Wolfgang Schöfberger et al.
Synthesis of quinoxalines or quinolin-8-amines from N-propargyl aniline derivatives employing tin and indium chlorides
Synthesis of quinoxalines or quinolin-8-amines from \(N\)-propargyl aniline derivatives employing tin and indium chlorides†

Stefan Aichhorn, a Markus Himmelsbach b and Wolfgang Schöfberger a

Pyrazino compounds such as quinoxalines are 1,4-diazines with widespread occurrence in nature. Quinolin-8-amines are isomerically related and valuable scaffolds in organic synthesis. Herein, we present intramolecular main group metal Lewis acid catalyzed formal hydroamination as well as hydroarylation methodology using mono-propargylated aromatic ortho-diamines. The annulations can be conducted utilizing equal aerobic conditions with either stannic chloride or indium(III) chloride and represent primary examples for main group metal catalyzed 6-exo-dig and 6-endo-dig, respectively, cyclizations in such settings. Both types of reactions can also be utilized in a one-pot manner starting from ortho-nitro \(N\)-propargyl anilines using stoichiometric amounts SnCl\(_2\)·2H\(_2\)O or In powder. Mechanistic considerations are presented regarding the substituent-depending regioselectivity.

Results and discussion

In order to exploit this observation towards more general application for aromatic heterocycles, we investigated a one-pot procedure for six-membered nitrogen motifs, starting from ortho-nitro \(N\)-propargyl aniline derivatives. Furthermore, we decided to examine whether next to tin also homologous indium species could be facilitated in this context, as indium powder is a reducing agent for nitro groups and In(III) has been demonstrated to activate alkynes. Performing initial screening reactions revealed that the use of methanol as solvent did lead to high quantity of an unidentified side product. It is noteworthy that it was possible to conduct the six-membered nitrogen ring formations in aqueous solution at 85 °C, although such reactions resulted in decreased yields. Further, the same is true for employing toluene as solvent at 100 °C. Finally, we have developed two pragmatic protocols for the construction of pyrazines (Fig. 1). Both standard procedures are based on the use of isopropanol as solvent while stirring the reaction mixtures at reflux under aerobic...
conditions. To obtain the different 2-methylquinoxalines, the best yields were obtained employing 5.5 equivalents of SnCl₂·2H₂O. Mowing to elementary indium, 3 equivalents in combination with hydrochloric acid gave similar results. With these optimized protocols in hand, we conducted one-pot syntheses of quinoxalines using starting materials 1, 4, and 13. With reaction times ranging from two to 20 hours, derivatives 3, 6, and 15 could be afforded in good yields from 71–82% (Fig. 1).

To explore a variant of this approach with related substrates, readily available anilides as masked anilines were chosen. The monofunctionalization of an anilide appears to be less susceptible compared to primary ortho-nitro anilines. An acetyl group as in anisyl-compound 10 can be cleaved under acidic conditions like present in the one-pot procedures. By subjecting the N-propargyl anilide to hot hydrochloric acid solution, quantitative deacetylation can be established. When a standard reductive one-pot cyclization-aromatization reaction is conducted with 10, almost exclusively N'-propargyl-C2-methyl-benzimidazole 12 is created. Under these circumstances, reduction of the nitro-group and subsequent condensation of the five-membered ring seems to be faster than the incorporation of the alkyne. In this fashion, functionalized benzimidazoles can be generated in good yield (Fig. 2). For the synthesis of quinoxalines, the protocol had to be adjusted by stirring the alkynyl-anilide in 3 M HCl at 90 °C first. Employing our developed standard protocol in the same pot (isopropanol and the respective reducing agent) gave the quinoxaline 11 in good yields.

Soon, it became inevitable to examine whether only terminal β-γ-alkynylamines would serve as platform for such formal 6-exo-dig cyclizations. To access 3'-alkylated derivatives, the primary ortho-nitro arylamines were treated with sodium hydride and 1-bromo-2-pentyne, which gave the internal alkynes 13, 16, and 19. Those were subjected to reflux in isopropanol under the established aerobic one-pot conditions. At this point, it was surprising to observe complete consumption of educts without creation of pyrazine products.

While the reduced primary amines in ortho-position remained not further functionalized, we realized that indeed six-membered rings were synthesized from 13 and 16 (Fig. 1), but in contrast to previous intramolecular annulations, quinoline-8-amines 15 (75%) and 18 (68%) were afforded, formally in a 6-endo-dig fashion, exclusively. In case of 3-nitro-N-(pent-2-yn-1-yl)quinolin-4-amine, only reduction giving the corresponding 3,4-diamine occurred. These tendencies allow for a distinction between two different types of cascade reactions, which can be conducted employing identical conditions whilst generating unlike heterocycles. When a para-diazine compound is generated, the initial cyclization of the reduced intermediate can be considered as intramolecular hydroamination reaction. In contrast, the formation of quinolinamine structures follows a hydarylation pathway prior to aromatization.

