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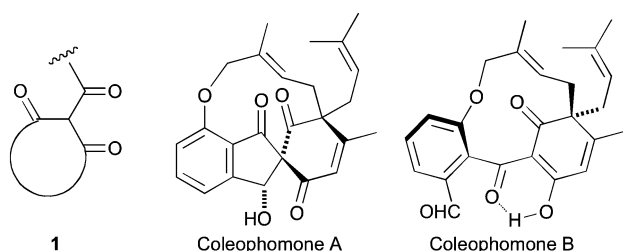
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# Isoxazole to oxazole: a mild and unexpected transformation†

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**3-Aryltetrahydrobenzoxazoles prepared en route to the coleophomone natural products and analogues, were found to undergo a remarkable base-mediated rearrangement to 2-aryltetrahydrobenzoxazoles. The scope of this unprecedented, facile transformation was probed: a range of analogues was produced, a mechanism proposed, and an application demonstrated by synthesis of a known herbicidal compound.**

As an extension of our interest in natural products containing the cyclic trione unit **1**,<sup>1,2</sup> we were attracted to the coleophomone natural products, exemplified by coleophomones A (**2**) and B (**3**), reported as being in equilibrium *via* an aldol process.<sup>3,4</sup> This group of metabolites have enzyme inhibitory properties towards bacterial cell wall transglycosylase and human heart chymase.<sup>4,5</sup>



Applying our previously reported isoxazole masking strategy for the cyclic trione unit<sup>1,2</sup> led us to propose the disconnection of Scheme 1, requiring 3-aryltetrahydrobenzoxazole building blocks to access the natural products and (masked) analogues. Whilst manipulating one such arylbenzoxazole, we observed a remarkable rearrangement to a 2-arylbenzoxazole. We report here our exploration of this unprecedented, facile transformation.

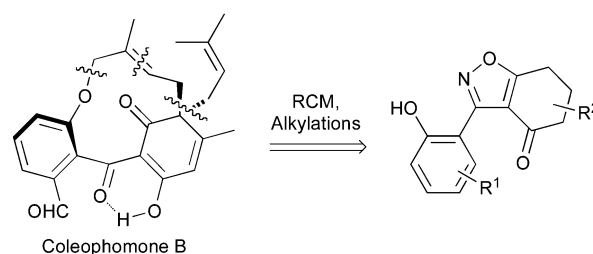
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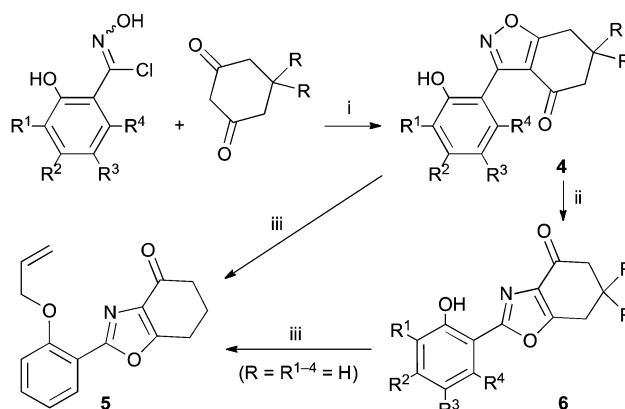
† Electronic supplementary information (ESI) available. CCDC 962972–962975. For ESI and crystallographic data in CIF or other electronic format see DOI: 10.1039/c4cc07999j



Scheme 1 Strategic disconnection of coleophomones.

A suitable set of 3-aryltetrahydrobenzoxazoles **4** was prepared by 1,3-dipolar cycloaddition of aryl nitrile oxides [available from benzaldehyde oximes *via* C-chlorination (NCS, CHCl<sub>3</sub> reflux) and 1,3-elimination] with cyclohexane-1,3-diones under basic conditions (Scheme 2).<sup>6</sup>

During attempts to complete *O*-allylation of 3-(2-hydroxyphenyl)-benzoxazole **4a** (R = R<sup>1</sup> = H) under standard basic conditions (Cs<sub>2</sub>CO<sub>3</sub>, THF reflux), we did not observe the expected product but instead isolated 2-(2-allyloxy)tetrahydrobenzoxazole **5**.



