; solvent E, EtOAc : petroleum ether = 1 : 4.

Preparation of the silylated alkynols 11 and 12: The silylated alkynols were prepared following a method used by Hiemstra and Speckamp[14] to synthesize 6-(trimethylsilyl)-4-hexyn-1-ol. To a magnetically stirred solution of THP-ether of the alkynol **9** or **10** (100 mmol) in dry THF (100 ml) at -30°C under argon is added dropwise a 10 M solution of *n*-butyllithium (102 mmol) in hexane. After stirring for 15 min at -30°C and 15 min at 0°C, iodomethyltrimethylsilane[14] (110 mmol) is added. Then the reaction flask is covered with aluminium foil, and the mixture (light-sensitive) is heated for 20 h at 58-60°C. After cooling to room temperature, ether/petroleum ether (1 : 1, 250 ml) is added, and the organic layer is washed with water (3 x 100 ml), brine (100 ml), dried ($MgSO_4$), and concentrated in vacuo. The yellow oil obtained is dissolved in methanol (250 ml) containing concentrated H_2SO_4 (0.1 ml), and the solution is stirred for 16 h at room temperature. Then the mixture is diluted with ether/petroleum ether (1 : 1, 250 ml) and successively washed with satd. $NaHCO_3$ solution (250 ml), water (2 x 250 ml), and brine (250 ml), dried ($MgSO_4$), and concentrated in vacuo. The residue is distilled to give the silylated alkynols as colorless liquids.

6-(Trimethylsilyl)-4-hexyn-1-ol 11: Yield 77%. - R_f (solvent B) = 0.58. - b.p. = 74°C (0.2 mbar). - IR (film): ν = 3346 cm^{-1} (-OH), 2954, 2902, (CH), 2222 (alkyne), 1436 (CH_2), 1250, 856 ($SiMe_3$). - ^{1}H-NMR ($CDCl_3$): δ = 0.05 (s, 9 H, $SiMe_3$), 1.37 (t, *J* = 3.2 Hz, 2 H, 6-H), 1.69 (tt, *J* = 7.0 Hz, 2 H, 2-H), 2.24 (mc, 2 H, 3-H), 2.45 (br.s, 1 H, -OH), 3.72 (t, *J* = 7.0 Hz, 2 H, 1-H). - MS (70 eV): *m/z* (%) = 155 (5) [M^+ - CH_3], 153 (1) [M^+ - OH], 125 (2) [M^+ - 3 x CH_3], 111 (3) [M^+ - C_3H_7O], 97 (3) [M^+ - $SiMe_3$], 83 (3) [M^+ - CH_2SiMe_3], 73 (100) [$SiMe_3$], 59 (7) [M^+ - $C_6H_{11}Si$], 43 (12) [$SiCH_3$].

7-(Trimethylsilyl)-5-heptyn-1-ol 12: Yield 86%. - b.p. = 80°C (0.2 Torr). - IR (film): ν = 3344 cm^{-1} (O-H), 2950, 2942 (CH), 2222 (alkyne), 1436 (CH_2), 1170 (C-O), 1250, 850 ($SiMe_3$). - UV (acetonitrile): λ_{max} (lg ε) = 222 nm (2.696). - ^{1}H-NMR ($CDCl_3$): δ = 0.02 (s, 9 H, $SiMe_3$), 1.39 (t, *J* = 1.0 Hz, 2 H, 7-H), 1.48 - 1.70 (m, 4 H, 2-H, 3-H), 1.93 (br. s, 1 H, OH), 2.16 (m, 2 H, 4-H), 3.65 (t, *J* = 7.6 Hz, 2 H, 1-H). - ^{13}C-NMR ($CDCl_3$): δ = -2.05 ($SiMe_3$), 6.94 (C-7), 18.72 (C-3), 25.71 (C-4), 31.84 (C-2), 62.36 (C-1), 75.53* (C-6), 78.74* (C-5). - MS (70 eV): *m/z* (%) = 184 (5) [M^+], 169 (8) [M^+ - CH_3], 153 (4) [M^+ - CH_2OH], 111 (3) [M^+ - $SiMe_3$], 80 (6) [M^+ - $C_4H_{12}OSi$], 73 (100) [$SiMe_3$], 59 (9) [C_3H_7O]. - Anal. Calcd for $C_{10}H_{20}OSi$ (184.4): C, 65.15; H, 10.93. Found: C, 65.29; H, 10.93%.

Preparation of the azides 13 and 14: A solution of **11** or **12** (100 mmol) in CH_2Cl_2 (500 ml) is treated at 0°C successively with methanesulfonyl chloride (105 mmol) and triethylamine (120 mmol). The mixture is stirred for 1 h at 0°C, poured onto ice-water (250 ml) and the layers are separated. The organic layer is washed with water (2 x 250 ml), brine (250 ml), dried ($MgSO_4$) and all volatiles are removed in vacuo. The residue is dissolved in DMSO (200 ml) and sodium azide (150 mmol) is added at room temperature. After the reaction has been stirred overnight, the mixture is poured onto ice-water (200 ml) and extracted with ether (4 x 100 ml). The combined organic layers are washed with brine (100 ml), dried

($MgSO_4$), and concentrated in vacuo. The resulting oil is purified by flash-chromatography (solvent C) to give the azides as colourless liquids.