With protocols for specific six-membered rings in hand, we became interested in exploring the mechanistic aspects of this kind of annulation reactions. Preliminary experiments were conducted with β-γ-alkynyl-diamines like 2 or 14 exposed to oxygen in isopropanol at 82 °C. In the absence of any additives, no conversion was observed. The same was true for the addition of water or stannic chloride. By using less than one equivalent of SnCl₂·2H₂O or InCl₃, product formation was observed. The same was true for the incorporation of the alkyne. In this fashion, functionalized benzimidazoles can be generated in good yield (Fig. 2). For the synthesis of quinoxalines, the protocol had to be adjusted by stirring the alkynyl-anilide in 3 M HCl at 90 °C first. Employing our developed standard protocol in the same pot (isopropanol and the respective reducing agent) gave the quinoxaline 11 in good yields.

Soon, it became inevitable to examine whether only terminal β-γ-alkynylamines would serve as platform for such formal 6-exo-dig cyclizations. To access 3'-alkylated derivatives, the primary ortho-nitro arylamines were treated with sodium hydride and 1-bromo-2-pentyne, which gave the internal alkynes 13, 16, and 19. Those were subjected to reflux in isopropanol under the established aerobic one-pot conditions. At this point, it was surprising to observe complete consumption of educts without creation of pyrazine products.

While the reduced primary amines in ortho-position remained not further functionalized, we realized that indeed six-membered rings were synthesized from 13 and 16 (Fig. 1), but in contrast to previous intramolecular annulations, quinoline-8-amines 15 (75%) and 18 (68%) were afforded, formally in a 6-endo-dig fashion, exclusively. In case of 3-nitro-N-(pent-2-yn-1-yl)quinolin-4-amine, only reduction giving the corresponding 3,4-diamine occurred. These tendencies allow for a distinction between two different types of cascade reactions, which can be conducted employing identical conditions whilst generating unlike heterocycles. When a para-diazine compound is generated, the initial cyclization of the reduced intermediate can be considered as intramolecular hydroamination reaction. In contrast, the formation of quinolinamine structures follows a hydarylation pathway prior to aromatization.

With protocols for specific six-membered rings in hand, we became interested in exploring the mechanistic aspects of this kind of annulation reactions. Preliminary experiments were conducted with β-γ-alkynyl-diamines like 2 or 14 exposed to oxygen in isopropanol at 82 °C. In the absence of any additives, no conversion was observed. The same was true for the addition of water or stannic chloride. By using less than one equivalent of SnCl₂·2H₂O or InCl₃, product formation was observed. The same was true for the incorporation of the alkyne. In this fashion, functionalized benzimidazoles can be generated in good yield (Fig. 2). For the synthesis of quinoxalines, the protocol had to be adjusted by stirring the alkynyl-anilide in 3 M HCl at 90 °C first. Employing our developed standard protocol in the same pot (isos...
other six-membered rings (Fig. S1† – right column). Gold-catalysis sets the standards in the field due to the advantageous properties of Au-complexes concerning the interactions with C-C triple bonds.17 Regarding the hydroamination type reactions, a few older reports cover intramolecular conversions attaining quinoxalines similarly to our approach. However, copper and mercury based mediating reagents have to be utilized in stoichiometric fashion.18 In this sense, the tin(ii) as well as indium(III) promoted cyclizations described here are the first main group metal catalyzed 6-exo-dig hydroamination. The situation with electrophilic aromatic substitution reactions is different as there are no reports on vicinal monoalkylated diamino-substrates, but several transition metal catalyzed annihilations giving quinoline derivatives.19 The best matching related ring formations are indium(III) catalyzed syntheses of phenanthrenes and chromenes.20 Considering this, the Sn(II) and In(III) mediated cyclizations described here are the first examples of main group metal catalyzed 6-endo-dig hydroarylation to afford quinoline derivatives.

To provide starting materials for several screening reactions, the nitro precursors had to be reduced to the corresponding diamines in a controlled manner. Therefore, chemoselective transformations of 1, 4, 7, 13, and 16, respectively, were conducted employing sodium dithionite as reducing agent to prepare 2, 5, 8, 14, and 17 (Fig. 3). This proved to be a useful reaction procedure, since the reaction stopped at the ortho-diamine stages in reasonable yields.

Concerning the mediating metal species, tin(ii) as well as indium(III) could be employed as catalysts (Table 1). In contrast to that, Sn(IV) salts and In(0) did not convert the substrates to the desired products. Soon we realized that no product is formed under strictly anaerobic conditions. On the other hand, atmospheric oxygen supply usually proves adequate and O2-bubbling is crucial only when it comes to syntheses in NMR tubes. It was observed that fast conversions are initiated above 70 °C, hence refluxing at 82 °C was chosen as general measure. Moreover, it turned out to be an important finding that a minimum amount of water is necessary for conversion of educts to proceed. With respect to one-pot procedures, which are not quenched in presence of an excess of water, it is noteworthy that water of crystallization from catalyst salts is sufficient for successful conversions.

