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Synthesis of 3-substituted indolizidines from amino-ynones derivatives

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Abstract

Two types of indolizidine derivatives can be synthesized from amino-ynones. In the presence of methanesulfonic acid, Meyer-Schuster rearrangement furnished vinylogues of indolizidin-3-ones whereas treatment with zinc chloride gave stable 3-alkynyl-1,5,6,7,8,8a-hexahydroindolizine-zinc complexes that were reduced to 3-alkynylindolizidines.

Graphical Abstract

Keywords: amino-ynone, indolizidine, methanesulfonic acid, zinc chloride
In previous publications, the reactivity of ynone bearing N-Boc protected primary amines \( I \) in the presence of electrophilic reagents was reported. Treatment with methanesulfonic acid (\( \text{CH}_3\text{SO}_3\text{H} \)), gave pyrrolidine exocyclic vinylogous amides via Meyer-Schuster rearrangement, whereas zinc chloride (\( \text{ZnCl}_2 \)) furnished acetylenic cyclic imines. In both cases a cyclic carbinolamine intermediate was formed, which underwent either a Meyer-Schuster rearrangement with protic acid or dehydration with Lewis acid.

In this paper, we present an extension of this study to amino-ynones having a secondary Boc-protected amine. Thus, when applied to the piperidine derivatives \( \text{II} \), reaction with \( \text{CH}_3\text{SO}_3\text{H} \) or \( \text{ZnCl}_2 \) resulted in formation of vinylogues of indolizidin-3-ones \( \text{III} \) or very stable cyclic enamine-zinc complexes. Reduction of these complexes led to the indolizidines \( \text{IV} \), which are frequently found as key structural components of numerous bioactive alkaloids (Fig. 1).

Figure 1. Overall aim of this work.

The starting amino-ynones were easily prepared from racemic pipecolic acid. The method included transformation of the carboxylic acid to an aldehyde, Wittig chain elongation, alkene hydrogenation and conversion to the racemic Weinreb amide \( \text{I} \). Reaction of \( \text{I} \) with acetylides allowed isolation of compounds \( \text{2 to 5} \) in good yields (> 80% from Weinreb amide \( \text{I} \), Scheme 1).
Scheme 1. Synthesis of starting materials 2 to 5. Reagents and conditions: (a) H-C≡CMgBr, THF, 0 °C; (b) R-C≡CH, nBuLi, THF, -50 °C.

Compounds 2-5 were then submitted to reaction with either methanesulfonic acid or zinc chloride. Five equivalents of methanesulfonic acid were used to perform the N-Boc deprotection. The mixture was then made alkaline with sodium or potassium carbonate, leading to formation of the indolizidin-3-one vinylogues 6-8 through a Meyer-Schuster rearrangement \(^1\) (Scheme 2). The very poor yield observed for compound 6 \((R = H)\) either under our conditions or those reported by Georg (HCl in dioxane then Na\(_2\)CO\(_3\))\(^{5b}\) is presumably due to its instability; numerous degradation products were observed by TLC analysis.

Scheme 2. Synthesis of amide vinylogues 6-8. Reagents and conditions: (a) CH\(_3\)SO\(_3\)H (5 equiv), CH\(_3\)Cl\(_2\)/CH\(_3\)OH, RT, 4 h then Na\(_2\)CO\(_3\), 12 h.

Contrary to a previous report\(^{5b}\) that described formation of seven-membered enaminones under similar conditions, we obtained indolizidine vinylogous amides 6-8, whose derivatives are seldom reported\(^6\). Structural assignment was made on the basis of several key analytical features: the \(^1\)H NMR spectrum of 6 showed a resonance signal at 9.38 ppm, corresponding to an aldehydic proton that
would not be observed in a seven member enaminone, which correlates closely with structurally related compounds found in the literature\(^7\) (Fig. 2).

