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MECHANISM ON ONE-SIDED WESSELY-MOSER REARRANGEMENT REACTION

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Abstract - Wessely-Moser rearrangement reaction of 5,7-dihydroxychromone derivatives with an isopentyl side chain at C-6 or C-8 position was examined. All reactions gave 8-isopentylchromone derivative predominantly as rearrangement product. Kinetic analysis of the one-sided rearrangement reaction revealed that the reaction depends on stability of a flavylium cation originated from 8-isopentylchromone derivative.

Wessely-Moser rearrangement is a characteristic reaction of flavonoid compounds, involving change of the substituted pattern of the A ring (Figure 1).[1] However, it has been reported that some kinds of flavonoids with 6- or 8-isoprenyl group caused one-sided rearrangement reaction to 8-isoprenylated product, in spite of an equilibrium reaction. Typical example was of the work on the chemical correlation between artocarpin (**1**) and mulberrin (**2'**) by Venkataraman *et al.* (Figure 2).[2] Later, the structure of mulberrin was revised to that of kuwanon C (**2**).[3-5] Mereyala *et al.* reported that demethylation of tetrahydroartocarpin (**1a**) with hydroiodic acid resulted in tetrahydrokuwanon C (**2a**) as sole product through Wessely-Moser rearrangement.[6] Our examination using tetramethyl ether of **2a** gave no evidence for the reaction, because of sole product (**2a**) (Figure 2).[3,4] Thus, the Wessely-Moser rearrangement reaction gives often 8-substituted product predominantly. In our survey of flavonoid compounds, we examined the one-sided reaction mechanism of Wessely-Moser rearrangement. This paper describes the structure determination of