Scheme 2 Synthesis and rearrangement of 3-aryltetrahydrobenzoxazoles **4**. Reagents: (i), NaOi-Pr, i-PrOH; (ii), Cs<sub>2</sub>CO<sub>3</sub>, THF reflux; (iii), H<sub>2</sub>C=CHCH<sub>2</sub>Br, Cs<sub>2</sub>CO<sub>3</sub>, THF reflux.

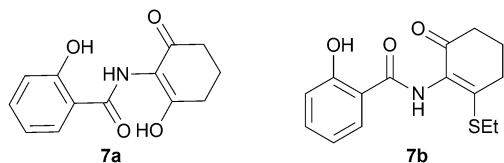


**Table 1** Rearrangement of isoxazole **4a** to oxazole **6a** under various reaction conditions<sup>a</sup>

| Entry | Base                                   | Solvent               | Yield <sup>b</sup> (%) |
|-------|----------------------------------------|-----------------------|------------------------|
| 1     | Cs <sub>2</sub> CO <sub>3</sub>        | THF                   | 87                     |
| 2     | K <sub>2</sub> CO <sub>3</sub>         | THF                   | 84                     |
| 3     | Na <sub>2</sub> CO <sub>3</sub>        | THF                   | 5                      |
| 4     | Et <sub>3</sub> N                      | THF                   | 0                      |
| 5     | DMAP                                   | THF                   | 0                      |
| 6     | DBU                                    | THF                   | 83                     |
| 7     | LDA                                    | THF                   | 37                     |
| 8     | Cs <sub>2</sub> CO <sub>3</sub>        | Toluene               | 97                     |
| 9     | NaOi-Pr                                | i-PrOH                | 85                     |
| 10    | Cs <sub>2</sub> CO <sub>3</sub>        | EtOH-H <sub>2</sub> O | 87 (for 7a)            |
| 11    | None                                   | H <sub>2</sub> O      | 8                      |
| 12    | Cs <sub>2</sub> CO <sub>3</sub>        | H <sub>2</sub> O      | 91 (for 7a)            |
| 13    | Cs <sub>2</sub> CO <sub>3</sub> & EtSH | THF                   | 6 (for 7b)             |

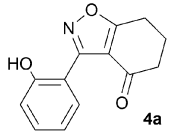
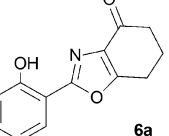
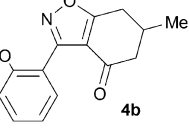
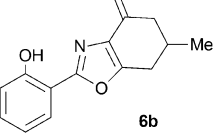
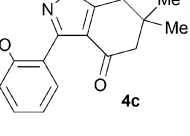
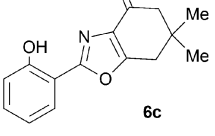
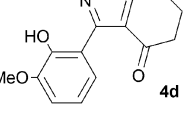
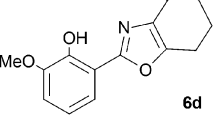
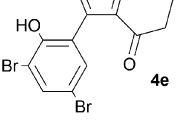
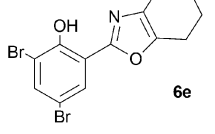
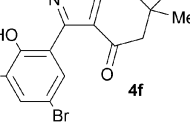
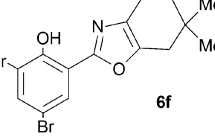
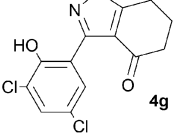
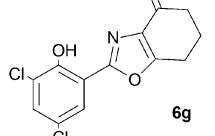
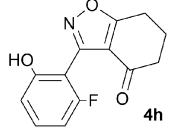
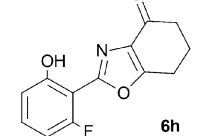
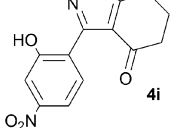
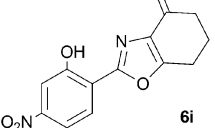
This rearrangement also took place in the absence of alkylating agent (Scheme 2); the phenolic product **6a** ( $R = R^{1-4} = H$ ) was stable to the basic conditions, and was successfully *O*-allylated to give ether **5** on addition of allyl bromide. We have verified the structures of both isoxazole **4a** and dimethyl product oxazole **6b** ( $R = Me$ ,  $R^{1-4} = H$ ; *vide infra*) through X-ray crystal structure determinations, Fig. 1a and b.‡

