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Structures of Three New 2-Arylbenzofuran Derivatives from the Chinese Crude Drug "Sang-Bai-Pi" (Morus Root Bark)[1,2]

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Three new 2-arylbenzofuran derivatives named mulberrofurans K, N, and O were isolated from the extract of the Chinese crude drug "Sang-Bai-Pi" (Japanese name "Sōhakuhi"), the root bark of *Morus* sp. (Moraceae). The structures of mulberrofurans K, N and O were shown to be **1**, **2**, and **3**, respectively, on the basis of spectral and chemical evidence. Mulberrofurans K and O are optically active and may be regarded biogenetically as Diels–Alder type adducts of chalcone derivatives and a dehydroprenyl-2-arylbenzofuran derivative. Furthermore, mulberrofuran K seems to be derived from the Diels–Alder type adduct by intramolecular ketalization.

Keywords——*Morus*; Moraceae; 2-arylbenzofuran; mulberrofuran K; mulberrofuran N; mulberrofuran O; Diels–Alder type adduct

In the previous papers,[3] we reported the structure determination of a series of natural Diels–Alder type adducts and of isoprenylated flavonoid derivatives obtained from the Chinese crude drug "Sang-Bai-Pi" (Japanese name "Sōhakuhi") imported from the People's Republic of China. In the course of our studies, three new 2-arylbenzofuran derivatives, mulberrofurans K (**1**), N (**2**), and O (**3**), were isolated as minor components from the extract of the crude drug as described in the experimental section. This paper deals with the structure elucidation of the three new components.

Mulberrofuran K (**1**) was obtained as colorless needles, mp 176 °C (dec.), $[\alpha]_D^{21}$ +425°, and was negative in the methanolic ferric chloride test. The field desorption mass spectrum (FD-MS) showed the molecular ion peak at *m/z* 628. Treatment of **1** with dimethyl sulfate and potassium carbonate in acetone effected exhaustive methylation to give a tetramethyl ether (**1a**) as an amorphous powder. The molecular formula of **1a** was determined to be $C_{43}H_{40}O_8$ by high-resolution MS, and hence **1** could be formulated as $C_{39}H_{32}O_8$. The infrared (IR) spectrum of **1** disclosed hydroxyl group, conjugated double bond, and benzene ring absorption bands, while no evidence was obtained for a carbonyl function. The ultraviolet (UV) spectrum of **1** exhibited maxima at 225, 286, 320, and 334 nm, and was similar to those of mulberrofurans F[4] (**4**), G[4] (=albanol A,[5] **5**), suggesting that **1** is one of the 4′-substituted 6,3′,5′-trioxygenated 2-arylbenzofuran derivatives. This suggestion was supported through a comparative examination of the ^{1}H-nuclear magnetic resonance (^{1}H-NMR) spectrum of **1** with those of **4**, **5**, chalcomoracin[6] (**6**), and mulberrofuran C[7] (**7**). The chemical shifts and coupling constants of the 2-arylbenzofuran moiety were as follows: δ 6.81 (1H, dd, J=2, 8 Hz, C_5-H), 6.94 and 6.95 (each 1H, d, J=2 Hz, $C_{2'}$- or $C_{6'}$-H), 6.97 (1H, br d, J=2 Hz, C_7-H), 7.03 (1H, d, J=1 Hz, C_3-H), 7.40 (1H, d, J=8 Hz, C_4-H). As the chemical shift values and the coupling constants of the 2-arylbenzofuran moiety were similar to those of the corresponding protons of **4** and **5**, it was suggested that **1** has the same substitution pattern on this moiety. The presence of the following moieties was also supported by the comparative