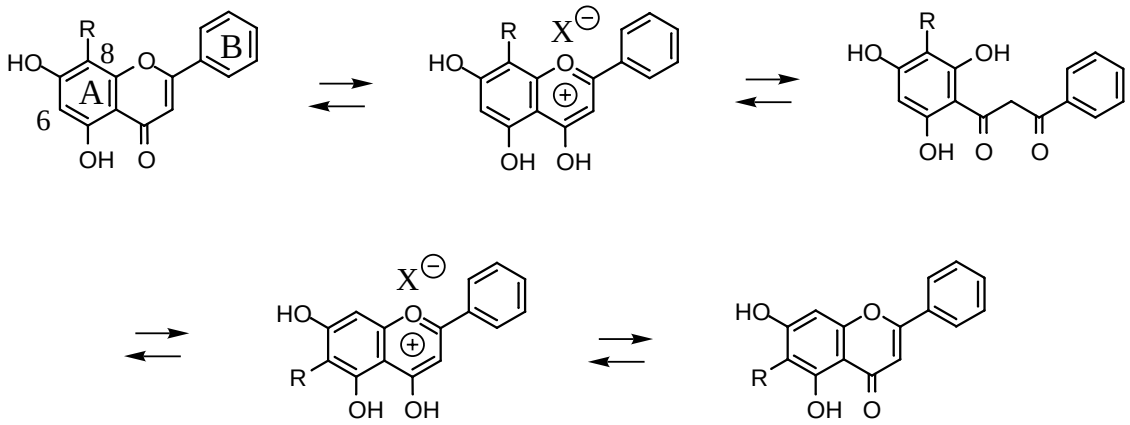


Figure 1 Wessely-Moser rearrangement reaction

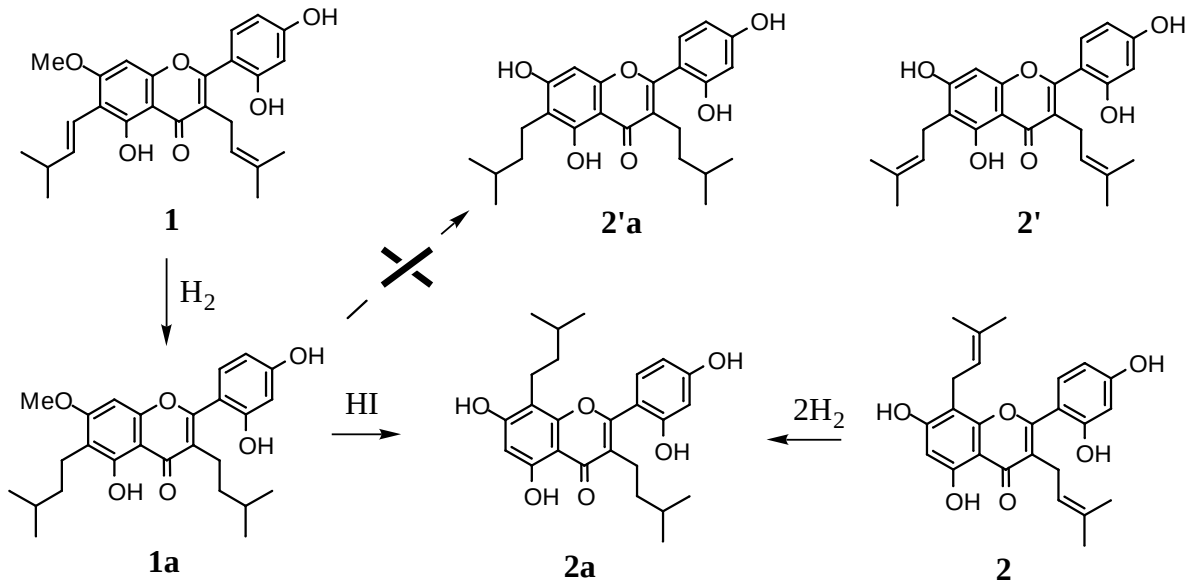


Figure 2 Chemical correlation between artocarpin (**1**) and kuwanon C (**2**)

a new flavone, artonin Y, isolated from the bark of *Artocarpus heterophyllus* and a detailed analysis of the preferential rearrangement of flavonoids in the Wessely-Moser rearrangement reaction.

Artonin Y (**3**), a new flavone derivative, has been isolated from the bark of *Artocarpus heterophyllus*, an Indonesian moraceous plant. The structure of artonin Y was shown to be **3**, a structural isomer of artocarpesin (**4**),[7] on the basis of the NMR spectroscopic data. Further evidence for the structure of artonin Y was obtained by the Wessely-Moser rearrangement of dihydroartocarpesin (**4a**). A solution of dihydroartocarpesin (**4a**) in acetic anhydride containing hydroiodic acid was heated at 170 - 200 ˚C for 2 h in a sealed tube. After usual work-up, the reaction mixture was purified by preparative HPLC to afford two products (**4a**) and (**3a**) in a ratio of *ca.* 1 : 2 (Figure 3). The product (**3a**) was identified as dihydroartonin Y (**3a**) by comparison of spectroscopic data of **3a** with those of hydrogenated product of **3**. The structure of artonin Y was thus conclusively represented by the formula **3**.

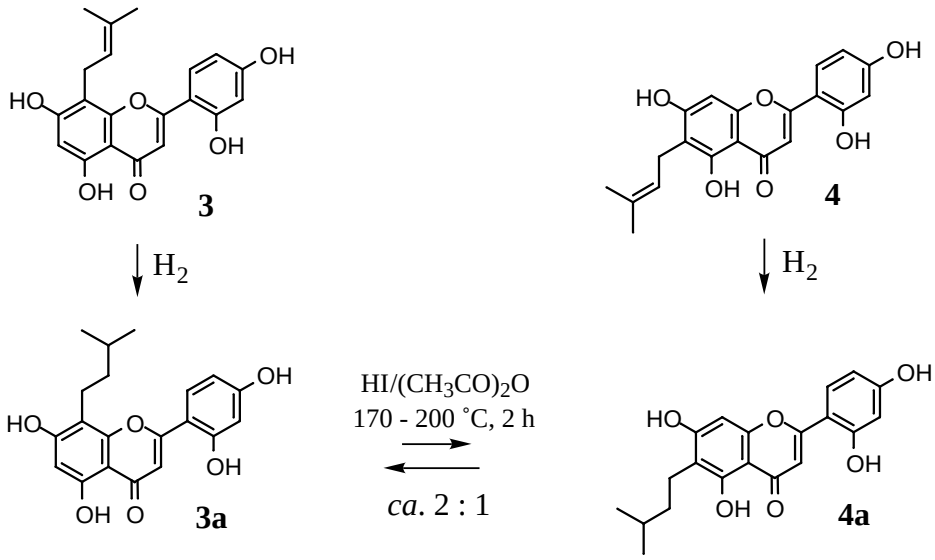


Figure 3 Artonin Y (**3**) and its chemical correlation with artocarpesin (**4**)