6-Azido-1-trimethylsilyl-2-hexyne 13: Yield 83%. - R_f = 0.45 (solvent B). - IR (film): ν = 2955 cm^{-1}, 2882 (CH), 2222 (alkyne), 2100 (N_3), 1438 (CH_2), 1346, 1294 (N_3), 1250, 850 ($SiMe_3$). - ^{1}H-NMR ($CDCl_3$): δ = 0.07 (s, 9 H, $SiMe_3$), 1.40 (t, *J* = 2.5 Hz, 2 H, 1-H), 1.72 (tt, *J* = 7.0 Hz, *J* = 7.0 Hz, 2 H, 5-H), 2.25 (tt, *J* = 7.0 Hz, *J* = 2.5 Hz, 2 H, 4-H), 3.38 (t, *J* = 7.0 Hz, 2 H, 6-H). - ^{13}C-NMR ($CDCl_3$): δ = -1.84 ($SiMe_3$), 7.13 (C-1), 16.47, 28.78 (C-4, C-5), 50.53 (C-6), 76.65* (C-2), 77.00* (C-3). - MS (70 eV): *m/z* (%) = 180 (0.3) [M^+ - CH_3], 167 (4), 166 (25), 152 (36), 139 (24), 124 (17), 73 (100) [$SiMe_3$]. - Anal. Calcd for $C_9H_{17}N_3Si$ (195.3): C, 55.35; H, 8.77. Found: C, 55.34; H, 8.56%.

7-Azido-1-trimethylsilyl-2-heptyne 14: Yield 81%. - R_f = 0.50 (solvent B). - IR (film): ν = 2952 cm^{-1}, 2880 (CH), 2220 (alkyne), 2090 (N_3), 1438 (CH_2), 1332, 1292 (N_3), 1250, 850 ($SiMe_3$). - ^{1}H-NMR ($CDCl_3$): δ = 0.01 (s, 9 H, $SiMe_3$), 1.33 (t, *J* = 2.5 Hz, 2 H, 1-H), 1.37 - 1.72 (m, 4 H, 5-H, 6-H), 2.01 (tt, *J* = 6.5 Hz, *J* = 2.5 Hz, 2 H, 4-H), 3.21 (t, *J* = 7.0 Hz, 2 H, 7-H). - ^{13}C-NMR ($CDCl_3$): δ = -2.19 ($SiMe_3$), 6.82 (C-1), 18.40, 26.33, 27.88 (CH_2), 50.96 (C-7), 77.72* (C-2), 78.08* (C-3). - MS (70 eV): *m/z* (%) = 194 (0.3) [M^+ - CH_3], 181 (5), 180 (24), 166 (53), 152 (28), 138 (23), 73 (100) [$SiMe_3$]. - Anal. Calcd for $C_{10}H_{19}N_3Si$ (209.4): C, 57.37; H, 9.15. Found: C, 57.82; H, 9.16%.

Preparation of the amines 18 and 19: To a solution of the azide **13** or **14** (100 mmol) in dry THF (100 ml) is slowly added through a dropping funnel a solution of triphenylphosphine (100 mmol) in dry THF (20 ml). After complete addition, the mixture is stirred at room temperature for 16 h until the gas production has ceased, water (100 mmol) is added and the reaction is stirred for additional 5 h at room temperature. After removal of all volatiles in vacuo the residue is resolved in pentane (100 ml) and the mixture is cooled to 0°C to crystallize triphenylphosphinoxid, which is sucked off. This procedure is repeated several times until no more triphenylphosphinoxid precipitates. The solvent is removed in vacuo and the residue is distilled to give a colourless oil.

6-(Trimethylsilyl)-4-hexynyl-1-amine 18: Yield 86%. - b.p. = 64°C (2.0 mbar). - IR (film): ν = 3379 cm^{-1} (NH_2), 2954, 2882, 2858 (CH), 2220 (alkyne), 1202 (C-N), 1250, 850 ($SiMe_3$). - ^{1}H-NMR ($CDCl_3$): δ = 0.05 (s, 9 H, $SiMe_3$), 1.06 (br. s, 2 H, NH_2), 1.39 (t, *J* = 3.0 Hz, 2 H, 6-H), 1.56 (quin., *J* = 8.0 Hz, 2 H, 2-H), 2.15 (mc, 2 H, 3-H), 2.75 (t, *J* = 8.0 Hz, 2 H, 1-H). - ^{13}C-NMR ($CDCl_3$): δ = -2.62 ($SiMe_3$), 6.39 (C-6), 15.80 (C-3), 32.71 (C-2), 40.78 (C-1), 77.11* (C-4), 77.53* (C-5). - MS (70 eV): *m/z* (%) = 169 (6) [M^+], 168 (2) [M^+ - H], 154 (10) [M^+ - CH_3], 73 (100) [$SiMe_3$]. - Anal. Calcd for $C_9H_{19}NSi$ (169.3): C, 63.84; H, 11.31. Found: C, 63.83; H, 11.33%.

