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Rearrangement of Allyl Aryl Ethers I.
Reaction of Hydroquinone with Conjugated Dien-ols and Trien-ol

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Abstract: Thermal rearrangement of ethers **3** generated *in situ* from hydroquinone **1** and conjugated polyen-ols **2** afforded 2,3-dihydrobenzofuranols **5**, **8** and **10** with 1,3- and/or 3,5-shifts followed by acid-catalyzed intramolecular cyclization.

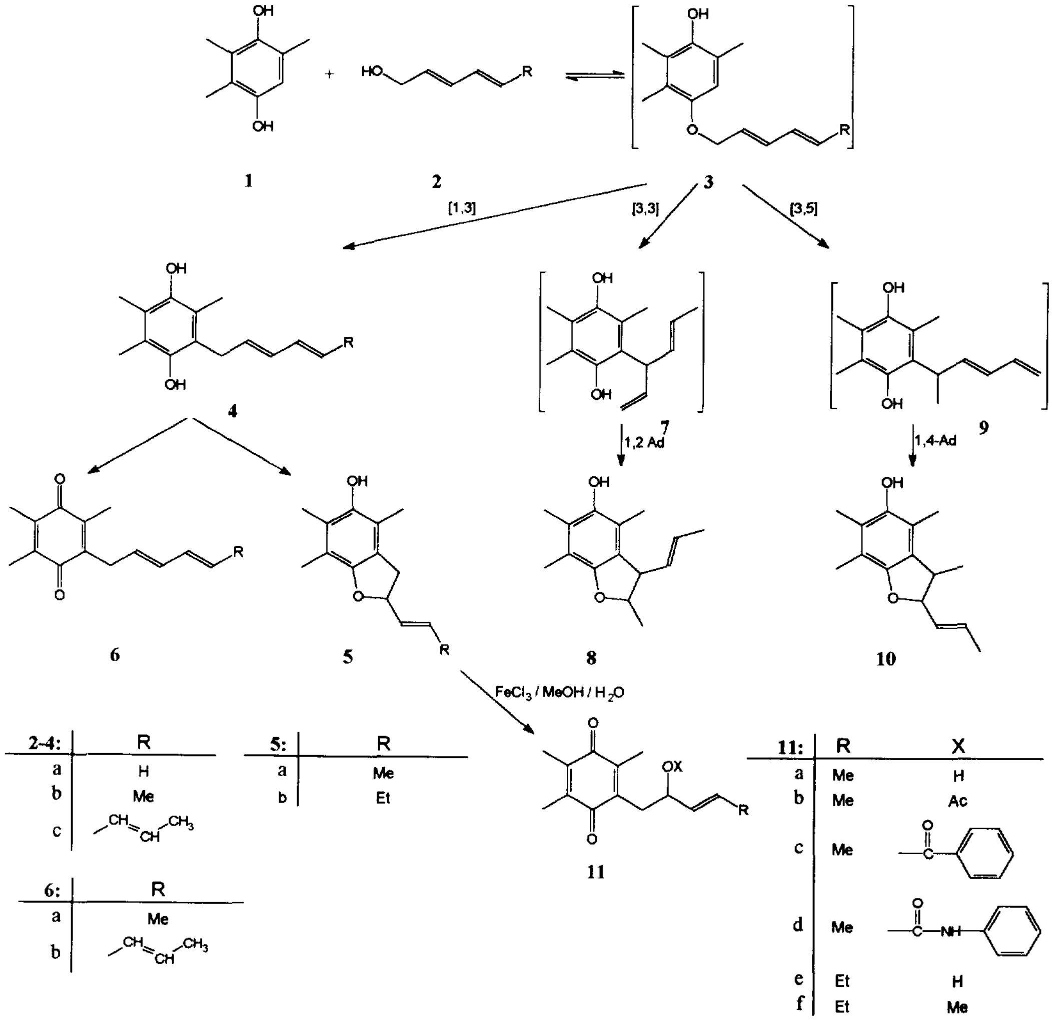
Recent investigations have shown that 2,3-dihydro-5-benzofuranols are potent inhibitors of leukotriene biosynthesis[1,2]. Therefore, the synthesis of this class of compounds have received considerable attention. One of the methods used was based on the rearrangement of allyl aryl ethers. In this connection, we recently reported a one-pot synthesis of vinyl-2,3-dihydrofuranols employing competing 1,3- and 3,3-rearrangements of properly substituted allyl aryl ethers[3].