We further investigated the scope of the remarkable rearrangement of benzisoxazoles **4** to benzoxazoles **6**. Using isoxazole **4a**, rearrangement was found to occur in aprotic solvents with reaction time of 4 h under a range of basic conditions (Table 1) including carbonates, alkoxide and amidine, but failed with tertiary amines. In the presence of water or ethanethiol (entries 12, 13) the amide products **7a,b**, respectively, of ring opening of the oxazole **6a** were isolated; the constitutions of the amides were confirmed by X-ray crystal structures.<sup>7</sup>

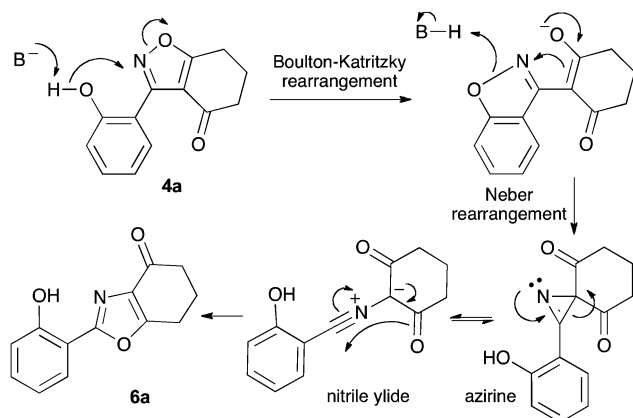


A range of 3-(2-hydroxyphenyl)tetrahydrobenzisoxazoles **4a-i**, differently substituted in the aryl and the cyclohexane ring were shown to undergo rearrangement (Table 2) using the convenient  $\text{Cs}_2\text{CO}_3$  conditions (THF reflux) to afford oxazoles **6a-i**.

We propose the mechanism illustrated in Scheme 3 for the rearrangement. Until the oxazole structure was determined, we had supposed that a Boulton–Katritzky ring transposition<sup>8</sup> (similar to that reported by Suzuki *et al.*<sup>9</sup>) was taking place,

| Isoxazole 4                                                                          | Oxazole 6                                                                             | Yield (%)       |
|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|-----------------|
|    |    | 87 <sup>b</sup> |
|    |    | 59 <sup>b</sup> |
|    |    | 82 <sup>b</sup> |
|    |    | 70 <sup>c</sup> |
|   |   | 28 <sup>c</sup> |
|  |  | 55 <sup>c</sup> |
|  |  | 58 <sup>d</sup> |
|  |  | 75 <sup>d</sup> |
|  |  | 77 <sup>d</sup> |

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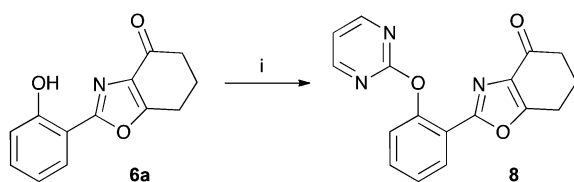


Scheme 3 Proposed mechanism for isoxazole-oxazole rearrangement.

so we retain this as the initial step in this remarkable isoxazole-to-oxazole conversion.<sup>10</sup> This can be followed by a Neber rearrangement<sup>11</sup> to give an azirine, thus overall replacing the N–O bond of the isoxazole by an N–C bond. The azirine may be envisaged to be in equilibrium with a nitrile ylide<sup>12</sup> stabilised at the formal negative end by the 1,3-dione system, and at the formal positive end by the electron-rich 2-hydroxyphenyl substituent. The 1,3-dipole finally collapses to the oxazole in a 6 $\pi$  electrocyclic ring closure.