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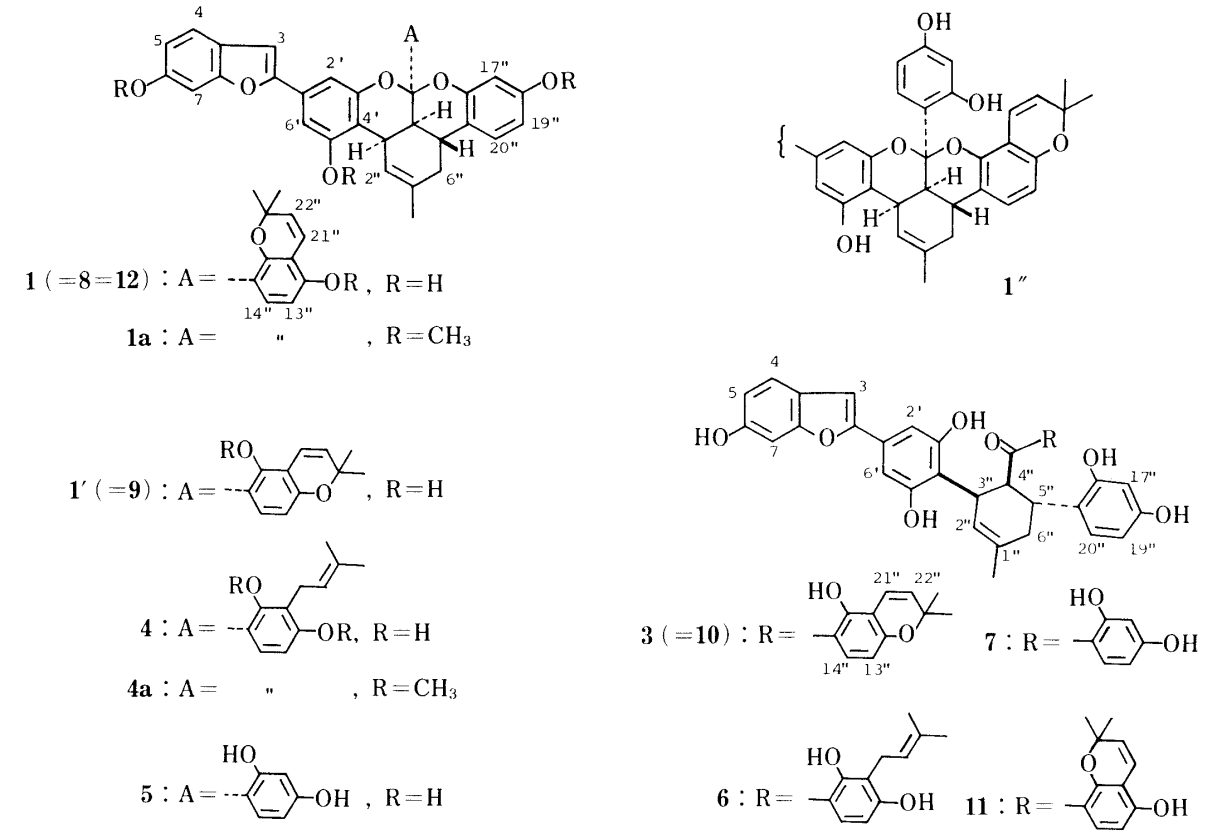

$$4 \xrightarrow[95\%\ MeOH\text{-}H_2O]{PdCl_2} 8\ (=1) + 9\ (=1')$$

$$6 \xrightarrow[95\%\ MeOH\text{-}H_2O]{PdCl_2} \begin{cases} 10\ (=3) \xrightarrow[h\nu]{1.5\%\ H_2SO_4\text{-}EtOH} 9\ (=1') \\ 11 \xrightarrow[h\nu]{1.5\%\ H_2SO_4\text{-}EtOH} 1 \\ 12\ (=1) \end{cases}$$

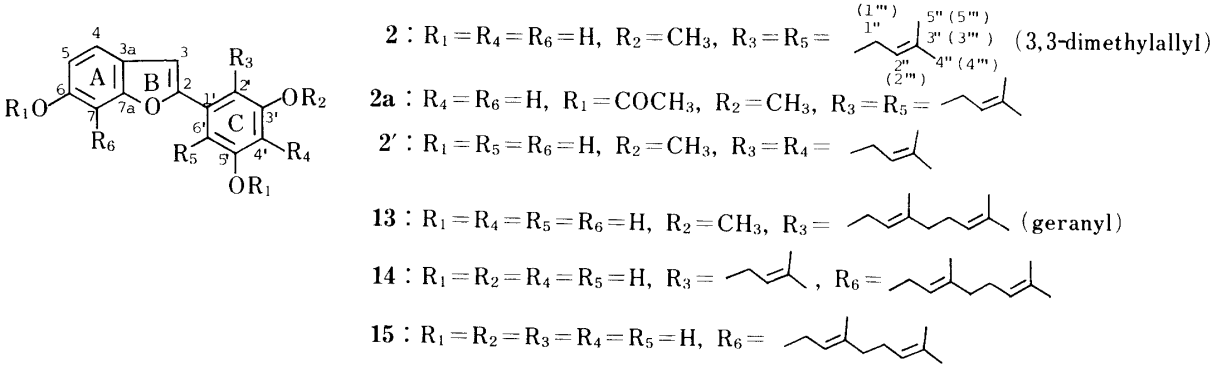

Fig. 1

examination of the ^{1}H-NMR spectrum of **1** with those of **4**[4] and **5**.[4] The signals of protons in a 5-oxygenated 2,2-dimethylchromene moiety were observed at δ 1.34, 1.35 (each 3H, s, $C_{23''}$-CH_3), 5.66 (1H, d, J=10 Hz, $C_{22''}$-H), 6.26 (1H, d, J=9 Hz, $C_{13''}$-H), 6.68 (1H, d, J=10 Hz,

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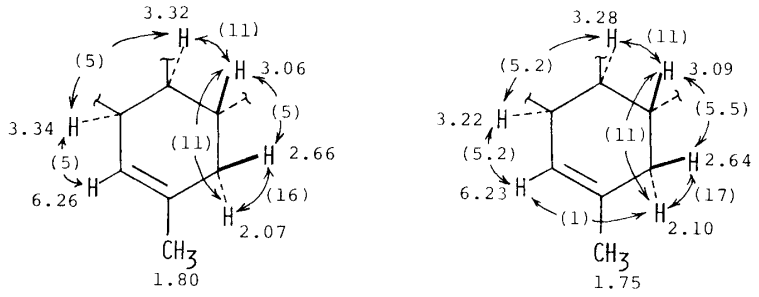