Although, the rearrangements (1,3- and 3,3-) of allyl aryl ethers were widely employed in synthesis[4-7], less attention had been focused on the rearrangement reactions of ethers generated from phenols and conjugated dien-ols[8]. Our general interest in the synthesis of novel dihydrobenzofuranols and the mechanism of sigmatropic shift prompted us to investigate the rearrangement of ethers formed *in situ* from hydroquinone **1** and conjugated polyen-ols **2** (Scheme 1).

The reaction between hydroquinone **1** and dien-ol **2a** was carried out in toluene at 70 °C in the presence of catalytic amounts of 10-camphorsulfonic acid. The reaction was rather slow and gave benzofuranol **5a** in good yield. The structure of this compound was established by ^{1}H- and ^{13}C NMR spectroscopies (Experimental). Chemical support for the structural assignment was also obtained by treatment of **5a** with iron(III)chloride: the oxidation afforded benzoquinone **11a**.

The formation of benzofuranols **5a** would likely involve the initial acid-catalyzed formation of ether **3a**, followed by 1,3- and/or 3,5-sigmatropic migrations[9]. The resulting hydroquinone **4a** then underwent acid-catalyzed intramolecular 1,4-addition to afford the sole product **5a**.

The acid-catalyzed reaction of **1** with the homologue **2b** afforded a mixture of three compounds **4b**, **10** and **8** in the ratio 44 : 55 : 1 (overall yield 83 %). The formation of these products could be interpreted as the result of competing rearrangement reactions (1,3-, 3,5- and 3,3-shifts). The 1,3- and 3,5-shifts were heavily favoured and the resulting hydroquinone **4b** dropped out from the reaction mixture. The intermediate of 3,5-shift (**9**) underwent cyclization to yield benzofuranol **10**. The trace amounts of 3,3- (Claisen) rearrangement product **8** was formed by intramolecular 1,2-addition of intermediate **7**.



2-4:	R
a	H
b	Me
c	$CH=CH-CH_3$

5:	R
a	Me
b	Et

6:	R
a	Me
b	$CH=CH-CH_3$

11:	R	X
a	Me	H
b	Me	Ac
c	Me	$-C(=O)-C_6H_5$
d	Me	$-C(=O)-NH-C_6H_5$
e	Et	H
f	Et	Me

Scheme 1.

Compound **4b** was cyclized in boiling toluene in the presence of 10-camphorsulfonic acid. The intramolecular 1,4-addition afforded benzofuranol **5b** in excellent yield. Oxidation of the latter with iron(III)chloride in aqueous methanol furnished a mixture of quinones **11e** and **11f**.

Because of the interesting result obtained above, the reaction of **1** with conjugated trien-ol **2c** was also tested. Here, the reaction was slow and only the 1,3-rearrangement product **4c** was isolated in moderate yield. This material was converted to the corresponding quinone **6b** with iron(III)chloride oxidation.

In summary, it may be concluded that ethers **3** show very low tendency for 3,3- (Claisen) rearrangement. In all cases investigated the corresponding 1,3- and/or 3,5-shifts were favoured. This may be a consequence of deconjugation leading to intermediate type **7** during 3,3-rearrangement. The MM2 calculations indicated considerably higher energy of **7** than the values for **4b** and **9** ($\Delta\Delta E$ = 4,5 kcal/mol)[10]. Results of the evaluation of **5**, **8** and **10** as inhibitors of leukotriene biosynthesis will be reported elsewhere.