7-(Trimethylsilyl)-5-heptynyl-1-amine 19: Yield 85%. - b.p. = 70°C (1.0 mbar). - IR (film): ν = 3380 cm^{-1}, 3316 (NH_2), 2936, 2878, 2862 (CH), 2220 (alkyne), 1436 (CH_2), 1200, 1170 (C-N), 1250, 850 ($SiMe_3$). - ^{1}H-NMR ($CDCl_3$): δ = 0.04 (s, 9 H, $SiMe_3$), 1.22 (br. s, 2 H, NH_2), 1.38 (t, *J* = 2.0 Hz, 2 H, 7-H), 1.44 - 1.56 (m, 4 H, 3-H, 4-H), 2.14 (mc, 2 H, 4-H), 2.67 (mc, 2 H, 1-H). - ^{13}C-NMR ($CDCl_3$): δ = -2.23 ($SiMe_3$), 6.77 (C-7), 18.65, 26.61, 32.87 (CH_2), 41.61 (C-1), 77.44* (C-5), 78.36* (C-6). - MS (70 eV): *m/z* (%) = 183 (3) [M^+], 168 (16) [M^+ - CH_3], 140 (12), 110 (54), 79 (24), 73 (100) [$SiMe_3$]. - Anal. Calcd for $C_{10}H_{21}NSi$ (183.4): C, 65.50; H, 11.54. Found: C, 65.65; H, 11.48%.

Preparation of the enaminecarbaldehydes 15 and 16: A solution of the amines **18** or **19** (11 mmol) in CH_2Cl_2 (15 ml) is added dropwise to a mixture of flame dried Na_2SO_4 (15 g) and methyl diformylacetate **17** (10 mmol) in CH_2Cl_2 (20 ml). The mixture is stirred at room temperature for 3-5 h (TLC), filtered, the filter cake is washed with CH_2Cl_2 (3 x 20 ml), and the eluents are combined. After removal of all volatiles in vacuo, the residue is purified by flash chromatography (solvent A) to give a slightly yellow oil.

Methyl 2-Formyl-3-(6-trimethylsilyl-4-hexynyl-1-amino)-2-propenoate 15: Yield: 78%. - R_f = 0.57 (solvent D). - IR (film): ν = 3210 cm^{-1}, 3148 (N-H), 2952, 2902, 2882 (CH), 2222 (alkyne), 1704, 1646 (CO), 1598 (C=C-N), 1264, 850 ($SiMe_3$). - UV (acetonitrile): λ_{max} (lg ε) = 234 nm (4.193), 299 (4.220). - ^{1}H-NMR ($CDCl_3$, TMS): δ = 0.07 (s, 9 H, $SiMe_3$), 1.40 (t, *J* = 3.0 Hz, 2 H, 6'-H), 1.73 (quint., *J* = 7.0 Hz, 2 H, 2'-H), 2.21 (mc, 2 H, 3'-H), 3.46 (dt, *J* = 7.0 Hz, *J* = 7.0 Hz, 2 H, 1'-H), 3.71 (s, 3 H, OCH_3), 7.89 (dd, *J* = 14.0 Hz, *J* = 3.5 Hz, 1 H, 3-H), 9.78 (d, *J* = 3.5 Hz, 1 H, CHO), 10.72 (br. mc, 1 H, N-H). - ^{13}C-NMR ($CDCl_3$) [E:(Z) = 80:(20)]: δ = -2.80 ($SiMe_3$), 6.13 (C-6'), 15.22 (C-3'), 29.06 (C-2'), 48.37 (C-1'), 49.96 (49.81) (OCH_3), 75.56* (C-4'), 78.58* (C-5'), 99.63 (99.27) (C-2), 158.3 (157.4) (C-3), 166.8 (168.5) (CO), 189.0 (186.0) (CHO). - MS (70 eV): *m/z* (%) = 281 (4) [M^+], 266 (5) [M^+ - CH_3], 264 (13), 235 (2) [M^+ - OCH_3], 222 (19) [M^+ - CO_2CH_3], 180 (19), 73 (100) [$SiMe_3$], 59 (11) [CO_2CH_3]. - Anal. Calcd for $C_{14}H_{23}NO_3Si$ (281.4): C, 59.76; H, 8.24. Found: C, 59.91; H, 8.34%.

