Formation of 2-oxa- or 2-azabicyclo[3.3.0]octa-3,7-diene by a novel tandem intramolecular photo-cyclization of 2,4,6-tris(phenylthio)hepta-2,4,6-trienal derivatives

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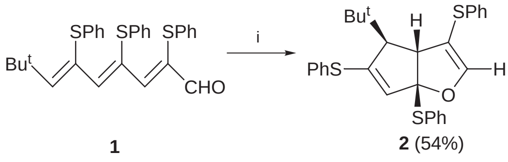
The photo-reactions of 2,4,6-tris(phenylthio)hepta-2,4,6-trienal 1 and its 2,4-dinitrophenylhydrazone 5 gave the 2-oxa- or 2-azabicyclo[3.3.0]octa-3,7-dienes 2 and 9, respectively, *via* a photo-induced intramolecular tandem cyclization reaction.

The Paterno–Büchi reaction has become increasingly familiar to chemists engaged in investigation of its mechanism or synthetic applications.[1] The widespread advances in this area of synthetic organic chemistry have led to convenient methodology for the preparation of the oxetane-containing biologically active materials.[2] Intramolecular photo-reactions of the vinyloxy ω-carbonyl compounds and their furan derivatives usually provides the fused oxetane ring compounds,[3] which lead to other useful compounds by successive transformations.[4]

Recently, we reported the tandem α-(thio)- or α-(seleno)-formylolefination reactions of the aldehydes.[5] Three cycles of the olefination process with pivalaldehyde stereoselectively afforded (2*E*, 4*E*, 6*E*)-8,8-dimethyl-2,4,6-tris(phenylthio)nona-2,4,6-trienal **1**, which contains three conjugated vinyl sufide moieties. This trienal **1** was found to be light-sensitive like the retinal chromophores.[6] This result prompted us to investigate the reactivities of the trienal under photo-irradiation conditions; surprisingly, a new ring system, oxabicyclo[3.3.0]octa-3,7-diene, was formed *via* an unusual photo-cyclization. Here we report the unprecedented intramolecular tandem cyclization reaction of trienal **1**.

Irradiation of an Ar saturated solution of **1** in MeCN (1.0×10^{-3} mol l^{-1}) using a 40 W fluorescent daylight lamp afforded (1*R**, 5*R**, 6*S**)-6-*tert*-butyl-1,4,7-tris(phenylthio)-2-oxabicyclo[3.3.0]octa-3,7-diene **2**[7] in 54% yield as shown in Scheme 1. The structure of **2** followed from the fact that the IR spectrum showed no carbonyl absorption, while the ^{1}H NMR spectrum showed two methine protons at δ 2.82 (t, *J* 2) and 3.40 (t, *J* 2) and two olefinic protons at δ 5.07 (s) and 6.50 (d, *J* 2). The stereochemistry of oxabicyclo compound **2** was determined as (1*R**, 5*R**, 6*S**) by single crystal X-ray analysis; the ORTEP drawing of **2** is shown in Fig. 1.[8] Furthermore, a few fundamental reactions of **2** were examined using oxidizing agents. MCPBA oxidation of **2** gave the corresponding sulfone **3** in 78% yield (Scheme 2). The reaction with Pd–C in toluene under reflux conditions afforded the ring-opened cyclopentadiene **4** in 40% yield. The structure of **4** was determined from the IR spectrum, which showed the carbonyl absorption at ν 1650 cm^{-1}, the ^{1}H NMR spectrum, which exhibited two doublets at δ 6.54 (d, *J* 7) (due to the olefinic proton) and 11.13 (d, *J* 7) (due to the aldehyde proton), and the mass spectrum, which showed a molecular ion peak ($C_{28}H_{22}OS$) at *m/z* 378. The stereochemistry of **4** was determined as *Z* by an NOE experiment. Irradiation of the *tert*-butyl protons at δ 1.22 increased the intensity of the olefinic proton at δ 6.54 (4%).