On the other hand, the Wessely-Moser rearrangement reaction of **4a** gave 8-substituted product (**3a**) predominantly. An analogous reaction with **3a** gave the same result, in which a ratio of products (**4a**/**3a**) was *ca.* 1 : 2. Hence, the Wessely-Moser rearrangement reaction of **4a** or **3a** also occurred an uneven rearrangement to yield preferentially 8-substituted product (**3a**). Such a preferential reaction might be depend on reaction velocity. This assumption led to examine kinetic analysis of the Wessely-Moser rearrangement reaction.

Kinetic analysis of the reaction was carried out on 2-cyclohexyl-6-isopentyl-5,7-dihydroxychromone (**5**) (Figure 4). A solution of **5** in acetic anhydride containing hydrochloric acid was heated at 85 ˚C in a sealed tube until the reaction nearly reach an equilibrium state. The compound (**5**) and its rearrangement product, 8-isopentylchromone derivative (**6**), in a passage of time were analyzed quantitatively by HPLC method (Figure 4 and Chart 1), and apparent rate constant ($k' = k_{\mathbf{5}\rightarrow\mathbf{6}} + k_{\mathbf{6}\rightarrow\mathbf{5}}$) was estimated 3.69 x 10^{-3}/min from opposing first-order reaction. Consequently, on the basis of concentration ratio of **5** and **6** (**6**/**5** = 3.18) in the equilibrium state, that means equilibrium constant, the net rate constants $k_{\mathbf{5}\rightarrow\mathbf{6}}$ and $k_{\mathbf{6}\rightarrow\mathbf{5}}$ were estimated 2.80 x 10^{-3} and 8.82 x 10^{-4}, respectively. It was thus found that the rate constant of forward reaction (**5** → **6**) was large different from that of reverse reaction (**6** → **5**). Similar kinetic analysis was carried out at 95 ˚C and 105 ˚C, and the rate constant was calculated on each experiment as shown in Table 1. Subsequently, activation energy for the rearrangement reaction was estimated E_a = 112.2 kJ/mol for the forward reaction and 104.0 kJ/mol for the reverse reaction, respectively, from Arrhenius plots (Chart 2). Although there was no significant difference between the activation energies of **5** and **6**, a large difference was observed in the value of frequency factor (Chart 2). The frequency factor is known as the number of collision with geometrically efficient orientation. In the first step of the Wessely-Moser rearrangement reaction, a flavylium cation would be formed and stabilized by a counter anion (Figure 1). If the counter anion has no geometrically efficient orientation, the reaction would not occur smoothly. It is likely that steric circumstance due to side chains at C-8 and C-2 positions of **6** prevent from an efficient approach of the counter anion to the flavylium cation. This proposition was supported by the experiment using other chromone derivatives, 2-ethyl-8-isopentyl-5,7-dihydroxychromone (**8**) and 2-methyl-8-isopentyl-5,7-dihydroxychromone (**10**), which were replaced 2-cyclohexyl group of **6** by an ethyl and a methyl groups, respectively. Each rearrangement reactions, including **6**, was carried out at 170 ˚C in a solution of acetic anhydride and hydroiodic acid, and concentration ratio of 6- and 8-substituted products in the equilibrium state was examined (Table 2). Reducing effect in the size of 2-substituent improved the concentration ratio of 6-isopentyl and 8-isopentyl products (Table 2). Furthermore, in the case of **6**, the concentration ratio of two rearrangement products was found to relate with the size of counter anion, in which the small size of counter anion also improved the ratio (Table 3). This fact strongly suggested that a steric circumstance affected to the stability of flavylium cation.