Since a distinctly acidic regime is prevalent in a nitro-one-pot reaction mixture, intensely protic or Brønsted acidic conditions do not inhibit the intramolecular cyclization. In turn, our simple methodology demonstrated that product formation is promoted by Lewis acids, which result in a moderately acidic pH regime.

The overall tendency revealed that a well-working standard protocol consisted of refluxing the isopropanol solution of N4-butyl-alkynyl ortho-diamine under air with stoichiometric water along with 25–50 mol% main group metal chloride. We reasoned that indium(III) is slightly more effective as catalyst than tin(ii). In terms of catalyst loading, complete conversion could not be attained with less than 25 mol%. The best results were obtained with 0.5 equivalents loading, when syntheses could be completed within two to twelve hours. Decreasing the amount of SnCl2 or InCl3 would elongate reaction times up to two days. The highest yields with both catalyst systems were achieved by refluxing 2 overnight using 50 mol% metal chloride affording 3 in 91% (SnCl2·2H2O) and 93% (InCl3). Results of catalytic hydroaminoation and hydroarylation reactions are listed in Table 1 (also compare Fig. 1, 3 and 4).

A set of control experiments was conducted: we examined whether Brønsted acid could facilitate ring closure. Therefore, solutions of 5 and 8 were refluxed after the addition of tosyllic acid, which only lead to the recovery of starting material both with 0.5 and 5 equivalents of TsOH·H2O, respectively. To study the behavior of the nitro-compounds, precursor 4 was reacted in combination with a non-reducing metal chloride. During both cases (catalytic and stoichiometric amounts of InCl3), no conversion of starting material 4 was observed utilizing our standard reaction protocol. The same was true for the N3-Boc-protected derivative of 5. Additionally, 2-(prop-2-yn-1-yloxy) aniline and 4-(pent-2-yn-1-yloxy)quinolin-3-amine were syn-

---

**Table 1** Pyrazine/quinoline syntheses in catalytic fashion

<table>
<thead>
<tr>
<th>Entry</th>
<th>Catalyst</th>
<th>Mol%</th>
<th>t/h</th>
<th>s.m.</th>
<th>Product</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SnCl2</td>
<td>50</td>
<td>12</td>
<td>2</td>
<td>3</td>
<td>91%</td>
</tr>
<tr>
<td>2</td>
<td>InCl3</td>
<td>50</td>
<td>12</td>
<td>2</td>
<td>3</td>
<td>93%</td>
</tr>
<tr>
<td>3</td>
<td>SnCl2</td>
<td>50</td>
<td>12</td>
<td>5</td>
<td>6</td>
<td>85%</td>
</tr>
<tr>
<td>4</td>
<td>InCl3</td>
<td>25</td>
<td>36</td>
<td>8</td>
<td>9</td>
<td>66%</td>
</tr>
<tr>
<td>5</td>
<td>SnCl2</td>
<td>25</td>
<td>36</td>
<td>17</td>
<td>18</td>
<td>76%</td>
</tr>
<tr>
<td>6</td>
<td>InCl3</td>
<td>25</td>
<td>36</td>
<td>14</td>
<td>15</td>
<td>80%</td>
</tr>
</tbody>
</table>

*a Conditions: 1 eq. starting material (0.1 M isopropanol soln), 82 °C, cat., 2 eq. H2O, air.

---

**Fig. 3** Dithionite as reducing agent to receive ortho-diamine compounds for catalytic annulation.
thesized in order to study the probability of generating oxygen-heterocycles with our main group metal system. None of the alkylnylxoy-compounds was converted to a cyclized scaffold after treatment with catalytic amounts of SnCl₂·2H₂O.

Further insight regarding the reactivity of the substrate-catalyst combinations could be achieved by subjecting simple N-(prop-2-yn-1-yl)-p-toluidine as well as N-(pent-2-yn-1-yl)-p-toluidine to standard catalytic conditions with both Sn(II) and In(III), respectively. After two days of stirring, the attempts with terminal alkynes just gave starting materials. On the other hand, reactions employing internal alkynes afforded small amounts of the hydroarylation product 4-ethyl-6-methylquinoline (“Sn”: 7%; “In”: 9%) besides educt.

Considering those tendencies, we have performed quantum mechanics calculations to determine the atomic charges and total charge densities (electrostatic potentials, ESPs) of compounds 5 and 17, respectively. By juxtaposing their relative charges concerning the propargylic moiety, there is a trend that the triple bond is much less polarized at the internal alkylne (Fig. S7 and S8†). In turn, the β-carbon of the terminal alkylne is clearly more electrophilic.