1a **4a**

Fig. 2. ^{1}H-NMR Chemical Shifts (ppm) and Coupling Constants (Hz) of Methylcyclohexene Ring Protons of **1a** and **4a** in $CDCl_3$

$C_{21''}$-H), 7.05 (1H, d, J=9 Hz, $C_{14''}$-H), and the signals of the aromatic protons in a 2,4-dioxygenated phenyl moiety at δ 6.37 (1H, d, J=2 Hz, $C_{17''}$-H), 6.50 (1H, dd, J=2, 8 Hz, $C_{19''}$-H), 7.13 (1H, d, J=8 Hz, $C_{20''}$-H). The presence of a trisubstituted methylcyclohexene ring was also supported by the examination of the ^{1}H-NMR spectrum of **1a** with the aid of sequential decoupling experiments, and the deduced structure is shown in Fig. 2 along with the chemical shift values and the coupling constants. The chemical shift values and the coupling constants of the protons on the ring of **1a** were similar to those of the corresponding protons of mulberrofuran F pentamethyl ether[4] (**4a**). From the above results, three possible structures (**1**, **1'**, and **1''**) were considered. The structure (**1''**)was excluded by the following results. The treatment of **4** with palladium chloride[8] in 95% methanol aqueous solution gave two compounds (**8** and **9**) each having a 2,2-dimethylchromene ring. The IR spectrum of **8** was in agreement with that of mulberrofuran K. In order to discrimenate the remaining two possible structures (**1** and **1'**), mulberrofuran K was derived from chalcomoracin (**6**) as described below. The treatment of **6** with palladium chloride in 95% methanol aqueous solution gave three compounds (**10**, **11**, and **12**). The structures of **10** and **11** were supported by the following spectral data. Compound **10** was obtained as an amorphous powder, which gave a brown color with methanolic ferric chloride and gave an FD-MS spectrum showing the molecular ion peak at m/z 646. In the ^{1}H-NMR spectrum of **10**, the signal of a hydrogen-bonded hydroxyl group was observed at δ 12.98, and the signals of a 5-hydroxy-2,2-dimethylchromene moiety at δ 1.37, 1.40 (each 3H, s, $C_{23''}$-CH_3), 5.65 (1H, d, J=10 Hz, $C_{22''}$-H), 6.27 (1H, d, J=9 Hz, $C_{13''}$-H), 6.59 (1H, d, J=10 Hz, $C_{21''}$-H), 8.44 (1H, d, J=9 Hz, $C_{14''}$-H). Compound **11** was obtained as an amorphous powder, which was negative in the methanolic ferric chloride test, and gave an FD-MS showing the molecular ion peak at m/z 646. The ^{1}H-NMR spectrum of **11** showed no signal of a hydrogen-bonded hydroxyl group, whereas the signals of a 5-hydroxy-2,2-dimethylchromene moiety were seen as follows: δ 1.31, 1.35 (each, 3H, s, $C_{23''}$-CH_3), 5.66 (1H, d, J=10 Hz, $C_{22''}$-H), 6.39 (1H, d, J=9 Hz, $C_{13''}$-H), 6.66 (1H, d, J=10 Hz, $C_{21''}$-H), 7.25 (1H, d, J=9 Hz, $C_{14''}$-H). Compound **12** was obtained as an amorphous powder, $[\alpha]_D^{23}$ +455°, which was negative in the methanolic ferric chloride test, and was identical with authentic mulberrofuran K (**1**) based on comparison of the ^{1}H-NMR and IR spectra of **12** with those of **1**.

Mulberrofuran K (**1**) was also derived from **11** by the following reaction:[4] a solution of **11** in ethanol containing sulfuric acid was irradiated with a high-pressure mercury lamp to provide **1**, which gave ^{1}H-NMR and IR spectra identical with those of authentic mulberrofuran K. On the other hand, **9** was derived from **10** by the same treatment as described in the case of **11**. In the previous paper,[4] our group reported that **4** and **5** were derived from **6** and **7** by irradiation in acidic solution with a high-pressure mercury lamp. From the above results, we propose the formula **1** for the structure of mulberrofuran K.

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Mulberrofuran O (**3**) was obtained as an amorphous powder, $[\alpha]_D^{18}$ +196°, which gave a brown color with methanolic ferric chloride, and gave an FD-MS which showed the molecular ion peak at *m/z* 646. The UV spectrum of **3** exhibited maxima at 278, 321, and 335 nm, and was similar to those of chalcomoracin[6] (**6**) and mulberrofuran C[7] (**7**), suggesting that **3** is a 4′-substituted 6,3′,5′-trioxygenated 2-arylbenzofuran derivative. The ^{1}H-NMR and IR spectra of **3** were in agreement with those of **10**. From these results, mulberrofuran O is represented by formula **3** (=**10**).

