[4+3]-Annulation of 3-Cyano-4-aryl-2-iminochromenes with 1,2-Diaminobenzene: An Access to Novel Chromenobenzodiazepines

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Received: 26.02.2018
Accepted after revision: 05.04.2018
Published online: 08.05.2018

Abstract 3-Cyano-4-aryl-2-iminochromenes undergo [4+3]-annulation with 1,2-diaminobenzene under mild acidic conditions to generate novel chromenobenzodiazepines in good yields. The annulation reaction was also successful with 2-aminophenol and 2-aminothiophenol. The chromenobenzodiazepines could be conveniently reduced to the corresponding 4H-chromenobenzodiazepines under mild acidic conditions.

Key words 3-cyano-4-aryl-2-iminochromene, 1,2-diaminobenzene, [4+3]-annulation, chromenobenzodiazepine, chromenobenzoazepine

Benzodiazepines have emerged as a ‘privileged heterocyclic scaffold’ in medicinal chemistry.1 More than 40 benzodiazepines have been commercialized as drugs and pharmaceuticals. A few biologically and medicinally important fused benzodiazepines are depicted in Figure 1. Benzodiazepines are known to possess anticancer, antioxidant, and antibacterial activities.2–5 Several benzodiazepine drugs greatly affect the central nervous system, especially in the brain and are used as antianxiety drugs.6 Benzodiazepines are believed to form a supramolecular complex with GABA\textsubscript{A} chloride ion channel, which modulates the action of gamma-aminobutyric acid on chloride ion flux.

2-Amino-3-cyano-4-aryl 4H-chromenes exhibit widespread biological profiles including anticancer, anti-HIV and antibacterial activities.7 Several 4H-chromene-derived heterocycles have also been found to possess important biological activities. For example, Kamal et al. generated chromenopyrimidine derivatives and showed that the compounds exhibit antitumor activities.8 Similarly, Prenca et al. reported the synthesis of fused chromenopyrimidines having antifungal activities.9 It has been observed that benzodiazepines when fused with heterocyclic compounds exhibit superior activities.10 Recently, we reported the selective dehydrogenation of 2-amino-3-cyano-4-aryl 4H-chromenes using disopropyl azodicarboxylate in a polar aprotic solvent under neutral reaction conditions.11 The method provided easy access to 2-iminochromenes and thereby allowed us to test their reactivity. Herein, we report an annulation reaction of 2-iminochromenes with 1,2-diaminobenzene to generate novel chromenobenzodiazepines in good yields (Scheme 1).

Figure 1 A selection of biologically and medicinally important fused benzodiazepines

We hypothesized that the imino- and cyano groups of 2-iminochromene would be activated in the presence of an acid and behave as nucleophilic centers. This would create the opportunity for an annulation reaction with bidentate nucleophiles. With this aim, we screened several conditions for the annulation reaction of 2-iminochromene 1a with 1,2-diaminobenzene (2a). As shown in Table 1, the annulation reaction occurs under weakly acidic conditions. Condensation in acetic acid provided chromenobenzodiazepine...
3a in 55% yield (Table 1, entry 1). Reaction in pivalic acid and formic acid provided the benzodiazepine in low yields (46% and 42% yields, respectively). When TFA was used as a solvent, coumarin 4 was isolated as the predominant product. Condensations using mixed solvents were also tested and the results are presented in Table 1 (entries 5–9). In EtOH-AcOH (9:1), the reaction generated chromenobenzodiazepine 3a in 40% yield. Reaction in DMF-AcOH (9:1) was rapid but generated unidentified polar compounds along with 3a (52%). A low yield was observed when the condensation was carried out in dioxane-AcOH (9:1) mixture. However, an increase in isolated yield (64%) was observed when the reaction was carried out in toluene-AcOH (9:1) mixture, and the best result was obtained using toluene-AcOH (4:1) (entry 9). No condensation reaction was observed in the absence of AcOH (entry 11).