It is particularly remarkable that catalytic annihilations of internal N¹-β-γ-alkynyldiamines produce quinoline-8-amines equally exclusive as with the corresponding one-pot attempts. This indicates that the nature of the alkylne moiety decides about the type of ring closure. There does not seem to be a competition between rates of conversion for reduction vs. aromatic substitution reaction, which would have had influenced the given selectivity.

An important remaining aspect was, if aryl-substituents²¹ at the alkylne would favour an equal mode of ring closing as ethyl-alkynes. We did not succeed to functionalize ortho-nitro precursors like 4 employing Sonogashira cross-coupling methodology. However, we could generate that kind of internal alkylnl-amine by using the reduced compound 5. It was possible to afford derivative 19 in very good yield (Fig. 4). Subjecting it to standard conditions with 25 mol% of indium(III) chloride for 36 h, 4-p-tolyquinolin-8-amine 20 was synthesized in 89% yield. This result evidently demonstrates the tendency that in settings with ortho-diamino-scaffolds substituted triple bonds follow a hydroarylation pathway, whereas terminal alkynes undergo hydroamination. This distinction at ring closing reactions with propargylic amine-type substrates catalyzed by InCl₃ was also described in a recent publication.²²

As it could be confirmed that the unexpected ring closing reactions, depending on the given substrates, indeed produce either methylpyrazino- or quinoline-8-amino-compounds, the explored set of reactions can therefore be differentiated between 6-exo-dig and 6-endo-dig annihilations, respectively.²³ Under the given conditions, this would involve a Lewis acid (LA) complex to increase the electrophilic character of an alkynle. Metallic Lewis acids can bind weakly in a side-on manner to the triple bond or attach directly to an sp-carbon.²⁴ Besides the more frequent reports on transition²⁵ or main group²⁶ metals and iodine²⁷ to promote exo- and endo-dig-cyclizations,²⁸ indium(III) species²⁹ are able to promote such bond formations. The given reaction mixtures seem to be favouring intramolecular hydroaminations³⁰ or hydroarylations.³¹ In order to examine mechanistic aspects of the annulation, syntheses were conducted in deuterated solvent and the mixtures analyzed by means of NMR and HR-MS.

The ¹H NMR spectra of reactions in isopropanol-ｄ₆ reveal which hydrogen positions are afected during the procedure. The most striking spectroscopic difference to standard protic condition spectra is the low intensity of two signals: the ɑllyl-singlet of the pyrazine ring as well as the methyl-peak show integrals of less than a third compared to their supposed values. This is true for every successfully tested experiment in deuterated reaction mixture, only the relative amounts of decreased peak area very specifically with the employed metal salt type. The corresponding ¹³C NMR spectra exhibit split signals for those carbons, which hold primarily deuterium instead of protons. Hence, heteronuclear coupling of carbons with ¹H nuclei is observable (JC₂,D = 27 Hz). Furthermore, the aromatic peaks in the quinoxaline case appear to display differently overlapping multiplicities and to a minor extent reduced integrals, which can be explained by isotope exchange effects. ESI-mass spectra illustrated a range of product isomers with various deuteration grades. The influence of the alkynle-manipulation and cyclization on the initial aromatic body of the molecule can also be studied by a quinoxaline synthesis in deuter-so solvent³² (Fig. 5): ¹H and ¹³C NMR spectra indicate changes in peak patterns and intensities for the phenylene scaffold, mass spectra signify considerable amounts of isomers with more than four Ds (Fig. S2–5†). Most importantly, this experiment proves that the ortho-H position, which gives rise to the electrophilic aromatic substitution pathway, is also activated at substrates with terminal alkynes, but does not afford quinoline product in such cases.

Comprehension of the ring closure might be facilitated by investigating certain screening reactions using 2 at reflux times of only 20 minutes along with catalytic amounts of Sn(II)
The isotope distribution effects in deuterated media. A range of tautomeric equilibria might foster H/D exchange. Indium(III) and tin(II) chlorides lower the signal intensity of the methylene group (HC=CH in products) down to values between 15–30%.

The need of molecular oxygen for the progress of the reaction can clearly be related to the oxidation of the 1,2-dihydro compounds (Scheme 1) to the final product. The gain of stability by reaching aromaticity explains the fast conversion of the cyclized skeleton. No evidence was found for the formation of an allene prior to ring closure.33 The prerequisite of water for the reactions to proceed might favour a hydration step prior to ring closure. Both tin and indium are known to be able to facilitate hydration reactions of alkynes to generate ketones.34 Those carbonyl intermediates could additionally be activated by Lewis acids. In a quinoxaline case, a structure like II may give rise to the condensation resulting in dihydro-compound III (Scheme 1 and Fig. S2†).

Applying this concept to a hydroarylation reaction, the hydration step (IV to V) would create the ketone at γ-position. This would then be attacked in an S₈Ar manner (V to VI), followed by rearomatization and water elimination (VI to VII to VIII). However, there is no evidence for such reactivity, although it would serve as a credible explanation for the extensive deuteration also (Fig. S4 and S5†). For all those reasons mentioned, the course of the reactions might be covered by the sequence of steps depicted in Scheme 1.