EXPERIMENTAL

Melting points are uncorrected. Infrared spectra were recorded on Spekord IR 20M spectrophotometer. ^{1}H NMR and ^{13}C NMR spectra were obtained with a Varian VXR-400 spectrometer internal standard TMS. The following abbreviations are used: singlet (s), doublet (d), triplet (t), quartet (q) and multiplet (m). MS measurements were carried out with a Kratos MS-25 RFA combined GC/MS system. HPLC chromatographic analyses were performed with a Waters 600 equipped with a photodiode array detector 990. Stationary phase: Spherisorb ODS 5μ (250x4.6 mm). Merck precoated silica gel 60 F_{254} plates were used for thin-layer chromatography and Kieselgel® 60 for column chromatography. All solvents were dried by means of standard methods and the reactions were carried out under argon.

(*E,E,E*)-Octa-2,4,6-trien-1-ol (2c). A solution of methyl (*E,E,E*)-Octa-2,4,6-trienoate[11] (10 g, 66 mmol) in ether (250 ml) was added dropwise to a stirred suspension of lithium aluminum hydride (7.0 g, 26 mmol) in ether (200 ml) at 0 °C. The resulting mixture was stirred for 1 h, then moist ether was cautiously added. The mixture was then acidified with 2 M sulphuric acid (pH = 3), the organic layer was separated and the aqueous layer was extracted with ether. The combined organic layers were washed with brine, dried ($MgSO_4$) and then concentrated to give **2c** (7.0 g, 85.4 %, white crystals); M.p.: 106 °C; TLC: R_f = 0.5 (hexane/acetone, 5 : 2, v/v); HPLC: R_t = 4 min. (hexane/CH_2Cl_2/dioxane; 9.6 : 0.3 : 0.1, v/v/v); ^{1}H NMR ($CDCl_3$/DMSO-d_6): δ = 1.75 (3H, d, J = 7 Hz, CH_3), 4.0 (2H, d, J = 6 Hz, CH_2–O), 5.6-6.2 (6H, m, CH=CH–CH=CH–CH=CH).

(*E*)-4,6,7-Trimethyl-2-propenyl-2,3-dihydro-benzofuran-5-ol (5a). To a stirred mixture of **1** (21.6 g, 0.25 mol) and **2a**[12] (39.1 g, 0.26 mol) in dry toluene (300 ml) was added (1*R*)-(-)-10-camphorsulfonic acid monohydrate and the resultant solution was stirred at 70 °C for 16 h under argon. After cooling, the reaction mixture was diluted with EtOAc and washed successively with water and brine, and then dried ($MgSO_4$).

Evaporation of the solvent in vacuo gave a syrup which was purified by chromatography with hexane/acetone (5 : 0.2, v/v) as eluent to yield **5a** (40.0 g, 71 %, colorless needles). M.p.: 143 °C (hexane); TLC: $R_f = 0.5$ (hexane/acetone, 5 : 2, v/v); HPLC: $R_t = 2.28$ min. ($MeOH/H_2O$, 7 : 3, v/v); IR (KBr): 3350, 1610 cm^{-1}; ^1H NMR ($CDCl_3$): $\delta = 1.77$ (3H, d, $J = 6$ Hz, CH_3), 2.12 (3H, s, CH_3), 2.13 (6H, s, $2CH_3$), 3.05 (2H, m, CH_2), 4.16 (1H, s, OH), 5.08 (1H, m, CH–O), 5.68 (1H, m, CH=), 5.82 (1H, m, CH=); ^{13}C NMR ($CDCl_3$): $\delta = 11.98$ (CH_3), 12.25 (CH_3), 12.87 (CH_3), 17.74 (CH_3-3'), 36.06 (CH_2-3), 83.01 (CH-2), 115.66 (C-4), 117.22 (C-6), 121.99 (C-3a), 122.90 (C-7), 128.93 (CH-2'), 131.02 (CH-1'), 145.59 (C-5), 151.32 (C-7a); Anal. calcd. for $C_{14}H_{18}O_2$: C, 77.03; H, 8.31 Found: C, 77.00; H, 8.53.