As stated above, it has been reported that the rearrangement reaction of tetrahydroartocarpin (**1a**) gave tetrahydrokuwanon C (**2a**) as sole product. On the other hand, stereochemistry of morusin (**11**), an analog of kuwanon C (**2**), was established by an X-Ray crystallographic analysis.[8] In the stereochemistry of **11**, an isoprenyl group at C-3 position causes perpendicular distortion of the B-ring face to the C-ring (Figure 5).[8] From the structural similarity of **2a** to **11**, the distortion of the B-ring in **2a** would prevent from approach of counter anion to flavylium cation, indicating that the reaction may be irreversible at the

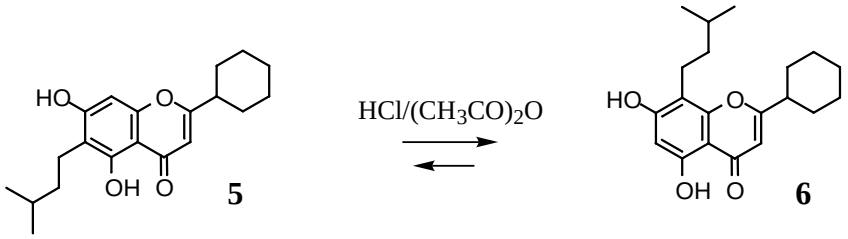


Figure 4 Kinetic analysis of Wessely-Moser rearrangement reaction using **5**

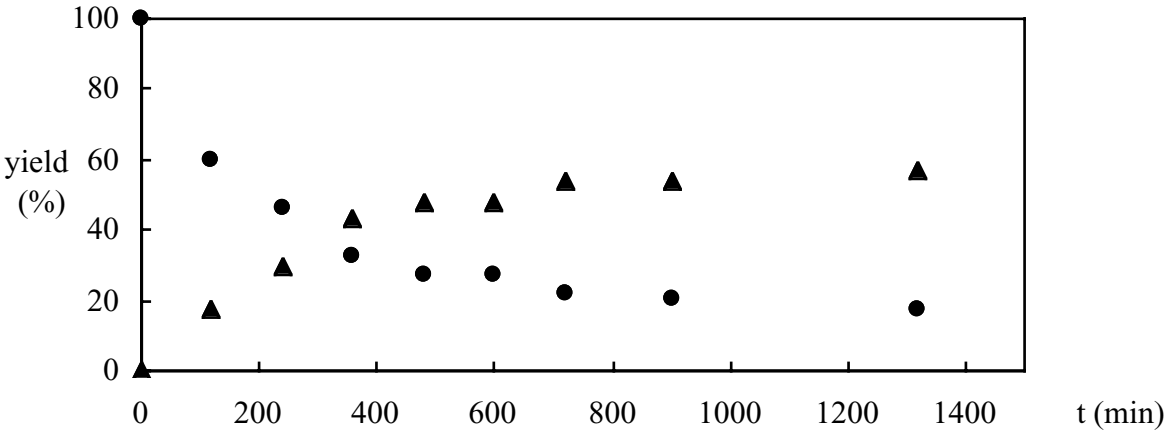


Chart 1 Change of concentrations with time of **5** (●) and **6** (▲)at 85 ˚C

Table 1 The rate constants in the Wessely-Moser rearrangement reaction of **5** and **6**

Temp. K	Apparant rate constant k'	Equilibrium constant K (= **6**/**5**)	Net rate constant min^{-1}	
			$k_{\mathbf{5} \longrightarrow \mathbf{6}}$	$k_{\mathbf{6} \longrightarrow \mathbf{5}}$
358	3.69×10^{-3}	3.18	2.80×10^{-3}	8.82×10^{-4}
368	1.06×10^{-2}	4.05	8.49×10^{-3}	2.10×10^{-3}
378	2.40×10^{-2}	3.68	1.88×10^{-2}	5.12×10^{-3}