Mulberrofuran N (**2**) was obtained as an oily substance, and was negative in the methanolic ferric chloride and Gibbs tests. The IR spectrum disclosed hydroxyl and benzene ring absorption bands, and showed no carbonyl function. The UV spectrum exhibited maxima at 255 (sh) and 296 nm. The MS of **2** showed the molecular ion peak at *m/z* 396. Treatment of **2** with acetic anhydride in pyridine effected exhaustive acetylation to give a diacetate (**2a**), the molecular formula of which was determined as $C_{29}H_{32}O_6$ by high-resolution MS. Hence **2** could be formulated as $C_{25}H_{28}O_4$. The presence of the following moieties was supported by the ^{1}H-NMR spectrum of **2**. The signals of protons in a 2-substituted-6-oxygenated benzofuran moiety were observed at δ 6.57 (1H, d, J=1 Hz, C_3-H), 6.82 (1H, dd, J=2, 8 Hz, C_5-H), 6.96 (1H, br d, J=2 Hz, C_7-H), 7.43 (1H, d, J=8 Hz, C_4-H), and the signals of two 3,3-dimethylallyl groups at δ 1.35, 1.36 (each 3H, s), 1.54 (6H, s), 3.10 (2H, d, J=7 Hz), 3.16 (2H, d, J=6 Hz), 5.10, 5.14 (each 1H, m). The signals of a methoxyl group and an aromatic ring proton were observed at δ 3.80 (3H, s) and 6.66 (1H, s), respectively. These results suggest that mulberrofuran N is a 6-oxygenated 2-arylbenzofuran derivative having two 3,3-dimethylallyl groups in the C ring. The biogenetic analogy to the other 2-arylbenzofuran derivatives[4,6,7,9] isolated from *Morus* species led us to assume that the

Table I. Acetylation Shifts for Aromatic Ring Protons of **2** and **2a** in Acetone-d_6

	4-H	5-H	7-H	4′-H
2	7.43	6.82	6.96	6.66
2a	7.67	7.05	7.35	6.90
Δ	−0.24	−0.23	−0.39	−0.24

Table II. ^{13}C-NMR Chemical Shifts (ppm) of **2** and **13**

	2[a]	**13**[b]		**2**[a]
C-2	155.4	154.4	C-1″	27.0
C-3	100.9	99.5	C-2″	124.4[c]
C-3a	121.8	121.4	C-3″	129.4[d]
C-4	121.1	121.2	C-4″	25.7
C-5	112.3	111.9	C-5″	17.6[e]
C-6	153.2	153.5	C-1‴	27.0
C-7	98.1	98.2	C-2‴	124.6[c]
C-7a	153.9	154.3	C-3‴	129.5[d]
C-1′	132.5	131.7	C-4‴	25.7
C-2′	122.3	122.9	C-5‴	17.7[e]
C-3′	156.4	159.3		
C-4′	106.5	105.2		
C-5′	156.1	155.4		
C-6′	120.9	107.0		
OCH_3	55.7	55.8		

a) Solvent: acetone-d_6. *b*) Solvent: $CDCl_3$. *c*–*e*) Assignments may be reversed.

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TABLE III. UV Spectral Parameters of **2**, **13**, **14** and **15** (EtOH)

Compd.	λ_{max} nm (log ε)				
2		255 (sh 3.99)		296 (4.11)	
13	216 (4.15)		280 (sh 4.08)	311 (4.37)	
14		250 (sh 3.94)	275 (sh 3.99)	310 (4.27)	
15	244 (sh 3.85)	254 (sh 3.79)	280 (infl. 3.81)	315 (4.30)	330 (sh 4.19)

C-ring has the 3′,5′-dioxygenated pattern. A comparative examination of the ^{1}H-NMR spectrum of **2** with that of **2a** showed that the signals of all the aromatic protons of **2a** appeared at lower applied magnetic fields than those of the corresponding protons of **2** (Table I). This result suggests that both the A and C rings of **2** carry a hydroxyl group. Considering the above spectral data and the result of the Gibbs test, the structure of mulberrofuran N seems to be **2** or **2′**.

The discrimination between the two structures (**2** and **2′**) was achieved based the following results. Dhami *et al.* reported that the signal of the di*ortho*-substituted methoxyl carbon nucleus appears at δ *ca.* 60 ppm, while that of the mono*ortho*-substituted methoxyl carbon nucleus appears at δ *ca.* 55 ppm.[10] In the case of **2** the signal of the methoxyl carbon appears at δ 55.7 ppm. The ^{13}C nuclear magnetic resonance (^{13}C-NMR) spectrum of **2** was analyzed by comparing it with the spectra of model compounds, mulberrofurans A[9c] (**13**), D[9d] (**14**) and L[9e] (**15**), and by use of the off-resonance decoupling technique. The chemical shift values of the 2-arylbenzofuran skeleton, except for the carbon atoms at the C-3′ and -6′ positions affected by the substituent effect, were similar to those of the corresponding carbon atoms of **13** (Table II). The UV spectrum of **2**, as compared with those of 2-arylbenzofuran derivatives,[9] showed a hypsochromic shift (10—15 nm), which resulted from the C-ring of **2** being twisted out of conjugation with the benzofuran system due to the presence of the bulky groups at the C-2′ and -6′ positions (Table III). All these results indicate that mulberrofuran N is represented by formula **2**.