![Figure 2. \(^1\)H NMR data of compounds related to 6-8.](image)

The \(^1\)H-coupled \(^{13}\)C NMR spectrum of 6 (R = H) showed a doublet (\(J = 158.9\) Hz) at 187.0 ppm, in accordance with an aldehydic carbonyl. NOESY correlation between the H5 and the ethylenic H confirmed the \(E\) configuration of the C=C double bond. Finally, the X-ray crystal data of compound 8 (Fig. 3) were in accordance with these findings.\(^8\)

![Figure 3. ORTEP drawing of the X-ray crystal structure of 8.](image)

The reactivity of 3-5 with ZnCl\(_2\) was then studied (Scheme 3). Conditions of a previous study\(^2\) were used: treatment with 1M ZnCl\(_2\) solution (5 equiv) in diethyl ether quantitatively gave 1,5,6,7,8,8a-indolizidines 9-11 as ZnCl\(_2\)-complexes which were stable and could be stored under anhydrous conditions for months. As in our previous paper,\(^2\) only degradation occurred with amino-ynone 2 (R = H). The NMR data unambiguously indicated an enamine function: the CH in the \(\beta\)-position relative to the nitrogen atom was shielded (\(\delta H2 = 4.5\) ppm and \(\delta C2 = 70\) ppm) and the C in the \(\alpha\)-position was
deshielded ($\delta C3 \approx 163$ ppm).$^9$ Elemental analysis performed with 11 was in accordance with a $M_3L_2$ zinc complex structure (see SI). As enamine reduction needs a protic medium in order to form an iminium salt,$^9$ we attempted direct reduction of these complexes using NaBH$_4$$^{10}$ in ethanol. The 3-alkynylindolizidines 12-14 were obtained as a 60/40 mixture of diastereomers, with the major isomers (12a-14a) having H3 and H8a configured cis. This configuration was assigned on the basis of NOESY correlations between H3, H8 and the axial H5 in compound 14a (See SI). Also of note was shielding of the equatorial H5 by the acetylenic substituent in the major isomers (Scheme 3). The yields of the isolated compounds were strongly affected by alkyne substituent R and isolation was complicated by difficult chromatographic separation. The best result (63% for 14) was obtained with a bulky 5-methoxynaphthyl group that facilitated chromatographic purification.

Scheme 3. Synthesis of zinc complexes 9-11 and their reduction to 12-14. Reagents and conditions:
(a) 1M ZnCl$_2$ in diethyl ether (5 equiv), RT, 12 h; (b) NaBH$_4$ (6 equiv), C$_2$H$_5$OH, 3 h.

The use of enantiopure pipecolic acid would allow for natural product and analogs synthesis. For example, trans natural indolizidines such as $(3,9E)$-3-propylindolizidine V found in the venom of the ant Myrmicaria melanogaster$^{3i}$ - as well as its diastereomer $(3,9Z)$ VI- would be accessible through this strategy (scheme 4):

Scheme 4. Possible synthesis of natural indolizidines V and VI
This study demonstrates access to indolizidines from racemic pipecolic acid with amino-ynones 2-5 as key intermediates. Treatment of 2-5 with methanesulfonic acid furnished indolizinones vinylogues 6-8, whose chemical structures were unambiguously established. When ZnCl$_2$ was used, enamines 9-11 could be isolated as stable zinc complexes, and subsequent hydride reduction gave 3-alkynylindolizidines 12-14 which are not often described in the literature.\textsuperscript{11}

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Supplementary data
Supplementary data associated with this article can be found, in the online version, at http….

References and notes


8. CCDC 1474017 (compound 8) contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.


8-Indolizin-3-one

Vinylogues of indolizin-3-one

CH₂SO₄H

ZnCl₂

NaBH₄

3-Alkynyl indolizidines

Zinc complexes
Indolizidine derivatives were efficiently obtained from amino-yrones.

With methane sulfonic acid, amino-yrones furnished vinylogues of indolizidin-3-ones.

In the presence of zinc chloride cyclization of amino-yrones produced stable enynes zinc complexes.

Reduction of enynes zinc complexes produced 3-alkynyl indolizidines.