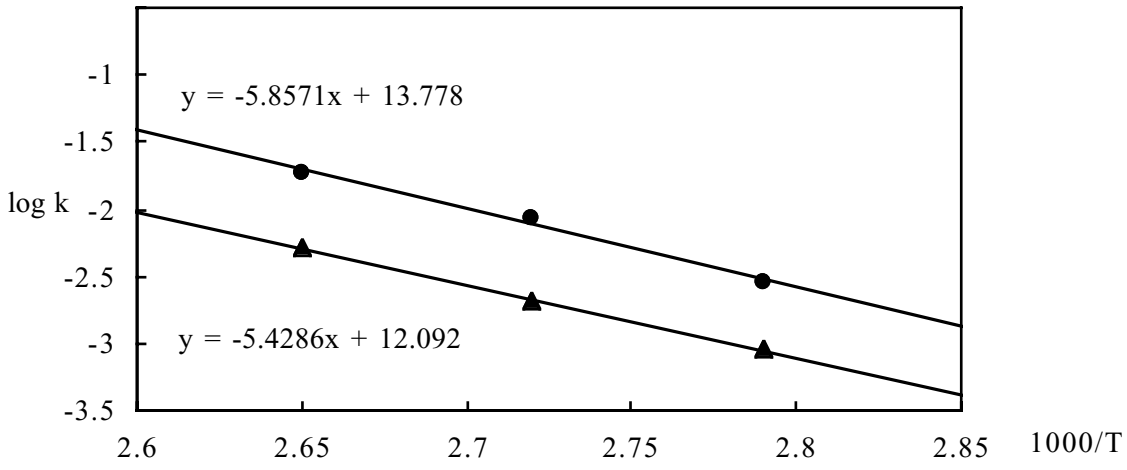


Chart 2 Arrhenius plots for the data of **5** (●) and **6** (▲)

Table 2 Effect of the size of 2-substituent on the ratio of 6- and 8-isopentylated products

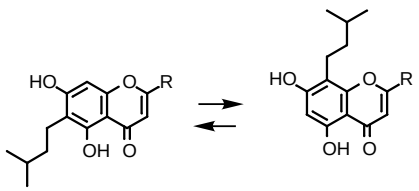
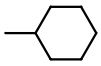
 **5**, **7**, **9** ⇌ **6**, **8**, **10**	R = 	R = CH_2CH_3	R = CH_3
	6/**5** = 4.7	**8**/**7** = 3.8	**10**/**9** = 3.3

Table 3 Effect on the size of counter anion on the ratio of **5** and **6**

5 ⇌ **6**	HCl	HBr	HI
	6/**5** = 3.7	**6**/**5** = 4.5	**6**/**5** = 4.7

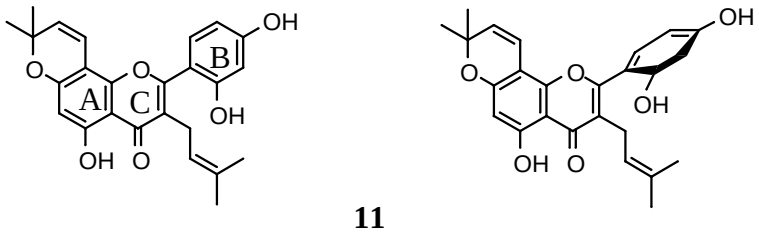


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Figure 5 Morusin (**11**) and its stereostructure

temperature. Hence, one-sided rearrangement of **1a** to **2a** could be explained by a steric factor. Present study has thus demonstrated that the Wessely-Moser rearrangement reaction depends on the stability of flavylium cation.

EXPERIMENTAL

Abbreviations: s = singlet, d = doublet, dd = double doublet, t = triplet, m = multiplet, br = broad, sh = shoulder, infl. = inflection.

General procedures

Melting points were measured on Yanaco MP-5000 micromelting apparatus (hot-stage type) and are uncorrected. UV and IR spectra were recorded on Shimadzu UV-265 spectrophotometer and Hitachi IR-

3000 spectrophotometer, respectively. ^{1}H (400 MHz) and ^{13}C (100 MHz) NMR spectra were recorded on JEOL EX-400 FTNMR spectrometer and tetramethylsilane (TMS) was used as internal standard. Wakogel C-200 and B-5F (Wako Pure Chem. Industry, Co., Japan) were used for column and preparative TLC, respectively.

Plant material

Bark of *Artocarpus heterophyllus* was collected in the Botanical Garden of Bogor, Bogor, Indonesia, in March 1988 and was identified by the members of Botanical Garden of Bogor.