(*E*)-2-(2-Hydroxy-pent-3-enyl)-3,5,6-trimethyl[1,4]benzoquinone (11a). To a stirred solution of **5a** (8.0 g, 34 mmol) in methanol (240 ml) was added dropwise a solution of $FeCl_3 . 6H_2O$ (170 g) in a mixture of methanol (1200 ml) and water (240 ml) during 1 h and the resulting mixture was stirred at r.t. for 1 h. Water (300 ml) was then added and the mixture was extracted several times with dichloromethane (1.5 L). The combined organic extracts were washed with water, dried ($MgSO_4$), the solvent was evaporated in vacuo, and the residue was purified by chromatography with hexane/acetone (5 : 0.2, v/v) as eluent to give **11a** (5.2 g, 66 %, red oil). TLC: $R_f = 0.5$ (hexane/acetone, 5 : 2, v/v); HPLC: $R_t = 1.87$ min. ($MeOH/H_2O$, 7 : 3, v/v); IR (nujol) 3470, 1610 cm^{-1}; ^1H NMR ($CDCl_3$): δ 1.68 (3H, d, $J = 6$ Hz, CH_3), 2.01 (3H, s, CH_3), 2.05 (6H, s, $2CH_3$), 2.73 (2H, d, $J = 6$ Hz, CH_2), 2.90 (1H, s, OH), 4.2 (1H, m, CH–O), 5.52 (1H, m, CH=), 5.56 (1H, m, CH=); ^{13}C NMR ($CDCl_3$): δ 12.30 (CH_3), 12.36 (CH_3), 12.71 (CH_3), 17.55 (CH_3-5'), 39.83 (CH_2-1'), 72.13 (CH-2'), 126.83 (CH-4'), 133.39 (CH-3'), 140.35 (C-5), 140.53 (C-6), 140.73 (C-3), 142.63 (C-2), 187.99 (C-1), 188.09 (C-4); MS [*m/z* (relative intensity %)]: 234 (M^+, 4), 218 (8), 189 (12), 165 (21), 164 (100); Anal. calcd. for $C_{14}H_{18}O_3$: C, 71.77; H, 7.74 Found: C, 71.91; H, 7.92.

Acetate derivative (11b) was prepared in 90 % yield by standard procedure. TLC: $R_f = 0.6$ (hexane/acetone, 5 : 2, v/v); HPLC: $R_t = 1.58$ min. ($MeOH/H_2O$, 9.5 : 0.5, v/v); IR (nujol): 1720, 1620 cm^{-1}; ^1H NMR ($CDCl_3$): $\delta = 1.68$ (3H, dd, $J = 6.5$ and 1.5 Hz, CH_3), 1.96 (3H, s, CH_3), 2.01 (6H, s, $2CH_3$), 2.07 (3H, s, CH_3), 2.81 (2H, m, CH_2), 5.31 (1H, m, CH–O), 5.47 (1H, d-m, $J = 16$ Hz, CH=), 5.72 (1H, d-m, $J = 16$ Hz, CH=); ^{13}C NMR ($CDCl_3$): $\delta = 12.37$ ($2CH_3$), 12.73 (CH_3), 17.67 (CH_3-5'), 21.18 (CH_3–CO), 32.10 (CH_2-1'), 73.90 (CH-2'), 128.95 (CH-4'), 129.51 (CH-3'), 139.71 (C-3), 140.52 (C-5), 140.61 (C-6), 142.26 (C-2), 170.10 (CH_3–*C*O), 186.73 (C-1), 187.51 (C-4); Anal. calcd. for $C_{16}H_{20}O_4$: C, 69.55; H, 7.30 Found: C, 69.62; H, 7.08.