The best conditions were then employed for the annulation reaction of several iminochromenes generated from chromenes via diisopropyl azodicarboxylate-mediated dehydrogenation. As shown in Figure 2, the condensation reactions usually generate chromenobenzodiazepines in good yields in short reaction times. Chromenobenzodiazepine 3b, with a phenyl group at the 4-position, was obtained in 72% yield. Iminochromene, with a 3,4-dimethoxyphenyl group at the 4-position, generated the corresponding chromenobenzodiazepine 3c in 68% yields. When iminochromene having a \( p \)-nitrophenyl group at the 4-position was subjected to the annulation reaction, benzodiazepine 3d was obtained in 72% yield. The iminochromene with a cyclohexyl group at the 4-position also underwent smooth condensation reaction with 1,2-diaminobenzene to generate chromenobenzodiazepine 3e in 74% yield within three hours. The iminochromene containing a pyridyl group at the 4-position underwent effective condensation to furnish

### Table 1 Optimization of Reaction Conditions for Annulation Reaction

<table>
<thead>
<tr>
<th>Entry</th>
<th>Solvent</th>
<th>Conditions</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AcOH</td>
<td>100 °C, 4 h</td>
<td>55</td>
</tr>
<tr>
<td>2</td>
<td>Me,CCO2H</td>
<td>100 °C, 4 h</td>
<td>46</td>
</tr>
<tr>
<td>3</td>
<td>HCOOH</td>
<td>100 °C, 3 h</td>
<td>42</td>
</tr>
<tr>
<td>4</td>
<td>TFA</td>
<td>80 °C, 1 h</td>
<td>ND</td>
</tr>
<tr>
<td>5</td>
<td>EtOH-AcOH (9:1)</td>
<td>80 °C, 4 h</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>DMF-AcOH (9:1)</td>
<td>100 °C, 3 h</td>
<td>52</td>
</tr>
<tr>
<td>7</td>
<td>dioxane-AcOH (9:1)</td>
<td>100 °C, 3 h</td>
<td>42</td>
</tr>
<tr>
<td>8</td>
<td>toluene-AcOH (9:1)</td>
<td>100 °C, 3 h</td>
<td>64</td>
</tr>
<tr>
<td>9</td>
<td>toluene-AcOH (4:1)</td>
<td>100 °C, 2 h</td>
<td>70</td>
</tr>
<tr>
<td>10</td>
<td>toluene-PhCO2Hb</td>
<td>100 °C, 4 h</td>
<td>48</td>
</tr>
<tr>
<td>11</td>
<td>toluene(^{c})</td>
<td>100 °C, 1 h</td>
<td>NR</td>
</tr>
</tbody>
</table>

* All reactions were carried out using iminochromene 1a (1.0 equiv), 1,2-diaminobenzene (1.0 equiv) in the appropriate solvent (0.25 M).
* \( \text{PhCO2H} \) (10 equiv) was used.
* Reaction was carried out in the absence of AcOH.
* ND = yield not determined; NR = no reaction.
chromenobenzodiazepine 3f in good yield (70%). Iminochromene 1g, generated from the resorcinol-derived chromene, failed to undergo condensation to generate the chromenobenzodiazepine 3g under the standard conditions. When the condensation reaction was carried out at higher temperature (150 °C), a complex reaction mixture was obtained. Similarly, iminochromene 1h, generated from the resorcinol-derived chromene, also failed to give measurable amounts of compound 3h. The successful annulations of iminochromenes generated from chromenes derived from α-naphthol encouraged us to test the reaction with 2-aminophenol and 2-aminothiophenol under the standard conditions. To our satisfaction, annulation reactions with 2-aminophenol and 2-aminothiophenol were also effective and produced chromenobenzoazepines in moderate to good yields. These reactions usually required longer reaction time, presumably due to the lower nucleophilicity of the phenol and thiophenol groups. The iminochromene having a p-methoxyphenyl group at the 4-position required six hours for completion of condensation with 2-aminophenol, producing chromenobenzoazepine 3i in moderate yield (60%). The iminochromene possessing a 3,4-dimethoxyphenyl group at the 4-position produced chromenobenzoazepine 3j in 64% yield. Chromenobenzoazepine 3k, having a p-nitrophenyl group at the 4-position, was obtained in 61% yield and iminochromene incorporating a 3-pyridyl group at the 4-position also generated chromenobenzoazepine 3l in good yield (76%). Annulation reactions of 2-aminothiophenols containing a 3,4-dimethoxyphenyl group and a 3-pyridyl group at the 4-position furnished the corresponding chromenobenzoazepines 3m and 3n in 56% and 74% yields, respectively.