Methyl 2-Formyl-3-(7-trimethylsilyl-5-heptynyl-1-amino)-2-propenoate 16: Yield: 80%. - R_f = 0.36 (solvent D). - IR (film): ν = 3210 cm^{-1}, 3148 (N-H), 2952, 2880, 2862 (CH), 2220 (alkyne), 1704, 1646 (CO), 1598 (C=C-N), 1250, 850 ($SiMe_3$). - UV (acetonitrile): λ_{max} (lg ε) = 235 nm (4.204), 300 (4.226). - ^{1}H-NMR ($CDCl_3$): δ = 0.04 (s, 9 H, $SiMe_3$), 1.37 (t, *J* = 3.0 Hz, 2 H, 7'-H), 1.39 - 1.55 (m, 2 H, 3'-H), 1.63 - 1.80 (2 H, 2'-H), 2.15 (tt, *J* = 7.0 Hz, *J* = 3.0 Hz, 2 H, 4'-H), 3.34 (dt, *J* = 7.0 Hz, *J* = 7.0 Hz, 2 H, 1'-H), 3.70 (s, 3 H, OCH_3), 7.86 (dd, *J* = 14.0 Hz, *J* = 3.5 Hz, 1 H, 3-H), 9.75 (d, *J* = 3.5 Hz, 1 H, CHO), 10.73 (mc, 1 H, N-H). - ^{13}C-NMR ($CDCl_3$) [E:(Z) = 86:(14)]: δ = -2.80 (-1.49) ($SiMe_3$), 6.16 (C-7'), 17.75 (17.58) (C-4'), 25.58 (C-5'), 28.95 (C-2'), 49.10 (48.95) (C-1'), 50.01 (49.85) (OCH_3), 76.85* (C-5'), 77.61* (C-6'), 99.60 (99.21) (C-2), 158.2 (157.3) (C-3), 166.9 (168.5) (CO), 189.0 (186.1) (CHO). - MS (70 eV): *m/z* (%) = 295 (11) [M^+], 280 (8) [M^+ - CH_3], 278 (9), 264 (6) [M^+ - OCH_3], 236 (14) [M^+ - CO_2CH_3], 194 (9), 73 (100) [$SiMe_3$], 59 (13) [CO_2CH_3]. - Anal. Calcd for $C_{15}H_{25}NO_3Si$ (295.5): C, 60.98; H, 8.53. Found: C, 61.13; H, 8.68%.

General Procedure for the sequential photochemical cycloaddition - iminium ion formation - propargylsilane cyclization:

I) A solution of the enaminecarbaldehyde (1.0 mmol) and the acrylic acid derivative (50 mmol) in dry dichloromethane (100 ml) is cooled to -35°C, purged with argon for 15 min and irradiated with a 500 watt Hanau high pressure mercury lamp for 10 - 15 h (TLC, solvent D). Two spots are observed, which correspond to the isomeric tetrahydropyridines **21** and **24**, respectively. The mixture is warmed to room temperature and all volatiles are removed in vacuo. Without further purification the residue is used for the cyclization.

IIa) *Cyclization with trifluoracetic acid:* The residue is dissolved in trifluoracetic acid (2 ml) at room temperature, and the reaction is complete within 2 - 5 min. All volatiles are removed in vacuo and the residue is dissolved in EtOAc (25 ml) and neutralized by adding 2N NaOH (25 ml). The aqueous layer is

extracted with EtOAc (3 x 10 ml) and the combined organic layers are washed with water (25 ml) and brine (25 ml), dried ($MgSO_4$) and concentrated. The residue is purified by flash chromatography (solvent E). Yields are indicated in table 1 and 2.

IIb) *Cyclization with TMSOTf and Lewis Acids:* The residue is dissolved in CH_2Cl_2 (15 ml), purged with argon and cooled to -78°C. Under an argon atmosphere the promotor (1.1 equivalents in reference to the weight of the crude photoproduct) is added and the reaction is monitored by TLC (solvent E). When the reaction is complete (1-2 h), the promotor is quenched by addition of water or in the case of TMSOTf with Et_3N/MeOH (1:1, 2 ml). After dilution with CH_2Cl_2 (25 ml), the organic layer is washed with saturated $NaHCO_3$ (25 ml), water (25 ml) and brine (25 ml), dried ($MgSO_4$) and concentrated in vacuo. The residue is purified by flash chromatography (solvent E). Yields are indicated in table 1 and 2.

Quinolizidine 22a: R_f = 0.41 (solvent D). - GC (200°C 15 min isotherm - 10°C/min) = $t_{R,\mathbf{22a}}$ = 19.8 min, $t_{R,\mathbf{23a}}$ = 20.7 min. - IR (film): ν = 2950 cm^{-1}, 2858 (CH), 1958 (C=C=CH_2), 1738 (CO), 1642, 1622, 1438. - UV (acetonitrile): λ_{max} (lg ε) = 229 nm (3.630), 287.5 (4.041), 349 (2.842). - ^{1}H-NMR ($CDCl_3$, TMS): δ = 1.65 (ttd, *J* = 13.0 Hz, *J* = 12.5 Hz, *J* = 3.5 Hz, 1 H, 7-H_{ax}), 1.75 - 1.81 (m, 1 H, 7-H_{eq}), 1.89 (ddd, *J* = 14.0 Hz, *J* = 10.0 Hz, *J* = 6.0 Hz, 1 H, 1-H_{ax}), 2.13 - 2.21 (m, 1 H, 8-H_{ax}), 2.23 (ddd, *J* = 14.0 Hz, *J* = 3.0 Hz, *J* = 3.0 Hz, 1 H, 1-H_{eq}), 2.47 (mc, 1 H, 8-H_{eq}), 3.19 (ddd, *J* = 12.5 Hz, *J* = 12.5 Hz, *J* = 3.0 Hz, 1 H, 6-H_{ax}), 3.42 (mc, 1 H, 6-H_{eq}), 3.58 (dd, *J* = 6.0 Hz, *J* = 3.0 Hz, 1 H, 2-H_{eq}), 3.63 (dtd, *J* = 10.0 Hz, *J* = 4.0 Hz, *J* = 3.0 Hz, 1 H, 9a-H_{ax}), 3.67 (s, 3 H, OCH_3), 3.70 (s, 3 H, OCH_3), 4.80 (td, *J* = 10.0 Hz, *J* = 4.0 Hz, 1 H, 11-H), 4.84 (td, *J* = 10.0 Hz, *J* = 4.0 Hz, 1 H, 11-H), 7.36 (s, 1 H, 4-H). - ^{13}C-NMR ($CDCl_3$, TMS): δ = 25.62 (C-7), 29.04, 29.47 (C-1, C-8), 36.22 (C-2), 50.78 (OCH_3), 50.85 (OCH_3), 52.11 (C-9a), 52.78 (C-6), 77.48 (C-11), 94.38 (C-9), 99.70 (C-3), 147.2 (C-4), 168.1 (CO), 175.7 (CO), 203.0 (C-10). - MS (70 eV): *m/z* (%) = 278 (4) [M^+ + H], 277 (22) [M^+], 262 (4) [M^+ - CH_3], 246 (11) [M^+ - OCH_3], 245 (27), 218 (100) [M^+ - CO_2CH_3], 158 (20), 59 (4) [CO_2CH_3]. - MS (EI): *m/z* (%) = 277.1314 (22%, 277.1314 calcd for $C_{15}H_{19}NO_4$). - Anal. Calcd for $C_{15}H_{19}NO_4$ (277.3): C, 64.97; H, 6.91. Found: C, 64.90; H, 7.19%.