Experimental

Melting points are uncorrected. The ^{1}H- and ^{13}C-NMR spectra were measured with tetramethylsilane (TMS) as an internal reference. Chemical shifts are expressed in ppm downfield from TMS, and coupling constants (J) in Hz. Abbreviations: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad, sh = shoulder, infl. = inflection. The following instruments were used to obtain the physical data: melting point, Yazawa micromelting point apparatus (a hot-stage type); UV spectra, Hitachi 340 UV spectrometer; IR spectra, Hitachi 260-30 IR spectrometer; ^{1}H- and ^{13}C-NMR spectra, JEOL GX-400 FT-NMR spectrometer; optical rotation, JASCO DIP-4; MS, JEOL JMS 01SG; high-resolution MS, Hitachi RMU-7M mass spectrometer. Wakogel B-5FM was used for thin layer chromatography (TLC), Wakogel B-5F for preparative TLC, and Wakogel C-200 for column chromatography.

Isolation of Mulberrofuran K (1)——The crude drug "Sang-Bai-Pi" (Japanese name "Sōhakuhi," 8 kg), a species of *Morus* (Moraceae), imported from the People's Republic of China, was finely cut and extracted with *n*-hexane, benzene, and MeOH successively.[3f] The MeOH extract (300 g) was dissolved in AcOEt. Evaporation of the AcOEt solution to dryness yielded 70 g of residue. The residue (36 g) was chromatographed on silica gel (300 g), *n*-hexane–$(CH_3)_2CO$ being used as an eluent, and each fraction was checked by TLC. The fractions eluted with *n*-hexane containing 40—50% $(CH_3)_2CO$, which showed a characteristic spot with blue fluorescence on a TLC plate under UV light, were evaporated to give the residue (18 g). To isolate the fluorescent compound, the residue (1 g) was rechromatographed on silica gel (50 g) by using benzene–AcOEt as an eluent. The fractions eluted with benzene containing 15% AcOEt were evaporated to give the residue (0.3 g), which was fractionated by preparative TLC (solvent system, AcOEt : benzene = 2 : 3) to give mulberrofuran K (**1**, 40 mg, 5×10^{-4}% from the root bark).

Isolation of Mulberrofurans N (2) and O (3)——The same crude drug (56 kg) as described in the case of **1** was extracted with *n*-hexane, benzene, and $(CH_3)_2CO$ successively. Evaporation of the benzene and the $(CH_3)_2CO$ solutions to dryness yielded 240 g and 740 g of residue, respectively. The benzene extract (240 g) was dissolved in MeOH. Evaporation of the MeOH solution yielded 75 g of residue, 50 g of which was chromatographed on silica gel

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(300 g) by using benzene–MeOH as an eluent. The fractions eluted with benzene were evaporated to give the residue (700 mg), which was fractionated by preparative TLC (*n*-hexane : $(CH_3)_2CO = 4:1$, $CHCl_3$: EtOH = 8 : 1) to give mulberrofuran N (**2**, 31 mg). The $(CH_3)_2CO$ extract (330 g) was chromatographed on silica gel (1200 g) by using benzene–MeOH as an eluent. The fractions eluted with benzene containing 3% MeOH were evaporated to give the residue (18 g), which was rechromatographed on silica gel (200 g) with benzene–$(CH_3)_2CO$ as an eluent. The fractions eluted with benzene containing 7% $(CH_3)_2CO$ were evaporated to give the residue (0.6 g), which was fractionated by preparative TLC (benzene : AcOEt = 1 : 2, $CHCl_3$: MeOH = 6 : 1, Et_2O : benzene = 3 : 1) to give mulberrofuran O (**3**, 4 mg).