Scheme 1 *Reagents and conditions*: i, $h\nu$ (500–600 nm), MeCN.

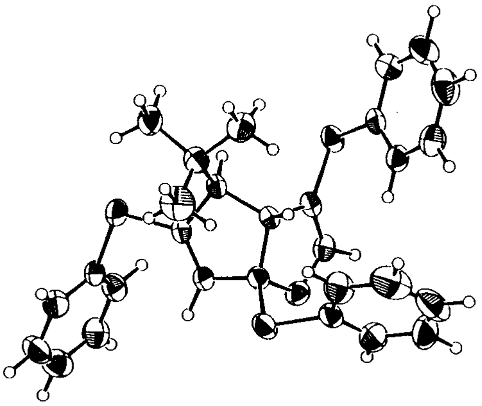
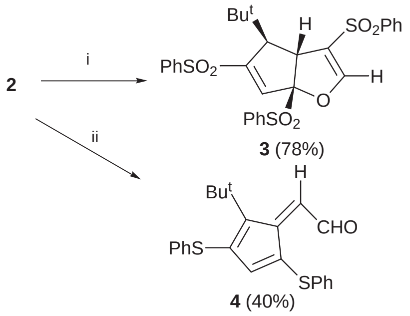
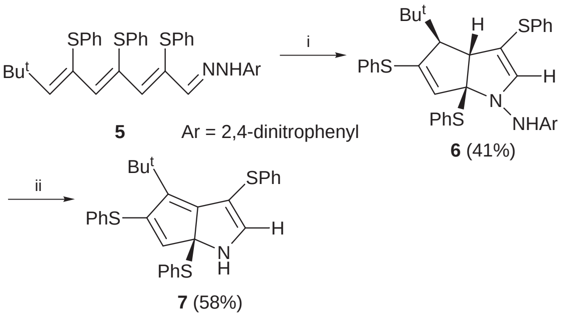


Fig. 1 ORTEP drawing of **2**.

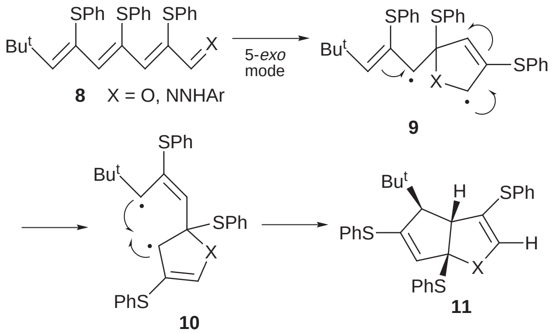


Scheme 2 *Reagents and conditions*: i, MCPBA, ClCH$_2$CH$_2$Cl; ii, Pd–C, toluene.

Next, we examined the photo-reaction of the trienal hydrazone **5**, irradiating at 400–500 nm in benzene to give 2-azabicyclo[3.3.0]octa-3,7-diene **6** in 41% yield (Scheme 3).[9]



Scheme 3 *Reagents and conditions*: i, $h\nu$ (400–500 nm), benzene; ii, AIBN, benzene, reflux.



Scheme 4

Recently, we reported that the 2,4-dinitrophenylhydrazones reacted with AIBN and underwent dearylamination.[10] Treatment of the hydrazone **6** with AIBN in benzene afforded 2-azabicyclo[3.3.0]octa-3,5,7-triene **7** in good yield.

A plausible mechanism for formation of the photo-reaction products is shown in Scheme 4. Intermolecular [2 + 2] photocycloadditions have been intensively investigated and have indicated that the reaction intermediate is a flexible 1,4-biradical.[11] Our intramolecular cyclization would also proceed *via* triplet biradical intermediates and cyclize in 5-*exo* mode to give the 1,4-biradical **9**. Isomerization of **9** affords a 1,5-biradical **10**. Tandem cyclization leads to the bicyclo-[3.3.0]octa-3,7-diene **11**.

In conclusion, 2,4,6-tris(phenylthio)hepta-2,4,6-trienal derivatives are highly sensitive to light and their photo-reactions were found to afford the 2-oxa- or 2-azabicyclic compounds *via* a unique tandem cyclization reaction.