Quinolizidine 22b: R_f = 0.24 (solvent A). - GC (200°C 25 min isotherm - 15°C/min) = $t_{R,\mathbf{22b}}$ = 27.3 min, $t_{R,\mathbf{23b}}$ = 27.7 min. - IR (film): ν = 2950 cm^{-1}, 2850 (CH), 1958 (C=C=CH_2), 1728 (CO), 1696, 1622, 1438. - UV (acetonitrile): λ_{max} (lg ε) = 288 nm (3.968), 356 (2.662). - ^{1}H-NMR ($CDCl_3$, TMS): δ = 1.44 (s, 9 H, ^{t}Bu), 1.40 - 1.80 (m, 2 H, 7-H), 1.85 (ddd, *J* = 14.5 Hz, *J* = 10.0 Hz, *J* = 6.0 Hz, 1 H, 1-H_{ax}), 2.07 - 2.28 (m, 1 H, 8-H_{ax}), 2.17 (ddd, *J* = 14.5 Hz, *J* = 3.0 Hz, *J* = 2.5 Hz, 1 H, 1-H_{eq}), 2.48 (mc, 1 H, 8-H_{eq}), 3.16 (ddd, *J* = 12.5 Hz, *J* = 12.5 Hz, *J* = 3.5 Hz, 1 H, 6-H_{ax}), 3.35 - 3.40 (m, 1 H, 6-H_{eq}), 3.53 (dd, *J* = 6.0 Hz, *J* = 3.0 Hz, 1 H, 2-H_{eq}), 3.55 - 3.70 (m, 1 H, 9a-H_{ax}), 3.66 (s, 3 H, OCH_3), 4.78 - 4.85 (m, 2 H, 11-H), 7.33 (s, 1 H, 4-H). - ^{13}C-NMR ($CDCl_3$, TMS): δ = 25.64 (C-7), 28.01 (3 x CH_3), 29.14, 29.54 (C-1, C-8), 37.36 (C-2), 50.68, 50.78 (OCH_3, C-9a), 52.73 (C-6), 77.32 (C-11), 80.20 ($OCMe_3$), 95.09 (C-9), 99.94 (C-3), 147.1 (C-4), 168.3 (CO), 174.7 (CO), 203.0 (C-10). - MS (70 eV): *m/z* (%) = 319 (20) [M^+], 288 (4) [M^+ - OCH_3], 262 (66) [M^+ - C_4H_9], 260 (1) [M^+ - CO_2CH_3], 246 (4) [M^+ - C_4H_9O], 218 (100) [M^+ - $CO_2{}^t$Bu], 204 (31), 59 (71) [CO_2CH_3], 57 (44) [C_4H_9]. - MS (EI): *m/z* (%) = 319.1783 (20%, 319.1783 calcd for $C_{18}H_{25}NO_4$). - Anal. Calcd for $C_{18}H_{25}NO_4$ (319.4): C, 67.69; H, 7.89. Found: C, 67.84; H, 8.08%.