Benzoate derivative (11c) was prepared in 62 % yield by standard method. TLC: $R_f = 0.63$ (hexane/acetone, 5 : 2, v/v); IR (nujol): 1700, 1620 cm^{-1}; ^1H NMR ($CDCl_3$): $\delta =$ 1.70 (3H, dd, $J = 6$ and 1 Hz, CH_3), 1.98 (3H, s, CH_3), 1.99 (3H, s, CH_3), 2.08 (3H, s, CH_3), 2.97 (2H, m, CH_2), 5.57 (1H, m, CH–O), 5.60 (1H, d-m, $J = 15$ Hz, CH=), 5.83 (1H, d-m, $J = 15$ Hz, CH=), 7.42 (2H, m, aromatic-H), 7.54 (1H, m, aromatic-H), 7.96

(2H, m, aromatic-H); ^{13}C NMR ($CDCl_3$): δ = 12.37 (2CH_3), 12.88 (CH_3), 17.71 (CH_3-5'), 32.12 (CH_2-1'), 74.38 (CH-2'), 128.34 (CH-2'' and CH-6''), 129.00 (CH-4'), 129.53 (CH-3'' and CH-5''), 129.66 (CH-4''), 130.24 (C-1''), 132.93 (CH-3'), 139.65 (C-3), 140.52 (C-5), 140.61 (C-6), 142.27 (C-2), 165.68 (*C*O), 186.81 (C-1), 187.44 (C-4).

Phenylcarbamoyl derivative (11d) was prepared in 70 % yield by standard procedure. M.p. 112 °C; TLC: R_f = 0.6 (hexane/acetone, 5 : 2, v/v); IR (nujol): 3320, 1670, 1610 cm^{-1}; ^{1}H NMR ($CDCl_3$): δ = 1.68 (3H, dd, *J* = 6.5 and 1 Hz, CH_3), 2.00 (6, s, 2CH_3), 2.09 (3H, s, CH_3), 2.89 (2H, m, CH_2), 5.30 (1H, m, CH–O), 5.52 (1H, d-m, *J* = 15 Hz, CH=), 5.78 (1H, d-m, *J* = 15 Hz, CH=), 6.55 (1H, s, NH), 7.04 (1H, m, aromatic-H), 7.3 (4H, m, aromatic-H); ^{13}C NMR ($CDCl_3$): δ = 12.37 (CH_3), 12.40 (CH_3), 12.82 (CH_3), 17.68 (CH_3-5'), 32.06 (CH_2-1'), 74.81 (CH-2'), 118.72 (CH-4'), 123.44 (CH-3'), 128.98 (CH-2'' and CH-6''), 129.00 (CH-3'' and CH-5''), 129.76 (CH-4''), 137.76 (C-1''), 139.60 (C-3), 140.52 (C-5), 140.61 (C-6), 142.34 (C-2), 152.78 (NH–*C*O), 186.80 (C-1), 187.47 (C-4).

(*E*,*E*)-2-Hexa-2,4-dienyl-3,5,6-trimethyl-benzene-1,4-diol (4b), (*E*)-3,4,6,7-tetramethyl-2-propenyl-2,3-dihydro-benzofuran-5-ol (10), and (*E*)-2,4,6,7-tetramethyl-3-propenyl-2,3-dihydro-benzofuran-5-ol (8). A mixture of **1** (15.2 g, 0.1 mol), **2b**[13] (11.0 g, 0.11 mol) and (1*R*)-(-)-10-camphorsulfonic acid monohydrate in toluene (100 ml) was stirred at 70 °C for 16 h under argon. After cooling, the precipitate was collected by filtration and recrystallized from methanol to yield **4b** (8.6 g, 37 %, colorless needles). M.p. 170 °C; TLC: R_f = 0.5 (hexane/acetone, 5 : 2, v/v); IR (KBr): 3300 cm^{-1}; ^{1}H NMR ($CDCl_3$): δ = 1.66 (3H, d, *J* = 6 Hz, CH_3), 2.08 (9H, s, 3CH_3), 3.35 (2H, d, *J* = 6 Hz, CH_2), 5.3-6.1 (4H, m, CH=CH–CH=CH); Anal. calcd. for $C_{15}H_{20}O_2$: C, 77.55; H, 8.68 Found: C, 77.37; H, 8.89.