What appears to be of special importance for the conception of a mechanism and the composition of the Lewis acid catalyst is the lack of reactivity in cases of nitro-precursors like 4 in combination with metal chlorides. The aromatic ortho-diamines are well suitable to act as bidentate ligand. As a consequence, we wish to emphasize that there could be deciding influence of a metal cation centred complex, involving an ortho-phenylene diamine type ligand,35 on mediating the cyclization steps.

Conclusions

We have demonstrated the utility of stannous chloride as well as indium powder under acidic conditions for intramolecular one-pot synthesis of either methylquinolinoxine or quinolin-8-amine derivatives. Starting from ortho-nitro-N-propargylaniline compounds, selectivity is dependent on the substitution of the alkyne. It was shown that such aerobic annulation reactions are suitable to be conducted in catalytic fashion employing tin (II) and indium(III) chlorides as Lewis acids catalysts by reaching aromaticity explains the fast conversion of the cyclized skeleton. No evidence was found for the formation of an allene prior to ring closure.33 The prerequisite of water for the reactions to proceed might favour a hydration step prior to ring closure. Both tin and indium are known to be able to facilitate hydration reactions of alkynes to generate ketones.34 Those carbonyl intermediates could additionally be activated by Lewis acids. In a quinoxaline case, a structure like II may give rise to the condensation resulting in dihydro-compound III (Scheme 1 and Fig. S2†).

Applying this concept to a hydroarylation reaction, the hydration step (IV to V) would create the ketone at γ-position. This would then be attacked in an S₈Ar manner (V to VI), followed by rearomatization and water elimination (VI to VII to VIII). However, there is no evidence for such reactivity, although it would serve as a credible explanation for the extensive deuteration also (Fig. S4 and S5†). For all those reasons mentioned, the course of the reactions might be covered by the sequence of steps depicted in Scheme 1.

What appears to be of special importance for the conception of a mechanism and the composition of the Lewis acid catalyst is the lack of reactivity in cases of nitro-precursors like 4 in combination with metal chlorides. The aromatic ortho-diamines are well suitable to act as bidentate ligand. As a consequence, we wish to emphasize that there could be deciding influence of a metal cation centred complex, involving an ortho-phenylene diamine type ligand,35 on mediating the cyclization steps.

Conclusions

We have demonstrated the utility of stannous chloride as well as indium powder under acidic conditions for intramolecular one-pot synthesis of either methylquinolinoxine or quinolin-8-amine derivatives. Starting from ortho-nitro-N-propargylaniline compounds, selectivity is dependent on the substitution of the alkyne. It was shown that such aerobic annulation reactions are suitable to be conducted in catalytic fashion employing tin (II) and indium(III) chlorides as Lewis acids catalysts by reaching aromaticity explains the fast conversion of the cyclized skeleton. No evidence was found for the formation of an allene prior to ring closure.33 The prerequisite of water for the reactions to proceed might favour a hydration step prior to ring closure. Both tin and indium are known to be able to facilitate hydration reactions of alkynes to generate ketones.34 Those carbonyl intermediates could additionally be activated by Lewis acids. In a quinoxaline case, a structure like II may give rise to the condensation resulting in dihydro-compound III (Scheme 1 and Fig. S2†).

Applying this concept to a hydroarylation reaction, the hydration step (IV to V) would create the ketone at γ-position. This would then be attacked in an S₈Ar manner (V to VI), followed by rearomatization and water elimination (VI to VII to VIII). However, there is no evidence for such reactivity, although it would serve as a credible explanation for the extensive deuteration also (Fig. S4 and S5†). For all those reasons mentioned, the course of the reactions might be covered by the sequence of steps depicted in Scheme 1.

What appears to be of special importance for the conception of a mechanism and the composition of the Lewis acid catalyst is the lack of reactivity in cases of nitro-precursors like 4 in combination with metal chlorides. The aromatic ortho-diamines are well suitable to act as bidentate ligand. As a consequence, we wish to emphasize that there could be deciding influence of a metal cation centred complex, involving an ortho-phenylene diamine type ligand,35 on mediating the cyclization steps.

Conclusions

We have demonstrated the utility of stannous chloride as well as indium powder under acidic conditions for intramolecular one-pot synthesis of either methylquinolinoxine or quinolin-8-amine derivatives. Starting from ortho-nitro-N-propargylaniline compounds, selectivity is dependent on the substitution of the alkyne. It was shown that such aerobic annulation reactions are suitable to be conducted in catalytic fashion employing tin (II) and indium(III) chlorides as Lewis acids catalysts by reaching aromaticity explains the fast conversion of the cyclized skeleton. No evidence was found for the formation of an allene prior to ring closure.33 The prerequisite of water for the reactions to proceed might favour a hydration step prior to ring closure. Both tin and indium are known to be able to facilitate hydration reactions of alkynes to generate ketones.34 Those carbonyl intermediates could additionally be activated by Lewis acids. In a quinoxaline case, a structure like II may give rise to the condensation resulting in dihydro-compound III (Scheme 1 and Fig. S2†).