Quinolizidine 22c: R_f = 0.59 (solvent D). - GC (200°C 15 min isotherm - 10°C/min) = $t_{R,\mathbf{22c}}$ = 20.4 min, $t_{R,\mathbf{23c}}$ = 21.3 min. - IR (film): ν = 2952 cm^{-1}, 2852 (CH), 2238 (CN), 1962 (C=C=CH_2), 1740 (CO),

1684, 1620, 1438. - UV (acetonitrile): λ_{max} (lg ε) = 286 nm (4.058). - ^{1}H-NMR ($CDCl_3$, TMS): δ = 1.66 (td, *J* = 12.5 Hz, *J* = 12.5 Hz, *J* = 4.0 Hz, 1 H, 7-H_{ax}), 1.78 - 1.88 (m, 1 H, 7-H_{eq}), 1.94 (ddd, *J* = 14.0 Hz, *J* = 10.0 Hz, *J* = 5.0 Hz, 1 H, 1-H_{ax}), 2.21 (m, 1 H, 8-H_{ax}), 2.38 (ddd, *J* = 14.0 Hz, *J* = 3.0 Hz, *J* = 2.9 Hz, 1 H, 1-H_{eq}), 2.51 (m, 1 H, 8-H_{eq}), 3.24 (ddd, *J* = 12.5 Hz, *J* = 12.5 Hz, *J* = 3.5 Hz, 1 H, 6-H_{ax}), 3.45 (m, 1 H, 6-H_{eq}), 3.69 - 3.89 (m, 2 H, 2-H, 9a-H), 3.72 (s, 3 H, OCH_3), 4.83 - 4.90 (m, 2 H, 11-H), 7.33 (s, 1 H, 4-H). - ^{13}C-NMR ($CDCl_3$, TMS): δ = 22.81 (C-2), 25.37 (C-7), 29.37, 29.64 (C-1, C-8), 50.91 (OCH_3), 51.16 (C-9a), 52.74 (C-6), 78.05 (C-11), 91.29 (C-9), 98.96 (C-3), 121.7 (CN), 147.8 (C-4), 166.9 (CO), 203.2 (C-10). - MS (70 eV): *m/z* (%) = 244 (48) [M^+], 229 (16) [M^+ - CH_3], 213 (47) [M^+ - OCH_3], 191 (67), 185 (36) [M^+ - CO_2CH_3], 133 (100), 59 (19) [CO_2CH_3]. - MS (EI): *m/z* (%) = 244.1211 (48%, 244.1211 calcd for $C_{14}H_{16}N_2O_2$). - Anal. Calcd for $C_{14}H_{16}N_2O_2$ (244.3): C, 68.83; H, 6.60. Found: C, 68.96; H, 6.91%.

Pyrido[1,2-a]azepine 25a: R_f = 0.22 (solvent D). - GC (200°C 15 min isotherm - 10°C/min) = $t_{R,\mathbf{25a}}$ = 21.5 min, $t_{R,\mathbf{26a}}$ = 21.0 min. - IR (film): ν = 2974 cm^{-1}, 2856 (CH), 1954 (C=C=CH_2), 1724 (CO), 1688, 1618, 1438. - UV (acetonitrile): λ_{max} (lg ε) = 287.5 nm (4.369). - ^{1}H-NMR ($CDCl_3$, TMS): δ = 1.35 (mc, 1 H, 8-H_{ax}), 1.44 - 1.56 (m, 1 H, 7-H_{ax}), 1.77 (mc, 1 H, 7-H_{eq}), 1.91 (mc, 1 H, 8-H_{eq}), 1.99 (mc, 1 H, 9-H_{ax}), 2.04 (ddd, *J* = 13.0 Hz, *J* = 6.5 Hz, *J* = 4.0 Hz, 1 H, 1-H_{ax}), 2.25 (mc, 1 H, 9-H_{eq}), 2.27 (ddd, *J* = 13.0 Hz, *J* = 7.0 Hz, *J* = 7.0 Hz, 1 H, 1-H_{eq}), 3.13 (ddd, *J* = 15.0 Hz, *J* = 12.0 Hz, *J* = 2.0 Hz, 1 H, 6-H_{ax}), 3.45 (mc, 1 H, 6-H_{eq}), 3.47 (dd, *J* = 7.0 Hz, *J* = 6.5 Hz, 1 H, 2-H_{eq}), 3.73 (s, 6 H, 2 x OCH_3), 3.96 (mc, 1 H, 10a-H), 4.69 (td, *J* = 10.5 Hz, *J* = 2.5 Hz, 1 H, 12-H), 4.72 (td, *J* = 10.5 Hz, *J* = 2.5 Hz, 1 H, 12-H), 7.50 (s, 1 H, 4-H). - ^{13}C-NMR ($CDCl_3$, TMS): δ = 29.04, 29.61 (C-7, C-8), 31.07, 31.70 (C-1, C-9), 37.01 (C-2), 50.69 (OCH_3), 51.80 (OCH_3), 55.83 (C-6), 57.25 (C-10a), 76.27 (C-12), 93.34 (C-10), 104.7 (C-3), 146.9 (C-4), 167.9 (CO), 175.1 (CO), 205.9 (C-11). - MS (70 eV): *m/z* (%) = 291 (10) [M^+], 276 (1) [M^+ - CH_3], 260 (6) [M^+ - OCH_3], 232 (93) [M^+ - CO_2CH_3], 205 (100), 190 (18), 172 (38), 147 (67), 59 (14) [CO_2CH_3]. - MS (EI): *m/z* (%) = 291.1470 (10%, 291.1470 calcd for $C_{16}H_{21}NO_4$). - Anal. Calcd for $C_{16}H_{21}NO_4$ (291.4): C, 65.96; H, 7.26. Found: C, 65.93; H, 7.33%.