The mechanism of chromenobenzoazepine synthesis is depicted in Scheme 2. Concomitant nucleophilic addition of 1,2-diaminobenzene to the imino and cyano group of 2-iminochromene 1 activated by the carboxylic acid via weak coordination generates intermediate 5, which liberates a molecule of ammonia to be converted into intermediate 6. Hydrolysis of the unstable intermediate 6 leads to the chromenobenzoazepide 3’. In case of resorcinol-derived iminochromenes (1g, 1h), the phenolic hydroxyl group in-
increases the electron density in the aromatic ring and presumably decreases the reactivity of the imino group towards nucleophiles.

Our efforts to convert the synthesized chromenobenzodiazepines into the corresponding 4H-chromenobenzodiazepines by reduction with NaBH₄ met with difficulties. Reduction with NaBH₄ in THF-MeOH (4:1) at 0 °C was not clean and generated several spots on TLC analysis. However, upon careful optimization, we were pleased to observe that addition of 10 equivalents of AcOH was necessary for clean reaction. The crude product was purified by silica gel column chromatography using a gradient mixture of 10–30% EtOAc in hexane as eluent to obtain 7-(4H-chromenobenzodiazepines in excellent yields (Scheme 3).

In summary, a general method for annulation of 2-iminochromenes with 1,2-diaminobenzene, 2-aminophenol and 2-aminothiophenol has been developed to generate biologically important 1,4-chromenobenzodiazepines and chromenobenzodiazepines in good yields. The chromenobenzodiazepines can be conveniently reduced to the corresponding 4H-chromenobenzodiazepines in the presence of AcOH. The reduced 4H-chromenobenzodiazepines offer opportunity for further structural elaboration.

Chemicals received from commercial sources were used without purification. The 2-iminochromenes were synthesized by following a reported procedure. All commercial grade solvents were used without purification. Column chromatography was performed on 60–120 mesh silica gel using a gradient mixture of EtOAc in petroleum ether (60–80 °C) as eluent. Mass spectra were recorded with a Waters Xevo G2-SQ TOF mass spectrometer. ¹H and ¹³C NMR spectra were recorded with a Jeol JNM-ECS spectrometer at operating frequencies of 400 MHz (¹H) or 100 MHz (¹³C), as indicated in the individual spectrum, using TMS as an internal standard. Multiplicities in the ¹H NMR spectra are presented as s for singlet, d for doublet, dd for doublet of doublet, t for triplet, and m for multiplet. Thin-layer chromatography was performed on aluminum plates (silica gel 60 PF₂₅₄, 0.25 mm) purchased from Merck.

**Typical Procedure**

A mixture of 3-cyano-4-(p-methoxyphenyl) 2-iminochromene 1a (200 mg, 0.61 mmol) and 1,2-diaminobenzene (66 mg, 0.61 mmol) in toluene-AcOH (4:1, 2.5 mL) was stirred in a pre-heated oil bath at 100 °C under a nitrogen atmosphere. After 2 hours, TLC analysis indicated complete consumption of starting material. The reaction mixture was cooled to r.t. and solvent was evaporated under reduced pressure. The crude product was purified by silica gel column chromatography using a gradient mixture of 10–30% EtOAc in hexane as eluent to obtain 3a (180 mg, 70%) as a pale-yellow solid.