The filtrate was diluted with toluene (100 ml) and washed successively with water and brine, and then dried ($MgSO_4$). Evaporation of the solvent in vacuo afforded a white syrup which was purified by flash chromatography with hexane/acetone (5 : 0.2, v/v) as eluent to give **10** (10.6 g, 45.6 %, colorless needles) and **8** (0.2 g, 0.9 %, semisolid). **10**: M.p. 72 °C; TLC: R_f = 0.6 (hexane/acetone, 5 : 2, v/v); HPLC: R_t = 9.86 min. (MeOH/H_2O, 9.5 : 0.5, v/v); IR (KBr): 3390 cm^{-1}; ^{1}H NMR ($CDCl_3$): δ = 1.08 (3H, d, *J* = 7 Hz, CH_3), 1.81 (3H, dd, *J* = 6.5 and 1.5 Hz, CH_3), 2.13 (6H, s, 2CH_3), 2.16 (3H, s, CH_3), 3.24 (1H, m-d, *J* = 7 Hz, CH), 4.19 (1H, s, OH), 4.91 (1H, t, *J* = 7 Hz, CH–O), 5.77 (1H, m-d, *J* = 15 Hz, CH=), 5.91 (1H, m-d, *J* = 15 Hz, CH=); ^{13}C NMR ($CDCl_3$): δ = 12.00 (CH_3), 12.18 (CH_3), 12.25 (CH_3), 15.22 (CH_3-3'), 18.02 (CH_3-1''), 40.49 (CH-3), 86.82 (CH-2), 116.13 (C-6), 116.84 (C-4), 121.45 (C-7), 126.95 (CH-2'), 129.53 (C-3a), 131.17 (CH-1'), 145.85 (C-5), 150.64 (C-7a). MS [*m/z* (relative intensity %)]: 232 ($M^{+\cdot}$, 100), 217 (35), 203 (96), 189 (35); Anal. calcd. for $C_{15}H_{20}O_2$: C, 77.55; H, 8.68 Found: C, 77.40; H, 8.94. **8**: TLC: R_f = 0.6 (hexane/acetone, 5 : 2, v/v); HPLC: R_t = 10.44 min. (MeOH/H_2O, 9.5 : 0.5, v/v); IR (KBr): 3400 cm^{-1}; ^{1}H NMR ($CDCl_3$): δ = 1.3 (3H, d, *J* = 6 Hz, CH_3), 1.72 (3H, d, *J* = 6 Hz, CH_3), 2.12 (6H, s, 2CH_3), 2.14 (3H, s, CH_3), 3.20 (1H, m, CH), 4.25 (1H, s, OH), 4.60 (1H, m, CH–O), 5.65 (1H, m, CH=), 5.90 (1H, m, CH=); Anal. calcd. for $C_{15}H_{20}O_2$: C, 77.55; H, 8.68 Found: C, 77.82; H, 8.46.

(*E,E*)-2-Hexa-2,4-dienyl-3,5,6-trimethyl-[1,4]benzoquinone (6a). To a stirred solution of **4b** (2.3 g, 10 mmol) in methanol (100 ml) was added dropwise a solution of $FeCl_3.6H_2O$ (40.0 g) in a mixture of methanol (400 ml) and water (80 ml) during 1 h. Stirring was continued at r.t. for 1 h and water (100 ml) was added, the resulting mixture was extracted several times with dichloromethane (300 ml). The combined organic extracts were washed successively with water and brine, and then dried ($MgSO_4$). Evaporation of the solvent in vacuo gave an oil which was purified by flash chromatography with hexane/acetone (5 : 0.2) as eluent to yield **6a** (1.38 g, 59.9 %, red oil). TLC: R_f = 0.9 (hexane/acetone, 5 : 2, v/v); HPLC: R_t = 20.47 min. ($MeOH/H_2O$, 9.5 : 0.5, v/v); IR (nujol): 1610 cm^{-1}; ^1H NMR ($CDCl_3$): δ = 1.72 (3H, d, J = 6 Hz, CH_3), 2.00 (3H, s, CH_3), 2.03 (6H, s, $2CH_3$), 3.25 (2H, d, J = 6 Hz, CH_2), 5.2-6.1 (4H, m, CH=CH–CH=CH); Anal. calcd. for $C_{15}H_{18}O_2$: C, 78.23; H, 7.88 Found: C, 78.02; H, 7.97.