*Extraction and Isolation of Artonin Y (**3**)*

The dried barks of *A. heterophyllus* (20 kg) were finely cut and extracted three times with methanol (200 L) at rt for 3 days. Evaporation of the methanol solution under reduced pressure yielded 1.1 kg of residue. Extraction of the residue (1.1 kg) with benzene (3 L) and then with acetone (3 L) at rt followed by removal of solvent afforded benzene soluble part (420 g) and acetone soluble part (365 g), respectively. The acetone extract (300 g) was chromatographed over silica gel (1200 g) using n-hexane, benzene, benzene - ethyl acetate (9 : 1, 8 : 2, 7 : 3, 6 : 4), and then acetone as solvent to prepare frs. 1 - 128. Each fraction was prepared by elution of 500 mL of volume. Combined fraction (frs. 51 - 69, 28 g) eluted with benzene - ethyl acetate (7 : 3) was subjected to silica gel column chromatography using benzene increasing amount of acetone as an eluent. The fraction (6 g) eluted with benzene - acetone (85 : 15) was rechromatographed on silica gel with chloroform - acetone as an eluent to prepare fractions 1' - 98'. Fractionation of combined fraction (frs. 24' - 56', 0.5 g) by preparative TLC followed by recrystallization from benzene - acetone afforded artonin Y (**3**, 10 mg).

*Artonin Y (**3**)*

Compound (**3**) was obtained as a pale yellow needle, mp 285 - 286 ˚C (benzene - acetone), and showed positive reaction to ferric chloride and magnesium - hydrochloric acid tests. UV λmax (EtOH) nm (log ε): 355 (3.90), 289 sh (3.65), 270 (3.89), 254 sh (3.79), 203 (4.21). UV λmax (EtOH + $AlCl_3$) nm: 396, 361, 298, 278, 260, 210. IR νmax (KBr) cm^{-1}: 3600 - 3300 (br), 1660, 1610, 1540, 1500. EI-MS: *m/z* (rel. int.) 354 (M^+, 86), 339 (100), 299 (41), 286 (60). ^{1}H-NMR (acetone-d_6): δ 1.66, 1.80 (each 3H, s, C-11-CH_3), 3.54 (2H, d, *J* = 7, C-9-H x 2), 5.28 (1H, m, C-10-H), 6.32 (1H, s, C-6-H), 6.59 (1H, dd, *J* = 2 and 9, C-5'-H), 6.62 (1H, d, *J* = 2, C-3'-H), 7.06 (1H, s, C-3-H), 7.87 (1H, d, *J* = 9, C-6'-H), 13.07 (1H, s, C-5-OH). ^{13}C-NMR (acetone-d_6): δ 18.1 (C-13), 22.4 (C-9), 25.9 (C-12), 99.0 (C-6), 104.4 (C-3'), 107.2 (C-4a), 107.8 (C-8), 108.4 (C-3), 109.1 (C-5'), 111.2 (C-1'), 123.7 (C-10), 131.0 (C-6'), 131.9 (C-11), 156.1 (C-8a), 159.3 (C-2'), 161.0 (C-5), 162.1 (C-7), 162.5 (C-2), 162.8 (C-4'), 183.8 (C-4). HR-EIMS: *m/z* 354.1090 (M^+, $C_{20}H_{18}O_6$ requires 354.1104).

*Dihydroartonin Y (**3a**)*

Artonin Y (**3**, 5 mg) in a EtOH solution (20 mL) was hydrogenated over PtO_2 (5 mg) as a catalyst for 12 h. After usual work-up, the reaction product was recrystallized from benzene - acetone to give **3a** (3.5 mg). Compound (**3a**), a pale yellow needle, mp > 300 ˚C. EI-MS: *m/z* (rel. int.) 356 (M^+, 23), 299 (100), 165

(30). ^{1}H-NMR (acetone-d_6): δ 1.00 (6H, d, *J* = 7, C-11-CH_3 x 2), 1.52 (2H, m, C-10-H x 2), 1.67 (1H, m, C-11-H), 2.87 (2H, m, C-9-H x 2), 6.32 (1H, s, C-6-H), 6.57 (1H, dd, *J* = 2 and 9, C-5'-H), 6.68 (1H, d, *J* = 2, C-3'-H), 7.10 (1H, s, C-3-H), 7.88 (1H, d, *J* = 9, C-6'-H), 13.06 (1H, s, C-5-OH).