Pyrido[1,2-a]azepine 25b: R_f = 0.40 (solvent D). - GC (220°C 15 min isotherm - 10°C/min) = $t_{R,\mathbf{25b}}$ = 18.8 min, $t_{R,\mathbf{26b}}$ = 17.9 min. - IR (film): ν = 2974 cm^{-1}, 2856 (CH), 1954 (C=C=CH_2), 1724 (CO), 1688, 1618, 1438. - UV (acetonitrile): λ_{max} (lg ε) = 287.5 nm (4.237). - ^{1}H-NMR ($CDCl_3$, TMS): δ = 1.35 (mc, 1 H, 8-H_{ax}), 1.41 (s, 9 H, ^{t}Bu), 1.42 - 1.78 (m, 2 H, 7-H), 1.80 - 1.92 (m, 1 H, 8-H_{eq}), 1.90 - 2.00 (m, 1 H, 9-H_{ax}), 2.05 (ddd, *J* = 13.0 Hz, *J* = 6.5 Hz, *J* = 4.0 Hz, 1 H, 1-H_{ax}), 2.21 (ddd, *J* = 13.0 Hz, *J* = 8.0 Hz, *J* = 8.0 Hz, 1 H, 1-H_{eq}), 2.30 (mc, 1 H, 9-H_{eq}), 3.15 (ddd, *J* = 15.0 Hz, *J* = 11.5 Hz, *J* = 2.0 Hz, 1 H, 6-H_{ax}), 3.35 (dd, *J* = 8.0 Hz, *J* = 6.5 Hz, 1 H, 2-H_{eq}), 3.45 (mc, 1 H, 6-H_{eq}), 3.64 (s, 3 H, OCH_3), 3.96 (mc, 1 H, 10a-H), 4.74 (mc, 2 H, 12-H), 7.49 (s, 1 H, 4-H). - ^{13}C-NMR ($CDCl_3$, TMS): δ = 27.97 (3 x CH_3), 29.27, 29.45 (C-7, C-8), 31.00, 32.22 (C-1, C-9), 38.34 (C-2), 50.53 (OCH_3), 55.39 (C-6), 57.47 (C-10a), 76.20 (C-12), 80.03 ($OCMe_3$), 94.12 (C-10), 104.9 (C-3), 146.9 (C-4), 168.3 (CO), 173.8 (CO), 206.5 (C-11). - MS (70 eV): *m/z* (%) = 333 (5) [M^+], 276 (2) [M^+ - C_4H_9], 274 (0.1) [M^+ - CO_2CH_3], 260 (3) [M^+ - C_4H_9O], 232 (100) [M^+ - $CO_2{}^tBu$], 205 (44), 59 (1) [CO_2CH_3], 57 (15) [C_4H_9]. - MS (EI): *m/z* (%) = 333.1940 (5%, 333.1940 calcd for $C_{19}H_{27}NO_4$). - Anal. Calcd for $C_{19}H_{27}NO_4$ (333.4): C, 68.44; H, 8.16. Found: C, 68.35; H, 8.35%.

Pyrido[1,2-a]azepine 25c: R_f = 0.19 (solvent D). - GC (200°C 20 min isotherm - 10°C/min) = $t_{R,\mathbf{25c}}$ = 25.5 min, $t_{R,\mathbf{26c}}$ = 25.9 min. - IR (film): ν = 2934 cm^{-1}, 2858 (CH), 2250 (CN), 1954 (C=C=CH_2), 1684 (CO), 1620, 1438. - UV (acetonitrile): λ_{max} (lg ε) = 284.5 nm (4.417). - ^{1}H-NMR ($CDCl_3$, TMS): δ = 1.42

(mc, 1 H, 8-H_{ax}), 1.49 - 1.70 (m, 2 H, 7-H), 1.83 (mc, 1 H, 8-H_{eq}), 2.02 (ddd, J = 13.5 Hz, J = 6.0 Hz, J = 4.5 Hz, 1 H, 1-H_{ax}), 2.00 - 2.20 (m, 2 H, 8-H_{ax}), 2.45 (ddd, J = 13.5 Hz, J = 4.5 Hz, J = 4.5 Hz, 1 H, 1-H_{eq}), 2.43 - 2.55 (m, 1 H, 9-H_{eq}), 3.12 (ddd, J = 15.0 Hz, J = 11.5 Hz, J = 2.5 Hz, 1 H, 6-H_{ax}), 3.64 (mc, 1 H, 6-H_{eq}), 3.71 (dd, J = 4.5 Hz, J = 4.5 Hz, 1 H, 2-H), 3.74 (s, 3 H, OCH_3), 4.15 (mc, 1 H, 10a-H), 4.80 (td, J = 10.5 Hz, J = 3.5 Hz, 1 H, 12-H), 4.92 (td, J = 10.5 Hz, J = 3.5 Hz, 1 H, 12-H), 7.53 (s, 1 H, 4-H). - ^{13}C-NMR ($CDCl_3$, TMS): δ = 20.71 (C-2), 28.74, 29.48 (C-7, C-8), 31.11, 31.11 (C-1, C-9), 51.02 (OCH_3), 55.71 (C-10a), 57.14 (C-6), 77.72 (C-12), 89.64 (C-10), 104.6 (C-3), 120.4 (CN), 146.6 (C-4), 166.9 (CO), 205.5 (C-10). - MS (70 eV): *m/z* (%) = 258 (7) [M^+], 243 (0.1) [M^+ - CH_3], 227 (20) [M^+ - OCH_3], 205 (63), 199 (11) [M^+ - CO_2CH_3], 190 (24), 147 (100), 59 (5) [CO_2CH_3]. - MS (EI): *m/z* (%) = 258.1368 (7%, 258.1368 calcd for $C_{15}H_{18}N_2O_2$). - Anal. Calcd for $C_{15}H_{18}N_2O_2$ (258.3): C, 69.74; H, 7.02. Found: C, 69.83; H, 7.07%.