Mulberrofuran K (1)——Compound **1** was obtained as colorless needles, mp 176 °C (dec.), $[\alpha]_D^{21}$ +425° (*c* = 0.024, MeOH), $FeCl_3$ test: negative. FD-MS *m/z*: 628 (M^+). EI-MS *m/z*: 628 (M^+), 613, 371, 308, 293, 242, 161. UV λ_{max}^{EtOH} nm (log ε): 225 (4.72), 286 (4.29), 306 (infl. 4.45), 320 (4.56), 334 (3.47). IR ν_{max}^{KBr} cm^{-1}: 3400 (br), 1620, 1600, 1570 (sh), 1430. ^{1}H-NMR ($(CD_3)_2CO$) δ: 1.34, 1.35 (each 3H, s, $C_{23''}$-CH_3), 1.78 (3H, s, $C_{1''}$-CH_3), 2.00—2.10 (1H, m, $C_{6''}$-H), 2.72 (1H, dd, *J* = 5, 16, $C_{6''}$-H), 2.95—3.00 (1H, m, $C_{5''}$-H), 3.36 (1H, m, $C_{3''}$-H), 3.37 (1H, dd, *J* = 5, 11, $C_{4''}$-H), 5.66 (1H, d, *J* = 10, $C_{22''}$-H), 6.26 (1H, d, *J* = 9, $C_{13''}$-H), 6.37 (1H, d, *J* = 2, $C_{17''}$-H), 6.44 (1H, br d, *J* = 4, $C_{2''}$-H), 6.50 (1H, dd, *J* = 2, 8, $C_{19''}$-H), 6.68 (1H, d, *J* = 10, $C_{21''}$-H), 6.81 (1H, dd, *J* = 2, 8, C_5-H), 6.94 (1H, d, *J* = 2, $C_{2'}$- or $C_{6'}$-H), 6.95 (1H, d, *J* = 2, $C_{6'}$- or $C_{2'}$-H), 6.97 (1H, br d, *J* = 2, C_7-H), 7.03 (1H, d, *J* = 1, C_3-H), 7.05 (1H, d, *J* = 9, $C_{14''}$-H), 7.13 (1H, d, *J* = 8, $C_{20''}$-H), 7.40 (1H, d, *J* = 8, C_4-H), 8.31, 8.57, 8.71, 8.77 (each br s, OH).

Mulberrofuran K Tetramethyl Ether (1a)——A mixture of mulberrofuran K (**1**, 5 mg), Me_2SO_4 (0.25 ml), K_2CO_3 (5 g) in dry $(CH_3)_2CO$ (30 ml) was refluxed for 12 h, and treated as usual. The products were purified by preparative TLC (Et_2O : *n*-hexane = 1 : 2) to give an amorphous powder (**1a**, 1.8 mg). High-resolution MS, Calcd. for $C_{43}H_{40}O_8$ (M^+): *m/z* 684.2721. Found: *m/z* 684.2748. EI-MS *m/z*: 684 (M^+), 670, 669, 560, 545, 342, 280. IR ν_{max}^{Nujol} cm^{-1}: 1621, 1584, 1560, 1490. ^{1}H-NMR ($CDCl_3$) δ: 1.35, 1.37 (each 3H, s, $C_{23''}$-CH_3), 1.80 (3H, s, $C_{1''}$-CH_3), 2.07 (1H, dd, *J* = 11, 16, $C_{6''}$-H), 2.66 (1H, dd, *J* = 5, 16, $C_{6''}$-H), 3.06 (1H, td, *J* = 11, 5, $C_{5''}$-H), 3.32 (1H, dd, *J* = 5, 11, $C_{4''}$-H), 3.34 (1H, br t, *J* = 5, $C_{3''}$-H), 3.75, 3.78, 3.87, 3.88 (each 3H, s, OCH_3), 5.57 (1H, d, *J* = 10, $C_{22''}$-H), 6.26 (1H, br d, *J* = 5, $C_{2''}$-H), 6.27 (1H, d, *J* = 9, $C_{13''}$-H), 6.56 (1H, d, *J* = 2.5, $C_{17''}$-H), 6.58 (1H, dd, *J* = 2.5, 9, $C_{19''}$-H), 6.65 (1H, d, *J* = 10, $C_{21''}$-H), 6.87 (1H, dd, *J* = 2, 8.5, C_5-H), 6.89 (1H, br s, C_3-H), 6.91 (1H, d, *J* = 1.5, $C_{6'}$-H), 7.06 (1H, d, *J* = 2, C_7-H), 7.13 (1H, d, *J* = 1.5, $C_{2'}$-H), 7.15 (1H, d, *J* = 9, $C_{20''}$-H), 7.18 (1H, d, *J* = 9, $C_{14''}$-H), 7.44 (1H, d, *J* = 8.5, C_4-H).