Previous reports indicate that it is possible to form oxazoles from azirines, and also that an azirine can be generated from an isoxazole either thermally or photolytically.<sup>13,14</sup> However, the energies required well exceed those of our reaction conditions and thus an alternative rationale was required. The Neber rearrangement is an alternative way of generating azirines given the appropriate leaving group.<sup>15</sup> This mechanism implies that the base is catalytic, and this was supported by isolation of **6a** (66%) from **4a** using 0.1 mol equiv. of Cs<sub>2</sub>CO<sub>3</sub> (THF reflux, 1.5 h). An intermediate with *m/z* identical to both the isoxazole and oxazole was observed by LC-MS during the rearrangements of **4a** and **4c** to **6a,c**, respectively, and isolated by HPLC. We were not able to unambiguously identify the structure, but NMR studies indicate the cyclohexane portion to be symmetrical, supporting either the azirine or nitrile ylide formulation.<sup>16</sup> An attempt to crystallise the dimethyl intermediate formed from **4c** led merely to recovery of the oxazole **6c**. The oxazole ring opening to form amides **7a,b** is consistent with nucleophilic attack at C-5 of the oxazole.

To discount the possibility of the oxazoles being formed by retro-cycloaddition from the isoxazoles and recombination *via* a different connectivity, we have shown that treatment of a

Scheme 4 Reagents: (i), 2-chloropyrimidine, Cs<sub>2</sub>CO<sub>3</sub>, Cu, dry DMF, 1 day.

mixture of the two tetrahydrobenzisoxazoles **4c** and **4i** under the Cs<sub>2</sub>CO<sub>3</sub>–THF reflux conditions led only to the tetrahydrobenzoxazoles **6c** and **6i** predicted by the mechanism of Scheme 3, with no crossover products observed.

The tetrahydrobenzoxazoles prepared herein are closely related to a series of herbicides described in a patent by Ueda *et al.*<sup>17</sup> Using benzoxazole **6a** we have prepared an example **8** of this group by reaction with 2-chloropyrimidine (47%) (Scheme 4).

In conclusion, we have discovered an unexpected, remarkably facile novel base-mediated rearrangement of tetrahydrobenzisoxazoles to tetrahydrobenzoxazoles, demonstrated the scope and probed the reaction mechanism of this surprising transformation. The synthetic utility of this rearrangement has been demonstrated by synthesis of a known bioactive compound.

The authors thank Loughborough University for a studentship (A. C.) and Lilly UK for financial support, and ENSIACET (Toulouse) for support for a work placement (R. M.).