(*E*)-2-But-1-enyl-4,6,7-trimethyl-2,3-dihydro-benzofuran-5-ol (5b). A mixture of **4b** (5.0 g, 21.6 mmol) and (1*R*)-(-)-10-camphorsulfonic acid monohydrate (0.5 g) in dry toluene (35 ml) was stirred under reflux for 10 h. After cooling, the reaction mixture was successively washed with water and brine, dried ($MgSO_4$) and concentrated in vacuo. The resultant oily residue was purified by flash chromatography with hexane/acetone (5 : 0.1) as eluent to yield **5b** (4.5 g, 90 %, colorless needles). M.p. 93 °C; TLC: R_f = 0.7 (hexane/acetone, 5 : 2, v/v); HPLC: R_t = 3.34 min. (acetonitrile/H_2O, 1 : 1, v/v); IR (KBr): 3400 cm^{-1}; ^1H NMR ($CDCl_3$): δ = 1.00 (3H, t, J = 6 Hz, CH_3), 1.61 (2H, m-t, J = 6 Hz, CH_2), 2.12 (3H, s, CH_3), 2.14 (6H, s, $2CH_3$), 2.95 (2H, m, CH_2), 4.1 (1H, s, OH), 4.80 (1H, m, CH–O), 5.5-5.9 (2H, m, CH=CH); Anal. calcd. for $C_{15}H_{20}O_2$: C, 77.55; H, 8.68 Found: C, 77.88; H, 8.86.

(*E*)-2-(2-Hydroxyhex-3-enyl)-3,5,6-trimethyl-[1,4]-benzoquinone (11e) and **(*E*)-2-(2-methoxyhex-3-enyl)-3,5,6-trimethyl-[1,4]benzoquinone (11f).** To a stirred solution of **5b** (17.0 g, 73 mmol) in methanol (500 ml) was added dropwise a solution of $FeCl_3.6H_2O$ (366 g) in a mixture of methanol (2 L) and water (500 ml) during 0.5 h. Stirring was continued at r.t. for 1 h and water (650 ml) was added, then the resulting mixture was extracted several times with dichloromethane. The combined organic extracts were successively washed with water and brine, and then dried ($MgSO_4$). Evaporation of the solvent in vacuo gave a mixture of compounds which was separated by flash chromatography with hexane/acetone (5 : 0.1, v/v) as eluent to give **11e** (11.0 g, 61.1 %, red oil) and **11f** (1.3 g, 6.8 %, red oil). **11e**: TLC: R_f = 0.5 (hexane/acetone, 5 : 2, v/v); IR (nujol): 3500, 1650 cm^{-1}; ^1H NMR ($CDCl_3$): δ = 0.96 (3H, t, J = 7.5 Hz, CH_3), 2.01 (6H, s, $2CH_3$), 2.02 (2H, m-t, J = 7.5 Hz, CH_2), 2.19 (1H, s, OH), 2.75 (2H, d, J = 6 Hz, CH_2), 4.23 (1H, q, J = 6 Hz, CH–O), 5.50 (1H, m-d, J = 15.5 Hz, CH=), 5.66 (1H, m-d, J = 15.5 Hz, CH=); ^{13}C NMR ($CDCl_3$): δ = 12.29 ($2CH_3$), 12.75 (CH_3), 13.31 (CH_3-6'), 25.10 (CH_2-5'), 35.16 (CH_2-1'), 71.22 (CH-2'), 131.63 (CH-3'), 133.56 (CH-4'), 140.49 (C-3), 140.87 (C-5 and C-6), 142.37 (C-2), 187.44 (C-4), 188.03 (C-1); MS [*m/z* (relative intensity %)]: 248 ($M^{+\cdot}$, 18), 231 (20), 164 (100), 136 (96), 121 (58), 91 (54), 85 (73), 83 (75); Anal. calcd. for $C_{15}H_{20}O_3$: C, 72.55; H, 8.12 Found: C, 72.35; H, 8.31. **11f**: TLC: R_f = 0.8 (hexane/acetone, 5 : 2, v/v); ^{1}H NMR ($CDCl_3$): δ = 0.82 (3H, t, *J* = 7 Hz, CH_3), 1.65 (2H, m, CH_2), 2.02 (6H, s, 2CH_3), 2.03 (3H, s, CH_3), 3.20 (3H, s, OCH_3), 3.35 (1H, m, CH–O), 5.4 (1H, m-d, *J* = 15 Hz, CH=), 5.70 (1H, m-d, *J* = 15 Hz, CH=); ^{13}C NMR ($CDCl_3$): δ = 9.54 (CH_3), 12.05 (2CH_3), 12.23 (CH_3), 28.34 (CH_2-5'), 29.22 (CH_2-1'), 55.99 (O–CH_3), 83.48 (CH-2'), 128.35 (CH-3'), 132.80 (CH-4'), 140.49 (C-3), 140.61 (C-5), 141.11 (C-6), 141.81 (C-2), 186.56 (C-4), 187.53 (C-1); Anal. calcd. for $C_{16}H_{22}O_3$: C, 73.25; H, 8.45 Found: C, 72.97; H, 8.66.