Formation of 8 (= 1) and 9 from Mulberrofuran F (4)——A mixture of **4** (39 mg) and $PdCl_2$ (11 mg) in 95% methanol aqueous solution (5 ml) was kept at room temperature for 4 h. The products were purified by preparative TLC (benzene : AcOEt = 2 : 1) to give **8** (6 mg) and **9** (13 mg). The IR spectrum of **8** was in agreement with that of **1**. Compound **9** was obtained as an amorphous powder. FD-MS *m/z*: 628 (M^+). UV λ_{max}^{EtOH} nm (log ε): 286 (4.13), 306 (infl. 4.19), 321 (4.37), 335 (4.29). IR ν_{max}^{KBr} cm^{-1}: 3420 (br), 1630 (sh), 1620, 1600. ^{1}H-NMR ($(CD_3)_2CO$) δ 1.34, 1.37 (each 3H, s, $C_{23''}$-CH_3), 1.80 (3H, s, $C_{1''}$-CH_3), *ca.* 2.1 (1H, m, $C_{6''}$-H, overlapping with solvent), 2.75 (1H, dd, *J* = 5, 16, $C_{6''}$-H), 2.98—3.06 (2H, m, $C_{5''}$- and $C_{4''}$-H), 3.70 (1H, m, $C_{3''}$-H), 5.64 (1H, d, *J* = 10, $C_{22''}$-H), 6.27 (1H, d, *J* = 9, $C_{13''}$-H), 6.39 (1H, d, *J* = 2.5, $C_{17''}$-H), 6.46 (1H, br d, *J* = 4, $C_{2''}$-H), 6.53 (1H, dd, *J* = 2.5, 8, $C_{19''}$-H), 6.67 (1H, d, *J* = 10, $C_{21''}$-H), 6.80 (1H, dd, *J* = 2, 8, C_5-H), 6.95 (1H, br d, *J* = 2, C_7-H), 6.97 (1H, d, *J* = 2, $C_{2'}$-H), 7.03 (1H, d, *J* = 2, $C_{6'}$-H), 7.04 (1H, s, C_3-H), 7.17 (1H, d, *J* = 8, $C_{20''}$-H), 7.26 (1H, d, *J* = 9, $C_{14''}$-H), 7.40 (1H, d, *J* = 8, C_4-H), 8.17, 8.35, 8.50, 8.76 (each 1H, br s, OH).

Formation of 10, 11, and 12 (= 1) from Chalcomoracin (6)——A mixture of **6** (108 mg) and $PdCl_2$ (27 mg) in 95% methanol aqueous solution (5 ml) was kept at room temperature for 4 h. The products were purified by preparative TLC (benzene : AcOEt = 1 : 1) to give **10** (7 mg), **11** (4 mg) and **12** (4 mg). Compound **10** was obtained as an amorphous powder. FD-MS *m/z*: 646 (M^+). $FeCl_3$ test: brown. UV λ_{max}^{EtOH} nm (log ε): 278 (4.47), 306 (infl. 4.29), 321 (4.63), 335 (4.53) IR ν_{max}^{KBr} cm^{-1}: 3400 (br), 1630 (sh), 1610, 1570 (sh), 1430. ^{1}H-NMR ($(CD_3)_2CO$) δ: 1.37, 1.40 (each 3H, s, $C_{23''}$-CH_3), 1.94 (3H, s, $C_{1''}$-CH_3), 2.23 (1H, m, $C_{6''}$-H), 2.52 (1H, dd, *J* = 5, 16, $C_{6''}$-H), 3.77 (1H, m, $C_{5''}$-H), 4.16 (1H, m, $C_{3''}$-H), 4.64 (1H, t, *J* = 4, $C_{4''}$-H), 5.65 (1H, d, *J* = 10, $C_{22''}$-H), 5.78 (1H, br s, $C_{2''}$-H), 6.27 (1H, d, *J* = 9, $C_{13''}$-H), 6.30 (1H, dd, *J* = 2, 8, $C_{19''}$-H), 6.49 (1H, d, *J* = 2, $C_{17''}$-H), 6.59 (1H, d, *J* = 10, $C_{21''}$-H), 6.77 (2H, s, $C_{2'}$- and $C_{6'}$-H), 6.78 (1H, dd, *J* = 2, 8, C_5-H), 6.92 (1H, d, *J* = 2, C_7-H), 6.93 (1H, s, C_3-H), 6.98 (1H, d, *J* = 8, $C_{20''}$-H), 7.36 (1H, d, *J* = 8, C_4-H), 8.44 (1H, d, *J* = 9, $C_{14''}$-H), 8.11, 8.16, 8.51, 8.54, 8.83 (each 1H, br s, OH), 12.98 (1H, s, $C_{10''}$-OH).

Compound **11** was obtained as an amorphous powder. FD-MS *m/z*: 646 (M^+). $FeCl_3$ test: negative. UV λ_{max}^{EtOH} nm (log ε): 285 (4.49), 293 (sh 4.48), 300 (infl. 4.51), 321 (4.63), 335 (4.55). IR ν_{max}^{KBr} cm^{-1}: 3400 (br), 1650 (sh), 1630, 1600 (sh), 1580, 1430. ^{1}H-NMR ($(CD_3)_2CO$) δ: 1.31, 1.35 (each 3H, s, $C_{23''}$-CH_3), 1.90 (3H, s, $C_{1''}$-CH_3), *ca.* 2.30 (1H, m, $C_{6''}$-H, overlapping with solvent), 2.44 (1H, dd, *J* = 5, 16, $C_{6''}$-H), 3.84 (1H, m, $C_{5''}$-H), 4.17 (1H, m, $C_{3''}$-H), 4.75 (1H, br t, *J* = 4, $C_{4''}$-H), 5.66 (1H, d, *J* = 10, $C_{22''}$-H), 5.77 (1H, br s, $C_{2''}$-H), 6.30 (1H, dd, *J* = 2, 8, $C_{19''}$-H), 6.39 (1H, d, *J* = 9, $C_{13''}$-H), 6.40 (1H, d, *J* = 2, $C_{17''}$-H), 6.66 (1H, d, *J* = 10, $C_{21''}$-H), 6.81 (1H, dd, *J* = 2, 8, C_5-H), 6.83 (2H, s, $C_{2'}$- and $C_{6'}$-H), 6.97 (1H, s, C_3-H), 6.98 (1H, d, *J* = 8, $C_{20''}$-H), 7.00 (1H, d, *J* = 2, C_7-H), 7.25 (1H, d, *J* = 9, $C_{14''}$-H), 7.41 (1H, d, *J* = 8, C_4-H), 8.06, 8.14, 8.22, 8.46, 8.51, 8.58 (each br s, OH).