## Notes and references

‡ Crystal data for **4a**: C<sub>13</sub>H<sub>11</sub>NO<sub>3</sub>, *M* = 229.23, orthorhombic, *Pca*2<sub>1</sub>, *a* = 15.024(3) Å, *b* = 21.464(4) Å, *c* = 13.309(3) Å, *V* = 4291.8(15) Å<sup>3</sup>, *Z* = 16,  $\mu$ (Mo–K $\alpha$ ) = 0.102 mm<sup>−1</sup>, 36 812 reflections measured, 8811 unique, *R*<sub>int</sub> = 0.064, *R*<sub>1</sub>[for 5081 data with *F*<sup>2</sup> > 2 $\sigma$ (*F*<sup>2</sup>)] = 0.056, *wR*<sub>2</sub> (all data) = 0.168, absolute structure *x* = −0.4(19). Four molecules in asymmetric unit. For **6b**: C<sub>15</sub>H<sub>15</sub>NO<sub>3</sub>, *M* = 257.28, orthorhombic, *Pna*2<sub>1</sub>, *a* = 12.930(2) Å, *b* = 9.3159(15) Å, *c* = 21.663(4) Å, *V* = 2609.4(8) Å<sup>3</sup>, *Z* = 8,  $\mu$ (Mo–K $\alpha$ ) = 0.09 mm<sup>−1</sup>, 25 390 reflections measured, 6484 unique, *R*<sub>int</sub> = 0.034, *R*<sub>1</sub>[for 5459 data with *F*<sup>2</sup> > 2 $\sigma$ (*F*<sup>2</sup>)] = 0.035, *wR*<sub>2</sub> (all data) = 0.088, absolute structure *x* = 0.2(4). Two molecules in asymmetric unit. CCDC 962972 and 962973.  
§ Typical procedure for oxazole formation: 3-(2-hydroxyphenyl)-6,7-dihydrobenzo[d]isoxazol-4(5*H*)-one **4a** (0.500 g, 2.18 mmol) and Cs<sub>2</sub>CO<sub>3</sub> (1.42 g, 4.37 mmol) in dry THF (30.0 mL) was heated under reflux for 4 h. Hydrochloric acid (2 M; 5 mL) and CH<sub>2</sub>Cl<sub>2</sub> (25 mL) were added after the reaction mixture had cooled to 20 °C. The mixture was separated and the combined organic layer washed with water (2 × 25 mL) and brine (25 mL). The organic layer was dried (MgSO<sub>4</sub>), filtered and evaporated to dryness under reduced pressure to yield 2-(2-hydroxyphenyl)-6,7-dihydrobenzo[d]oxazol-4(5*H*)-one **6a** (0.435 g, 87%) as a beige solid, mp 202–204 °C (decomp);  $\nu_{\text{max}}$ (CH<sub>2</sub>Cl<sub>2</sub>)/cm<sup>−1</sup> 3804, 1694;  $\delta_{\text{H}}$  (400 MHz; CDCl<sub>3</sub>) 2.20–2.27 (2H, m, CH<sub>2</sub>), 2.57 (2H, t, *J* = 5.6, OxCH<sub>2</sub>), 3.00 (2H, t, *J* = 6.0, CH<sub>2</sub>C=O), 6.86–6.90 (1H, m, Ar–CH), 7.10 (1H, dd, *J* = 0.8, 8.4, Ar–CH), 7.30–7.34 (1H, m, Ar–CH), 7.74 (1H, dd, *J* = 1.6, 8.0, Ar–CH) 10.58 (1H, br s, OH);  $\delta_{\text{C}}$  (100 MHz; CDCl<sub>3</sub>) 22.2, 37.9 (CH<sub>2</sub>), 110.0 (C), 117.6, 119.5, 126.3, 133.2 (Ar–CH), 133.7, 157.7, 161.2, 163.0 (C), 190.7 (C=O). HRMS: *M*H<sup>+</sup> 230.0809; C<sub>13</sub>H<sub>11</sub>NO<sub>3</sub> requires *M*H<sup>+</sup> 229.0812.

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- 16 Selected spectral data for the intermediate in rearrangement of **4a** to **6a**:  $\delta_{\text{H}}$  (500 MHz;  $\text{CDCl}_3$ ) 2.05–2.15 (m, 2H,  $\text{CH}_2\text{CH}_2\text{CH}_2$ ), 2.67 (4H, t,  $J = 6.4$ ,  $2 \times \text{CH}_2\text{CO}$ ), 7.30–7.33 (1H, m, Ar–H), 7.52–7.60 (2H, m,  $2 \times \text{Ar-H}$ ), 8.21 (1H, d,  $J = 8.2$ , Ar–H), 11.18 (s, 1H, OH).
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