*Dihydroartocarpesin (**4a**)*

Artocarpesin (**4**, 40 mg) in a EtOH solution (10 mL) was hydrogenated over Pd-C (10 mg) as a catalyst for 16 h. After usual work-up, the reaction product was purified by preparative HPLC (column, Senshu Pak SSC Silica 4251-N, 10 mm i.d. x 250 mm, solvent, $CHCl_3$ - AcOEt = 2 : 1, UV detector, 254 nm) to afford **4a** (35 mg). Compound (**4a**), a pale yellow needle, mp 263 - 265 ˚C (benzene - acetone). EI-MS: m/z (rel. int.) 356 (M^+, 13), 313 (11), 300 (100), 299 (50), 165 (19). HR-EIMS: *m/z* 356.1240 (M^+, $C_{20}H_{20}O_6$ requires 356.1260). ^{1}H-NMR (acetone-d_6): δ 0.96 (6H, d, *J* = 7, C-11-CH_3 x 2), 1.46 (2H, m, C-10-H x 2), 1.62 (1H, m, C-11-H), 2.68 (2H, m, C-9-H x 2), 6.55 (1H, dd, *J* = 2 and 9, C-5'-H), 6.59 (1H, s, C-8-H), 6.63 (1H, d, *J* = 2, C-3'-H), 7.11 (1H, s, C-3-H), 7.80 (1H, d, *J* = 9, C-6'-H), 13.34 (1H, s, C-5-OH).

*Wessely-Mosser Rearrangement of Dihydroartocarpesin (**4a**)*

A mixture of dihydroartocarpesin (**4a**, 7 mg), acetic anhydride (1 mL), and conc. HI (1 mL) in a sealed tube was heated at 170 - 200 ˚C for 2 h. After the reaction, to the mixture 15 % $NaHSO_3$ was added, and precipitate was extracted with Et_2O. The Et_2O layer was evaporated under reduced pressure to give a residue. The residue was purified by preparative TLC (column, Senshu Pak SSC Silica 4251-N, 10 mm i.d. x 250 mm, solvent, $CHCl_3$ - AcOEt = 2 : 1, UV detector, 254 nm) to afford **4a** (1.8 mg, t_R: 26 min) and **3a** (4 mg, t_R: 28.5 min). Compounds (**4a**) and (**3a**) were identified as dihydoartocarpasin (**4a**) and dihydroartonin Y (**3a**), respectively, by comparison of their physical and NMR data with those of **4a** and **3a**.

*Wessely-Mosser Rearangement of Compound (**3a**, = Dihydroartonin Y)*

The same procedure as in the case of **4a** on the rearrangement reaction with **3a** (3 mg) afforded **4a** (0.9 mg) and **3a** (1.9 mg) as reaction product.

*Preparation of 2-Cyclohexyl-5,7-dihydroxy-6-(3-methylbutyl)chromone (**5**) and 2-Cyclohexyl-5,7-dihydroxy-8-(3-methylbutyl)chromone (**6**)*

A solution of 5,7-dihydroxyflavone (= chrysin, 2.5 g), 2-methyl-3-buten-2-ol (2 mL), and catalytic amount of boron trifluoride ethyl ether complex in THF (30 mL) was heated at 50 ˚C for 12 h. After usual work-up, the reaction mixture was purified by silica gel column chromatography with $CHCl_3$ as an eluent followed by preparative TLC (silica gel, solvent system, *n*-hexane - acetone = 2 : 1, $CHCl_3$ - MeOH = 10 : 1) to give 6-(3-methyl-2-butenyl)-5,7-dihydroxyflavone (96 mg)[9] and 8-(3-methyl-2-butenyl)-5,7-dihydroxyflavone (268 mg).[9] These known flavones were identified by direct comparison of the data with those of authentic samples.[9] 5,7-Dihydroxy-6-(3-methyl-2-butenyl)flavone (30 mg) in a EtOH solution (10 mL) was hydrogenated in the presence of PtO_2 (30 mg) to yield 2-cyclohexyl-5,7-dihydroxy-6-(3-

methylbutyl)chromone (**5**, 26 mg, 87.8 %). An analogous hydrogenation of 5,7-dihydroxy-8-(3-methyl-2-butenyl)flavone yielded 2-cyclohexyl-5, 7-dihydroxy-8-(3-methylbutyl)chromone (**6**, 80 mg, 77.4 %).