Applying this concept to a hydroarylation reaction, the hydration step (IV to V) would create the ketone at γ-position. This would then be attacked in an S₈Ar manner (V to VI), followed by rearomatization and water elimination (VI to VII to VIII). However, there is no evidence for such reactivity, although it would serve as a credible explanation for the extensive deuteration also (Fig. S4 and S5†). For all those reasons mentioned, the course of the reactions might be covered by the sequence of steps depicted in Scheme 1.

What appears to be of special importance for the conception of a mechanism and the composition of the Lewis acid catalyst is the lack of reactivity in cases of nitro-precursors like 4 in combination with metal chlorides. The aromatic ortho-diamines are well suitable to act as bidentate ligand. As a consequence, we wish to emphasize that there could be deciding influence of a metal cation centred complex, involving an ortho-phenylene diamine type ligand,35 on mediating the cyclization steps.

Conclusions

We have demonstrated the utility of stannous chloride as well as indium powder under acidic conditions for intramolecular one-pot synthesis of either methylquinolinoxine or quinolin-8-amine derivatives. Starting from ortho-nitro-N-propargylaniline compounds, selectivity is dependent on the substitution of the alkyne. It was shown that such aerobic annulation reactions are suitable to be conducted in catalytic fashion employing tin (II) and indium(III) chlorides as Lewis acids catalysts by reaching aromaticity explains the fast conversion of the cyclized skeleton. No evidence was found for the formation of an allene prior to ring closure.33 The prerequisite of water for the reactions to proceed might favour a hydration step prior to ring closure. Both tin and indium are known to be able to facilitate hydration reactions of alkynes to generate ketones.34 Those carbonyl intermediates could additionally be activated by Lewis acids. In a quinoxaline case, a structure like II may give rise to the condensation resulting in dihydro-compound III (Scheme 1 and Fig. S2†).

Applying this concept to a hydroarylation reaction, the hydration step (IV to V) would create the ketone at γ-position. This would then be attacked in an S₈Ar manner (V to VI), followed by rearomatization and water elimination (VI to VII to VIII). However, there is no evidence for such reactivity, although it would serve as a credible explanation for the extensive deuteration also (Fig. S4 and S5†). For all those reasons mentioned, the course of the reactions might be covered by the sequence of steps depicted in Scheme 1.

What appears to be of special importance for the conception of a mechanism and the composition of the Lewis acid catalyst is the lack of reactivity in cases of nitro-precursors like 4 in combination with metal chlorides. The aromatic ortho-diamines are well suitable to act as bidentate ligand. As a consequence, we wish to emphasize that there could be deciding influence of a metal cation centred complex, involving an ortho-phenylene diamine type ligand,35 on mediating the cyclization steps.
added to a stirred 0.15 M solution of ortho-nitro N-propargylaniline compound (1 equiv.) in 2-propanol at room temperature. The mixture was heated at reflux under air until judged completed as indicated by thin layer chromatography. The mixture was brought to room temperature, filtrated and the filtrate concentrated under reduced pressure. The residue was quenched with saturated NaHCO₃ solution until pH 10. The aqueous solution was extracted with EtOAc three times, the combined organic layers were dried over anhydrous Na₂SO₄ and evaporated under reduced pressure. The residue was purified by column chromatography (silica gel, heptanes/EtOAc = 3/1).

**General procedure for main group metal chloride catalyzed formation of quinoxalines or quinolin-8-amines**

25–50 mol% of stannous chloride dihydrate or indium(III) chloride were added to a stirred 0.1 M solution of ortho-amine N-propargylaniline compound (1 equiv.) in 2-propanol at room temperature. Unless water of crystallization was present, 1 equiv. H₂O was added. The mixture was heated at reflux under air until judged completed as indicated by thin layer chromatography. The mixture was concentrated under reduced pressure. The residue was purified by column chromatography (silica gel, heptanes/EtOAc = 3/1).

**General procedure for alkylation of ortho-nitro anilines using NaH**

Sodium hydride (95%, 1.1 equiv.) was added to a 0.2 M aceto-nitrile solution of 2-nitroaniline compound (1 equiv.). The mixture was stirred at 0 °C for 15 min. Then, 1-bromoalk-2-yne (1.1 equiv.) was added and the mixture was brought to room temperature. It was thoroughly stirred under N₂ atmosphere for 40 h. The suspension was quenched with H₂O and saturated NaHCO₃ solution was added until pH 10. The resulting aqueous layer was extracted with DCM three times, the combined organic layers were dried over anhydrous Na₂SO₄ and evaporated under reduced pressure. The residue was purified by column chromatography (silica gel, heptanes/EtOAc = 3/1).