(*E,E,E*)-2,3,5-Trimethyl-6-octa-2,4,6-trienyl-benzene-1,4-diol (4c). A mixture of **1** (7.9 g, 52 mmol) and (*R*)-(-)-10-camphorsulfonic acid monohydrate (1.2 g) in toluene (100 ml) was stirred at 70 °C under argon for 60 h. Then the reaction was cooled to r.t. and filtered. The crude material was purified by recrystallization from methanol to give **4c** (4.9 g, 36.5 %, gray semisolid). TLC: R_f = 0.5 (hexane/acetone, 5 : 2, v/v); IR (KBr): 3280 cm^{-1}; ^{1}H NMR ($CDCl_3$): δ = 1.72 (3H, d, *J* = 5 Hz, CH_3), 2.08 (9H, s, 3CH_3), 3.4 (2H, d, *J* = 5 Hz, CH_2), 5.4-6.2 (6H, m, CH=CH–CH=CH–CH=CH); Anal. calcd. for $C_{17}H_{22}O_2$: C, 79.03; H, 8.58 Found: C, 78.86; H, 8.70.

(*E,E,E*)-2,3,5-Trimethyl-6-octa-2,4,6-trienyl-[1,4]benzoquinone (6b). To a stirred solution of **4c** (1.8 g 7 mmol) in methanol (50 ml) was added dropwise a solution of $FeCl_3.6H_2O$ (21 g) in a mixture of methanol (250 ml) and water (50 ml) during 0.5 h. Stirring was continued at r.t. for 1 h and water (100 ml) was added, then the resultant mixture was extracted three times with dichloromethane (300 ml). The combined organic extracts were successively washed with water and brine, and then dried ($MgSO_4$). Evaporation of the solvent in vacuo gave a red oil which was purified by flash chromatography with hexane/acetone (5 : 0.2) as eluent to afford **6b** (1.6 g, 89.2 %, red semisolid). TLC: R_f = 0.6 (hexane/acetone, 5 : 2, v/v); IR (KBr): 1610 cm^{-1}; ^{1}H NMR ($CDCl_3$): δ = 1.75 (3H, d, *J* = 5 Hz, CH_3), 2.00 (9H, s, 3CH_3), 3.25 (2H, d, *J* = 6 Hz, CH_2), 5.2-6.3 (6H, m, CH=CH–CH=CH–CH=CH); MS [*m/z* (relative intensity %)]: 256 ($M^{+\cdot}$, 100), 241 (54), 227 (25), 188 (20), 175 (58), 105 (25), 91 (70), 81 (82); Anal. calcd. for $C_{17}H_{20}O_2$: C, 79.65; H, 7.86 Found: C, 80.08; H, 8.48.

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