Photochemical Synthesis of the Acetylene Adducts and Dimers of 2*H*- and 4*H*-1-Benzopyranones[1]

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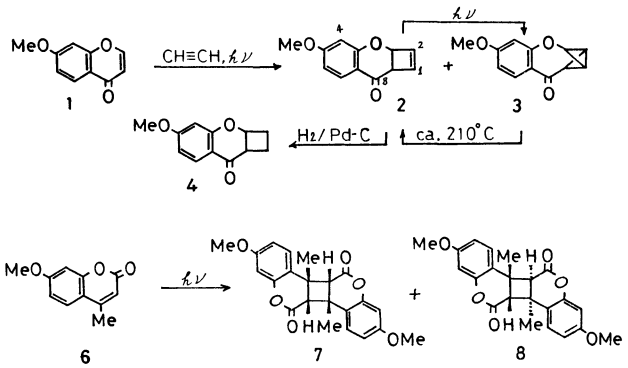
Synopsis. 7-Methoxychromone reacts photochemically with acetylene to form 5-methoxy-2a,8a-dihydro-8*H*-benzo[*b*]cyclobuta[*e*]pyran-8-one and its valence isomer. Photoaddition of acetylene to 6-methoxychromone and 7-methoxy-4-methylcoumarin did not proceed, but the latter underwent photodimerization to give the head-to-tail dimers.

In approach to the synthesis of trichothecane sesquiterpenes, we have reported that photochemical cycloaddition of α,β-unsaturated carbonyl compounds, such as 4a,5,6,7,8,8a-hexahydro-4a-methoxycarbonyl-7,7-ethylenedioxy-4-methylcoumarin with acetylene produced the 3,4-fused cyclobutene ring system in 62% yield, which was led to construct the five-menbered ring of trichothecane nucleus.[2] Our extensive interest is present in preparation of cyclobutene and cyclobutane skeleton from photochemical cycloaddition reaction of benzopyrones with several olefins, and in the development of construction of trichothecanes and trichothecane-like compounds *via* procedure containing the acid-catalysed rearrangement of the strained component. This paper describes preparation of the cyclobutane derivatives, acetylene adducts from 7-methoxychromone and coumarin dimers from 7-methoxy-4-methylcoumarin by photochemical cycloaddition,[3] respectivcly.

Irradiation of a solution of 7-methoxychromone (**1**) in acetone with bubbling introduction of acetylene using a 500-W high pressure mercury lamp through a Pyrex filter afforded 5-methoxy-2a,8a-dihydro-8*H*-benzo[*b*]cyclobuta[*e*]pyran-8-one (**2**) in 35% yield and its valence isomer, bicyclobutane (**3**) in 10% yield. These structures can be interpreted on the basis of the NMR spectral characteristics: for **2** ^{1}H-NMR signals of the two methine protons at δ 3.97 and 5.32 (each d, J=3 Hz) and the two olefin protons at 6.23 and 6.33 (each d, J=2 Hz), and ^{13}C-NMR signals at δ 54.8, 73.9, 140.0, and 140.7 due to C_{8a}, C_{2a}, C_1, and C_2 respectively, indicated the formation of cyclobutene ring system involving the 2,3-positions of the chromone and the formation of bicyclo[1.1.0]butane moiety in **3** was indicated by the ^{1}H-NMR signals due to the four methine protons at δ 2.51 (2H, t, J=3 Hz), 3.70—3.87 (1H, m), and 5.66 (1H, dt, J=2, 4 Hz), which were compatible with those of the bicyclobutane compound reported by Murata *et al.*[4] The gross structures of **2** and **3** were also supported by the mass spectrum, both of which showed intense peak at m/z 202 just to M^+.

Catalytic hydrogenation of **2** over Pd–C in ethanol yielded the cyclobutane derivative (**4**) in 72% yield. The confirmation of a cyclobutane ring in **4** was provided from the NMR spectra (the data are given in Experimental). Furthermore, we tried the isomerization between valence isomers **2** and **3** as follows.[5]



When a solution of **2** in acetone was irradiated, **3** was obtained in 33% yield. However, irradiation of **3** in acetone led to recovery of the starting material. Whereas the thermal reaction of **3** at 205—210 °C for 10 min gave **2** (26% yield) along with starting material.