**General procedure for the reduction of ortho-nitro N-alkynylanilines to diamines using Na₂S₂O₄**

To a stirred 0.1 M EtOH solution of 2-nitro-N-alk-2'-ynylaniline compound (1 equiv.) at 0 °C were added portions of sodium dithionite (85%, 6 equiv.) and H₂O (half volume of EtOH) alternatingly. Then the mixture was allowed to warm to room temperature and stirred for 1 h. Then it was filtrated and the bulk of aqueous EtOH of the filtrate was evaporated in vacuo. Under reduced pressure, quick column chromatographic purification of the residue over a short pad of silica in a sintered glass filter was performed using a solvent gradient from DCM/MeOH (10/1) to pure MeOH. The polar fractions were collected and concentrated in vacuo.

**3-Methylpyrazino[2,3-c]quinoline (3)**

Pale orange solid, m.p. 120–122 °C; ¹H NMR (700 MHz, CDCl₃, 298 K): δ = 2.88 (s, 3H), 7.81 (t, J = 7.5 Hz, 1H), 7.90 (t, J = 7.6 Hz, 1H), 8.27 (d, J = 8.1 Hz, 1H), 9.01 (s, 1H), 9.07 (d, J = 8.1 Hz, 1H), 9.52 (s, 1H) ppm;¹³C NMR (176 MHz, CDCl₃, 298 K): δ = 22.4, 123.5, 124.7, 128.2, 130.6, 135.4, 141.4, 146.0, 148.6, 153.9, 155.2 ppm; IR (film): ν = 2921, 2853, 1519, 1459, 1325, 1260, 1013, 797 cm⁻¹; HRMS (ESI): m/z calcd for C₁₂H₁₀N₂O: 196.0869 [M + H⁺]; found: 196.0870.

**7-Methoxy-2-methylquinoline (11)**

To N-alkyn-ortho-nitro-anilide (1 equiv.) was added 3 M hydrochloric acid solution (30 equiv.). The mixture was stirred at 90 °C under N₂ atmosphere for 7 h. Then, the mixture was directly subjected to one-pot reaction conditions as described in the General procedure. Physical and spectroscopic properties are in accordance with published data.³⁶ ¹H NMR (300 MHz, CDCl₃, 298 K): δ = 3.74 (s, 3H), 3.96 (s, 3H), 7.31 (d, J = 2.7 Hz, 1H), 7.35 (dd, J = 2.7 Hz, 9.1 Hz, 1H), 7.94 (d, J = 9.1 Hz, 1H), 8.59 (s, 1H) ppm; HRMS (ESI): m/z calcd for C₁₀H₁₁N₂O: 175.0866 [M + H⁺]; found: 175.0862.

**5-Methoxy-2-methyl-1-(prop-2-yn-1-yl)-1H-benzo[d]imidazole (12)**

Brown solid, m.p. 110–116 °C; eluent DCM/MeOH = 7/1; ¹H NMR (300 MHz, CDCl₃, 298 K): δ = 2.34 (t, J = 2.5 Hz, 1H), 2.62 (s, 3H), 3.84 (s, 3H), 4.80 (d, J = 2.5 Hz, 2H), 6.90 (dd, J = 2.4 Hz, 8.8 Hz, 1H), 7.18 (d, J = 2.4 Hz, 1H), 7.25 (d, J = 8.8 Hz, 1H) ppm;¹³C NMR (75 MHz, CDCl₃, 298 K): δ = 13.9, 33.3, 56.0, 73.6, 76.7 (overlaid by solvent signal), 101.2, 109.5, 112.0, 120.9, 134.3, 151.5, 156.3 ppm; IR (film): ν = 3194, 2112, 1519, 1489, 1439, 1276, 1198, 1151, 1034, 787 cm⁻¹; HRMS (ESI): m/z calcd for C₁₀H₁₁N₂O: 201.0212 [M + H⁺]; found: 201.1027.

**4-Ethyl-5,6-dimethylquinolin-8-amine (15)**

Brownish orange oil; ¹H NMR (700 MHz, CDCl₃, 298 K): δ = 1.33 (t, J = 7.5 Hz, 3H), 2.40 (s, 3H), 2.62 (s, 3H), 3.25 (q, J = 7.5 Hz, 2H), 6.82 (s, 1H), 7.18 (d, J = 4.4 Hz, 1H), 8.55 (d, J = 4.4 Hz, 1H) ppm;¹³C NMR (176 MHz, CDCl₃, 298 K): δ = 16.2, 18.6, 22.1, 29.8, 113.3, 120.0, 122.7, 128.7, 135.7, 138.4, 142.1, 145.7, 150.9 ppm; IR (film): ν = 3292, 2823, 1519, 1459, 1325, 1260, 1013, 797 cm⁻¹; HRMS (ESI): m/z calcd for C₁₀H₁₅N₂O: 201.1386 [M + H⁺]; found: 201.1386.