7-(4-Methoxyphenyl)benzo[b]benzo[7,8]chromeno[2,3-e][1,4]diazepin-8(2H)-one (3a)

Yield: 200 mg (70%); dark-brown solid; mp 198–200 °C.

1H NMR (DMSO-d₆, 400 MHz): δ = 12.49 (br s, 1 H, NH), 8.51–8.45 (m, 1 H), 8.07–8.01 (m, 1 H), 7.81 (d, J = 8.6 Hz, 1 H), 7.79–7.74 (m, 2 H), 7.48 (d, J = 8.0 Hz, 1 H), 7.44 (d, J = 7.8 Hz, 1 H), 7.26 (d, J = 8.7 Hz, 2 H), 7.21 (d, J = 8.8 Hz, 1 H), 7.17–7.05 (m, 2 H), 6.91 (d, J = 8.7 Hz, 2 H), 3.69 (s, 3 H).

13C NMR (DMSO-d₆, 100 MHz): δ = 160.0, 159.8, 156.6, 150.7, 146.3, 143.6, 135.2, 134.5, 130.7, 130.1, 128.6, 128.4, 126.1, 124.9, 123.6, 120.9, 122.7, 122.4, 121.8, 119.6, 117.9, 115.4, 114.2, 112.0, 55.6.


7-(Pyridin-3-yl)-8H-benzo[b]benzo[7,8]chromeno[2,3-e][1,4]diazepin-8-one (3b)

Yield: 200 mg (76%); dark-brown solid; mp 198–200 °C.

1H NMR (CDCl₃, 400 MHz): δ = 8.74–8.65 (m, 2 H), 8.62 (s, 1 H), 7.93–7.87 (m, 1 H), 7.78–7.71 (m, 1 H), 6.99–6.83 (m, 2 H), 7.45–7.36 (m, 2 H), 7.35–7.26 (m, 2 H), 7.16 (d, J = 8.6 Hz, 1 H).

13C NMR (CDCl₃, 100 MHz): δ = 158.2, 156.9, 155.2, 152.0, 150.6, 148.7, 141.1, 136.3, 135.7, 130.2, 128.0, 127.9, 125.9, 125.0, 124.7, 123.3, 123.0, 122.4, 121.8, 119.6, 117.9, 115.4, 114.2, 112.0, 55.6.


7-(Pyridin-3-yl)-9,14-dihydrobenzo[b]benzo[7,8]chromeno[2,3-e][1,4]oxazepin-8-one (3c)

Yield: 45 mg (90%); yellow solid; mp 235–236 °C.

1H NMR (DMSO-d₆, 400 MHz): δ = 10.25 (br s, 1 H, NH), 8.14 (br s, 1 H), 7.86 (d, J = 8.2 Hz, 7.71–7.54 (m, 1 H), 7.54–7.21 (m, 7 H), 7.18–6.89 (m, 4 H), 6.11 (d, J = 11.8 Hz, 1 H), 5.87 (d, J = 11.8 Hz, 1 H).

13C NMR (CDCl₃, 100 MHz): δ = 153.4, 153.0, 150.3, 150.2, 147.7, 143.2, 142.6, 138.4, 136.0, 134.7, 133.5, 127.9, 126.3, 126.0, 125.5, 123.9, 123.7, 122.7, 121.9, 121.7, 120.2, 118.9, 118.7, 111.9, 44.5.

Funding Information
A research grant from DST-SERB (YSS/2014/000957) and UGC (F-45/2006/BSR), New Delhi is gratefully acknowledged.

Acknowledgment
M.M. and H.S. thank UGC, New Delhi for Research Fellowships. We thank MRC, MNIT Jaipur for NMR spectra. We are also grateful to USIC, University of Rajasthan for recording HRMS data.

Supporting Information
Supporting information for this article is available online at https://doi.org/10.1055/s-0036-1591573.

References