In contrast to the photochemical activity of **1** with acetylene, neither 6-methoxychromone (**5**) nor 7-methoxy-4-methylcoumarin (**6**) was reactive toward acetylene. Consequently, **5** was almost recovered in the photochemical reaction. On the other hand, **6** dimerized upon direct irradiation in methanol to give the head-to-tail dimers, **7** (45% yield) and **8** (25% yield). Upon benzophenone-sensitized irradiation in benzene, **8** was prepared in 90—92% yield. There are two possible cycloutane photodimers of 4-methylcoumarin having the *syn* and *anti* head-to-tail configuration.[6] The assignment of *syn* and *anti* isomers were made on the basis of a NMR diamagnetic shielding effect, indicating that dimer **7** with the more highly shielded aromatic protons (δ 6.04, 6.66, and 7.10 for **7** and 6.70, 6.84, and 7.14 for **8**) has the *syn* configuration and dimer **8** with the more highly shielded methyl protons (δ 1.66 for **7** and 1.26 for **8**) corresponds to the *anti* configuration.[7]

Presently, the work is under the investigation of the acid-catalysed transformation of all synthetic cyclobutanes described here and their functionalized compounds in order to construct the five-menbered ring of trichothecane analogues.

Experimental

Melting points are uncorrected. IR spectra were measured in $CHCl_3$ with a Hitachi 260-50 spectrophotometer. ^{1}H-NMR and ^{13}C-NMR spectral data were obtained in $CDCl_3$ on a JEOL JNM MH-100 spectrometer (100 MHz) and a JEOL JNM-FX 60 Fourier transform spectrometer (60 MHz) operating at 15.1 MHz, respectively. Chemical shifts are reported in δ values downfield from TMS as an internal standard. Mass spectra were obtained on a JEOL JMS-D 300S spectrometer. All irradiations were performed

with a 500-W high pressure mercury lamp (Eikosha EHB-WI-500). Column chromatography was performed with Merck silica gel (0.063 mm).

*Photoaddition of Acetylene to 7-Methoxychromone (**1**).* A solution of **1** (550 mg) in acetone (400 ml) was irradiated through a Pyrex filter at 25—30 °C with bubbling introduction of acetylene for 5 h. After removal of the solvent under reduced pressure, the residue was subjected to column chromatography on silica gel using ethyl acetate–benzene (1:19) as eluent to give mainly three products, unidentified oil (*ca.* 30 mg), **3** (64 mg), **2** (220 mg), and **1** (160 mg) in the order of elution. **2**: Mp 96—97 °C (acetone–hexane); IR: 1665, 1615, and 1580 cm^{-1}; ^{1}H-NMR: 3.82 (3H, s, OCH_3), 3.97(1H, d, J=3 Hz, C_{8a}–H), 5.32(1H, d, J=3 Hz, C_{2a}–H), 6.23 (1H, d, J=2 Hz, C_1–H), 6.33 (2H, d, J=2 Hz, C_2– and C_4–H), 6.54 (1H, dd, J=2 and 11 Hz, C_6–H), and 7.81 (1H, d, J=11 Hz, C_7–H); ^{13}C-NMR: 54.8 (d, C_{8a}), 55.6 (q, OCH_3), 73.9 (d, C_{2a}), 101.4 (d, C_4), 110.2 (d, C_6), 112.4 (s, C_{7a}), 129.6 (d, C_7), 140.0 and 140.7 (each d, C_1 and C_2), 160.7 (s, C_{4a}), 166.3 (s, C_5), and 192.4 (s, C_8); MS: m/z 202 (M^+); Found: C, 71.27; H, 4.95%. Calcd for $C_{12}H_{10}O_3$: C, 71.28; H, 4.99%. **3**: Mp 66—68 °C (acetone–hexane); IR: 1660, 1610, and 1575 cm^{-1}; ^{1}H-NMR: 2.51 (2H, t, J=3 Hz, C_1– and C_2–H), 3.70—3.87 (1H, m, C_{8a}–H, overlapped with methoxyl peak), 3.87 (3H, s, OCH_3), 5.66 (1H, dt, J=2 and 4 Hz, C_{2a}–H), 6.43 (1H, d, J=3 Hz, C_4–H), 6.60 (1H, dd, J=3 and 9 Hz, C_6–H), and 8.00 (1H, d, J=9 Hz, C_7–H); ^{13}C-NMR: 15.6 (d, C_1 and C_2), 55.6 (q, OCH_3), 59.3 (d, C_{8a}), 85.8 (d, C_{2a}), 103.3 (d, C_4), 109.4 (d, C_6), 116.8 (s, C_{7a}), 132.6 (d, C_7), 157.4 (s, C_{4a}), 164.9 (s, C_5), and 200.9 (s, C_8); MS: m/z 202 (M^+); Found: C, 71.35; H, 4.93%. Calcd for $C_{12}H_{10}O_3$: C, 71.28; H, 4.99%.