Compound **12** was obtained as an amorphous powder. $[\alpha]_D^{23}$ +455° (*c* = 0.011, MeOH). $FeCl_3$ test: negative. The IR and ^{1}H-NMR spectra of **12** were in agreement with those of **1**.

Formation of 9 from 10——A solution of **10** (7 mg) in EtOH (1 ml) containing 1.5% H_2SO_4 was externally

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irradiated in a glass vessel with a 100 W high-pressure mercury lamp for 105 min. The reaction mixture was purified by preparative TLC (benzene : AcOEt = 1 : 1) to give an amorphous powder (**9**, 2 mg). The compound (**9**) thus obtained was identical with the compound (**9**) derived from mulberrofuran F (**4**) on the basis of the IR, UV and ^{1}H-NMR spectral comparisons.

Formation of Mulberrofuran K (1) from 11——A solution of **11** (4 mg) in EtOH (1 ml) containing 1.5% H_2SO_4 was irradiated as described in the case of **10**. The reaction mixture was purified by preparative TLC (benzene : AcOEt = 1 : 1) to give **1** (2 mg). The compound (**1**) thus obtained was identical with mulberrofuran K on the basis of the IR and ^{1}H-NMR spectral comparisons.

Mulberrofuran N (2)——Compound **2** was obtained as an oily substance. $FeCl_3$ test: negative. Gibbs test: negative. EI-MS *m/z*: 396 (M^+), 349. UV λ_{max}^{EtOH} nm (log ε): 255 (sh 3.99), 296 (4.11). IR ν_{max}^{KBr} cm^{-1}: 3400, 1620, 1590. ^{1}H-NMR ($(CD_3)_2CO$) δ: 1.35, 1.36 (each 3H, s), 1.54 (6H, s, $CH_3 \times 2$), 3.10 (2H, d, J=7, $-CH_2-CH=C<$), 3.16 (2H, d, J=6, $-CH_2-CH=C<$), 3.80 (3H, s, OCH_3), 5.10, 5.14 (each 1H, m, $-CH_2-CH=C<$), 6.57 (1H, d, J=1, C_3-H), 6.66 (1H, s, $C_{4'}$-H), 6.82 (1H, dd, J=2, 8, C_5-H), 6.96 (1H, br d, J=2, C_7-H), 7.43 (1H, d, J=8, C_4-H).

Mulberrofuran N Diacetate (2a)——A mixture of **2** (5 mg), acetic anhydride (0.9 ml) and pyridine (0.3 ml) was kept at room temperature for 4 min, and treated as usual. The reaction mixture was purified by preparative TLC (*n*-hexane : $(CH_3)_2CO$ = 3 : 1) to give an amorphous powder (**2a**, 2 mg). EI-MS *m/z*: 476 (M^+), 434, 391. High-resolution MS, Calcd. for $C_{29}H_{32}O_6$ (M^+): *m/z* 476.2197. Found: *m/z* 476.2210. IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1760, 1590. ^{1}H-NMR ($(CD_3)_2CO$) δ: 1.36, 1.37, 1.51, 1.55, (each 3H, s, CH_3), 2.27, 2.29 (each 3H, s, $OCOCH_3$), 3.07 (2H, d, J=7, $-CH_2-CH=C<$), 3.20 (2H, d, J=7, $-CH_2-CH=C<$), 3.86 (3H, s, OCH_3), 4.93, 5.05 (each 1H, m, $-CH_2-CH=C<$), 6.83 (1H, d, J=0.5, C_3-H), 6.90 (1H, s, $C_{4'}$-H), 7.05 (1H, dd, J=2, 8, C_5-H), 7.35 (1H, br d, J=2, C_7-H), 7.67 (1H, d, J=8, C_4-H).

Mulberrofuran O (3)——Compound **3** was obtained as an amorphous powder, $[\alpha]_D^{18}$ +196° (c=0.014, MeOH). $FeCl_3$ test: brown. FD-MS *m/z*: 646 (M^+). The compound (**3**) was identical with **10** on the basis of the IR and ^{1}H-NMR spectral comparisons.

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References and Notes

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