**N⁴-(Pent-2-yn-1-yl)benzene-1,2-diamine (17)**

Brown oil; ¹H NMR (300 MHz, CDCl₃, 298 K): δ = 1.14 (t, J = 7.5 Hz, 3H), 2.21 (qt, J = 2.2 Hz, 7.5 Hz, 2H), 3.44 (br s, 3H), 3.89 (t, J = 2.2 Hz, 2H), 6.70–6.79 (m, 3H), 6.80–6.88 (m, 1H) ppm;¹³C NMR (75 MHz, CDCl₃, 298 K): δ = 12.5, 14.0, 34.5, 76.5, 85.4, 113.0, 116.5, 119.8, 120.6, 135.1, 136.7 ppm; IR (film): ν = 3334, 3042, 1573, 1506, 1455, 1315, 1269, 738 cm⁻¹; HRMS (ESI): m/z calcd for C₁₁H₁₄N₂: 175.1230 [M + H⁺]; found: 175.1232.

**N⁴-(3-(p-Toly)prop-2-yn-1-yl)benzene-1,2-diamine (20)**

Prepared in analogy to literature.³⁷ To a solution of 5 (0.68 mmol, 99 mg, 1 equiv.) in 4 ml acetonitrile were added 1-iodo-4-methylbenzene (0.75 mmol, 165 mg, 1.1 equiv.), triethylamine (4.1 mmol, 566 µl, 6 equiv.), copper(I) iodide (0.026 mmol, 5 mg, 0.04 equiv.), and bis(triphenylphosphine) palladium(0) dichloride (0.026 mmol, 19 mg, 0.04 equiv.). The mixture was stirred under N₂ atmosphere at room temperature for 20 h.
Then it was filtrated and washed with EtOAc. The filtrate was quenched with water and saturated NaHCO₃ solution was added until pH 10. It was extracted with EtOAc three times, the combined organic layers were dried over anhydrous Na₂SO₄ and evaporated under reduced pressure. The residue was purified by column chromatography (silica gel, heptanes/EtOAc = 3/1) and gave 20 as a light brown oil (0.578 mmol, 137 mg, 85%). ¹H NMR (300 MHz, CDCl₃, 298 K): δ = 2.34 (s, 3H), 3.49 (br s, 3H), 4.14 (s, 2H), 6.73–6.89 (m, 4H), 7.10 (d, J = 8.0 Hz, 2H), 7.31 (d, J = 8.0 Hz, 2H) ppm; ¹³C NMR (75 MHz, CDCl₃, 298 K): δ = 21.6, 35.1, 83.8, 85.9, 113.4, 116.6, 120.1, 120.6, 129.1 (2C), 131.7 (2C), 135.3, 136.6, 138.4 ppm; IR (film): v = 3334, 2920, 1597, 1508, 1450, 1271, 816, 740 cm⁻¹; HRMS (ESI): m/z calcd for C₁₆H₁₄N₂: 237.1386 [M + H]⁺; found: 237.1384.

(4-p-Toly)quinolin-8-amine (21). Pale yellow oil; ¹H NMR (700 MHz, CDCl₃, 298 K): δ = 2.46 (s, 3H), 5.05 (br s, 2H), 6.94 (dd, J = 1.9 Hz, 6.7 Hz, 1H), 7.24–7.30 (m, 3H), 7.32 (d, J = 7.9 Hz, 2H), 7.41 (d, J = 7.9 Hz, 2H), 8.77 (d, J = 4.4 Hz, 1H) ppm; ¹³C NMR (176 MHz, CDCl₃, 298 K): δ = 21.3, 109.9, 114.3, 121.7, 127.2, 127.4, 129.1 (2C), 129.4 (2C), 135.7, 138.1, 138.8, 144.2, 146.9, 148.4 ppm; IR (film): v = 3447, 3319, 2360, 1618, 1502, 1358, 1282, 818, 761 cm⁻¹; HRMS (ESI): m/z calcd for C₁₆H₁₄N₂: 237.1320 [M + H]⁺; found: 237.1320.

Acknowledgements

WS kindly acknowledges the financial support of the project 836532 (“Prä-klinische Entwicklung einer Off-the-Shelf individualisierten Krebsimmuntherapie”) by the Austrian Research Promotion Agency (FFG). The NMR spectrometers were acquired in collaboration with the University of South Bohemia (CZ) with financial support from the European Union through the EFRE INTERREG IV ETC-AT-CZ program (project M00146, “RERI-ushb”).

Notes and references

17 (a) T. S. Symeonidis, I. N. Lykakis and K. E. Litinas, Tetra-
21 X. Zhang, T. Yao, M. A. Campo and R. C. Larock, Tetra-