*Conversion between **2** and **3**.* *a)*: A solution of **2** (100 mg) in acetone (300 ml) was irradiated at room temperature for 2 h through a Pyrex filter. Evaporation of the solvent, followed by silica-gel column chromatography of the residual oil gave **2** (12 mg) and **3** (33 mg).

b): 100 mg of **3** was prepared in a round bottom flask and heated at 205—210 °C for 10 min. This thermal reaction showed that a mixture of **2** (26 mg) and **3** (41 mg) was contained after separation by column chromatography on silica gel.

*Hydrogenation of **2**.* A mixture of **2** (187 mg) and 5% Pd–C (50 mg) in ethanol (20 ml) was treated with H_2 at room temperature until equimolar H_2 was consumed. The mixture was filtered and concentrated *in vacuo*. Chromatographic separation of the residue through silica-gel coloumn eluting with benzene afforded **4** (128 mg, 72% yield) as colorless oil. IR: 1660, 1605, and 1570 cm^{-1}; ^{1}H-NMR: 1.88—2.78 (4H, m, 2 $-CH_2-$), 3.15—3.39 (1H, m, $-\overset{|}{C}OCH-$), 5.06 (1H, dd, J=8 and 16 Hz, $-O\overset{|}{C}H-$), 6.33 (1H, d, J=3 Hz, C_4–H), 6.56 (1H, dd, J=3 and 8 Hz, C_6–H), and 7.89 (1H, d, J=8 Hz, C_7–H); ^{13}C-NMR: 20.8 and 28.6 (each t, C_1 and C_2), 45.4 (d, C_{8a}), 55.5 (q, OCH_3), 72.5 (d, C_{2a}), 101.2 (d, C_4), 109.8 (d, C_6), 113.8 (s, C_{7a}), 128.9 (d, C_7), 161.5 (s, C_{4a}), 166.3 (s, C_5), and 193.1 (s, C_8); MS: m/z 204 (M^+); Found: C, 70.28; H, 5.94%. Calcd for $C_{12}H_{12}O_3$: C, 70.57; H, 5.92%.

*Photoaddition of 7-Methoxy-4-methylcoumarin (**6**).* *a) In Methanol*: A solution of **6** (300 mg) in methanol (500 ml) was irradiated at room temperature for 5 h through a Pyrex filter with introduction of acetylene. Usual work-up gave 480 mg of crude solid, which was taken up in a small amount of ethyl acetate and the insoluble material was filtered off, followed to recrystallization from acetone to give dimer **8** in 25% yield; mp 199—201 °C; IR: 1765, 1625, and 1585 cm^{-1}; ^{1}H-NMR: 1.26 (6H, s, 2 CH_3), 3.39 (2H, s, 2 $-\overset{|}{C}H-$), 3.87 (6H, s, 2 OCH_3), 6.70, 6.84, and 7.14 (each 2H, d, J=3 Hz, dd, J=3 and 9 Hz, and d, J=9 Hz, aromatic protons); MS: m/z 380 (M^+); Found: C, 69.27; H, 5.16%. Calcd for $C_{22}H_{20}O_6$: C, 69.46; H, 5.30%. The filtrate was concentrated in a rotary evaporator to afford **7** as a solid, which was further purified by column chromatography on silica gel with ethyl acetate–benzene (1:19), 140 mg (45% yield); mp 226—227 °C (methanol); IR: 1750, 1625, and 1585 cm^{-1}; ^{1}H-NMR: 1.66 (6H, s, 2 CH_3), 3.40 (2H, s, 2 $-\overset{|}{C}H-$), 3.65 (6H, s, 2 OCH_3), 6.04, 6.66, and 7.10 (each 2H, d, J=3 Hz, dd, J=3 and 9 Hz, and d, J=9 Hz, aromatic protons); MS: m/z 380 (M^+); Found: C, 69.21; H, 5.26%. Calcd for $C_{22}H_{20}O_6$: C, 69.46; H, 5.30%.

b) In Benzene with Benzophenone: Irradiation of a solution containing **6** (500 mg) and benzophenone (96 mg) in 300 ml of benzene with acetylene through a Pyrex filter at room temperature for 6 h, followed by chromatographic work-up on silica gel afforded **8** in 92% yield. However, the photoreaction by using conditions similar to those described above, changing reaction time, temperature, and solvent did not lead to yields of cycloadducts of acetylene to **6**.

References

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