Notes and references

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7. *Selected data* for **2**: $\nu_{\max}$/cm^{-1} 1130 (ether); δ_H 0.91 (9H, s, Me $\times$ 3), 2.82 (1H, t, J 2, 6-H), 3.40 (1H, t, J 2, 5-H), 5.07 (1H, s, 8-H), 6.50 (1H, d, J 2, 3-H), 6.55–6.59 (2H, m, ArH), 7.01–7.07 (3H, m, ArH), 7.36–7.42 (5H, m, ArH), 7.46–7.51 (3H, m, ArH), 7.60–7.62 (2H, m, ArH); δ_C 28.60 (q $\times$ 3), 34.54 (s), 54.53 (d), 64.28 (d), 107.23 (s), 107.77 (s), 123.29 (d), 125.03 (d $\times$ 2), 126.16 (d), 128.89 (d $\times$ 2), 129.00 (d), 129.07 (d), 129.15 (d $\times$ 2), 129.57 (d $\times$ 2), 131.19 (s $\times$ 2), 132.13 (s), 132.46 (d $\times$ 2), 135.95 (d $\times$ 2), 150.10 (d), 150.65 (s); *m/z* 488 (M$^+$) (Calc. for $C_{29}H_{28}OS_3$; C, 71.27; H, 5.77. Found: C, 71.12; H, 5.77%).
8. *Crystal data* for **2**: $C_{29}H_{28}OS_3$ M = 488.72, monoclinic, a = 9.007(2), b = 26.879(6), c = 10.945(2) Å, β = 99.34(2)°, V = 2614.7(9) Å^3, T = 298 K, space group $P2_1/n$, Z = 4, μ(Cu-Kα) = 2.728 mm^{-1}, D_c = 1.214 Mg m^{-3}, 4284 reflections collected (Rigaku AFC5R diffractometer) of which 4096 were unique (R_{int} = 0.030) and 2720 were observed [$I > 3.00\sigma(I)$]. Solved by direct methods (MITHRIL90 and DIRDIF) and refined by full-matrix least-squares (teXsan) on F of all unique data to R = 0.056 (observed data), wR = 0.070 (all data). CCDC 182/1222. See http://www.rsc.org/suppdata/cc/1999/909/ for crystallograpic files in .cif format.
9. *Selected data* for **6**: $\nu_{\max}$/cm^{-1} 3330 (NH), 1620, 1340 (NO_2); δ_H 1.28 (9H, s, Me $\times$ 3), 4.47 (1H, s, 6-H), 6.29 (1H, s, 8-H), 6.47 (1H, s, 5-H), 6.57 (1H, s, 3-H), 6.74 (1H, d, J 10, ArH), 7.07–7.40 (15H, m, ArH), 8.13 (1H, dd, J 2 and 10 ArH), 9.02 (1H, br d, J 2, ArH), 10.06 (1H, s, NH); δ_C 30.39 (q $\times$ 3), 33.85 (s), 67.58 (d), 101.02 (s), 114.20 (d), 121.73 (s), 123.65 (d), 123.71 (d), 125.69 (d), 126.19 (d), 126.42 (d), 126.66 (d $\times$ 2), 128.23 (d), 128.45 (d $\times$ 2), 128.98 (d), 129.24 (d), 129.30 (d), 129.58 (s), 130.52 (d), 130.82 (s), 132.17 (d $\times$ 2), 132.74 (s), 133.92 (d), 133.98 (d), 134.08 (s), 138.33 (s), 138.68 (s), 140.31 (d), 147.70 (s), 152.78 (d); *m/z* 429 [M$^+$ $-$ (Bu^t + $(O_2N)_2C_6H_3NH$)] (Calc. for $C_{35}H_{32}N_4O_4S_3$: C, 62.85; H, 4.82; N, 8.38. Found: C, 62.71; H, 5.23; N, 7.96%).
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