Table 3. Bond Lengths (Å) of **25a**

C(1)-C(2)	1.540 (5)	C(1)-C(10A)	1.524 (4)	C(2)-C(2')	1.519 (5)
C(2)-C(3)	1.506 (5)	C(2')-O(2)	1.198 (5)	C(2')-O(2')	1.336 (5)
O(2')-C(2'')	1.442 (4)	C(3)-C(3')	1.448 (5)	C(3)-C(4)	1.360 (5)
C(3')-O(3)	1.217 (5)	C(3')-O(3')	1.356 (5)	O(3')-C(3'')	1.429 (5)
C(4)-N(5)	1.348 (4)	N(5)-C(6)	1.475 (4)	N(5)-C(10A)	1.451 (4)
C(6)-C(7)	1.510 (6)	C(7)-C(8)	1.515 (6)	C(8)-C(9)	1.532 (5)
C(9)-C(10)	1.519 (6)	C(10)-C(10A)	1.536 (5)	C(10)-C(11)	1.303 (5)
C(11)-C(12)	1.302 (6)				

Table 4. Bond Angles (°) of **25a**

C(2)-C(1)-C(10A)	112.4(3)	C(1)-C(2)-C(2')	111.5(3)	C(1)-C(2)-C(3)	109.4(3)
C(2')-C(2)-C(3)	116.0(3)	C(2)-C(2')-O(2)	123.5(4)	C(2)-C(2')-O(2')	113.3(3)
O(2)-C(2')-O(2')	123.2(3)	C(2')-O(2')-C(2'')	115.0(3)	C(2)-C(3)-C(3')	117.5(3)
C(2)-C(3)-C(4)	121.0(3)	C(3')-C(3)-C(4)	121.4(3)	C(3)-C(3')-O(3)	125.0(3)
C(3)-C(3')-O(3')	113.2(3)	O(3)-C(3')-O(3')	121.7(3)	C(3')-O(3')-C(3'')	117.4(3)
C(3)-C(4)-N(5)	124.4(3)	C(4)-N(5)-C(6)	119.6(3)	C(4)-N(5)-C(10A)	119.5(3)
C(6)-N(5)-C(10A)	118.8(3)	N(5)-C(6)-C(7)	112.5(3)	C(6)-C(7)-C(8)	115.1(4)
C(7)-C(8)-C(9)	115.5(3)	C(8)-C(9)-C(10)	115.2(3)	C(9)-C(10)-C(10A)	120.0(3)
C(9)-C(10)-C(11)	120.5(3)	C(10A)-C(10)-C(11)	119.5(3)	C(1)-C(10A)-N(5)	109.1(3)
C(1)-C(10A)-C(10)	112.7(3)	N(5)-C(10A)-C(10)	112.3(3)	C(10)-C(11)-C(12)	178.3(4)

Table 5. Atomic coordinates ($x10^4$) and equivalent isotropic displacement coefficients ($Å^2x10^3$) of **25a**

	x	y	z	U(eq)*
C(1)	-4563(6)	9786(2)	3269(2)	45(1)
C(2)	-2830(6)	9995(2)	3915(2)	38(1)
C(2')	-1927(8)	9150(2)	4290(2)	41(1)
O(2)	-3079(5)	8640(2)	4653(1)	57(1)
O(2')	285(5)	9033(1)	4179(1)	45(1)
C(2")	1197(7)	8225(2)	4507(3)	68(2)
C(3)	-1086(7)	10633(2)	3602(2)	38(1)
C(3')	293(7)	11104(2)	4166(2)	43(1)
O(3)	117(5)	11042(2)	4874(1)	60(1)
O(3')	1878(5)	11632(2)	3829(1)	56(1)
C(3")	3406(7)	12087(3)	4338(2)	62(2)
C(4)	-846(7)	10769(2)	2820(2)	39(1)
N(5)	-2030(5)	10335(2)	2264(2)	42(1)
C(6)	-1425(7)	10451(3)	1432(2)	57(2)
C(7)	706(7)	9959(3)	1214(2)	58(2)
C(8)	642(8)	8962(3)	1351(2)	66(2)
C(9)	280(7)	8672(2)	2202(2)	53(1)
C(10)	-2149(6)	8702(2)	2485(2)	41(1)
C(10A)	-3448(6)	9588(2)	2484(2)	41(1)
C(11)	-3153(7)	7979(3)	2723(2)	48(1)
C(12)	-4173(9)	7268(3)	2979(3)	69(2)

*Equivalent isotropic U defined as one third of the trace of the orthogonalized U_{ij} tensor

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