*2-Cyclohexyl-5,7-dihydroxy-6-(3-methylbutyl)chromone (**5**)*

Colorless needles, mp 244 ˚C (*n*-hexane – acetone). EIMS *m/z* (rel. int.): 330 (M^+, 19 %), 287 (31), 274 (100). ^{1}H-NMR (acetone-d_6): δ 0.95 (6H, d, *J* = 7 Hz), 1.28 - 1.99 (14H, m), 6.00 (1H, s, 3-H), 6.46 (1H, s, 8-H), 13.16 (1H, s, 5-OH). ^{13}C-NMR (acetone-d_6): δ 20.0 (C-9), 22.1 (C-12 and C-13), 25.6 (C-4'), 25.7 (C-3' and C-5'), 28.1 (C-11), 30.3 (C-2' and C-6'), 37.8 (C-10), 42.5 (C-1'), 93.0 (C-8), 104.3 (C-4a), 105.6 (C-3), 112.5 (C-6), 156.1 (C-8a), 159.5 (C-5), 161.7 (C-7), 173.8 (C-2), 182.6 (C-4).

*2-Cyclohexyl-5,7-dihydroxy-8-(3-methylbutyl)chromone (**6**)*

Pale yellow needles, mp 148 ˚C (*n*-hexane – acetone). EIMS *m/z* (rel. int.): 330 (M^+, 99 %), 313 (23), 301 (56), 287 (77). ^{1}H-NMR (acetone-d_6); δ 0.98 (6H, d, *J* = 7 Hz), 1.27 - 2.02 (14H, m), 6.02 (1H, s, 3-H), 6.30 (1H, s, 8-H), 12.81 (1H, s, 5-OH). ^{13}C-NMR (acetone-d_6): δ 20.3 (C-9), 22.1 (C-12 and C-13), 25.7 (C-3', 4' and C-5'), 28.3 (C-11), 30.3 (C-2' and C-6'), 38.6 (C-10), 42.8 (C-1'), 98.3 (C-6), 104.5 (C-4a), 105.5 (C-3), 107.5 (C-8), 155.6 (C-8a), 159.8 (C-5), 161.4 (C-7), 173.7 (C-2), 183.0 (C-4).

*General Procedure for Preparation of Chromones (**7** - **10**)*

2-Ethyl-5,7-dihydroxychromone, which is a starting material leading to **7** and **8**, was synthesized according to the method of Robeson *et al.*[10] A solution of 2-ethyl-5,7-dihydroxychromone (1.0 g), 2-methyl-3-buten-2-ol (0.5 mL) and catalytic amount of boron trifluoride ethyl ether complex in THF (20 mL) was allowed to stand at rt for 12 h. After usual work-up, the resultant mixture was purified by silica gel column chromatography using $CHCl_3$ as an eluent followed by preparative TLC (silica gel, *n*-hexane - acetone = 3 : 1) to yield 2-ethyl-5,7-dihydroxy-6-(3-methyl-2-butenyl)chromone (120 mg) and 2-ethyl-5,7-dihydroxy-8-(3-methyl-2-butenyl)chromone (250 mg). Hydrogenation of both isoprenylated chromones (50 mg of each) in the presence of PtO_2 (50 mg) at rt for 16 h yielded 2-ethyl-5,7-dihydroxy-8-(3-methylbutyl)chromone (**7**, 43 mg, 84.3 %) and 2-ethyl-5,7-dihydoxy-6-(3-methylbutyl)-chromone (**8**, 44 mg, 86.8 %), respectively. 2-Methyl-5,7-dihydroxy-8-(3-methyl-2-butenyl)chromone and 2-methyl-5,7-dihydroxy-6-(3-methyl-2-butenyl)chromone, which are the starting materials for **9** and **10**, were synthesized according to the method reported in the literatures.[11-13] Hydrogenation of these chromones in the same way as above afforded 2-methyl-5,7-dihydroxy-8-(3-methylbutyl)chromone (**9**, 73.2 %) and 2-methyl-5,7-dihydroxy-6-(3-methylbutyl)chromone (**10**, 80.4 %), respectively.

*2-Ethyl-5,7-dihydroxy-8-(3-methylbutyl)chromone (**7**)*

Pale yellow needles, mp 168 ˚C (*n*-hexane – Et_2O). EIMS *m/z* (rel. int.): 276 (M^+, 93 %), 233 (9), 219 (100). ^{1}H-NMR (acetone-d_6); δ 0.97 (6H, d, *J* = 6.6 Hz), 1.32 (3H, t, *J* = 7.5 Hz), 1.45 (2H, m), 1.60 (1H, m), 2.73 (4H, m), 6.04, 6.30 (each 1H, s), 12.80 (1H, s). ^{13}C-NMR (acetone-d_6): δ 11.2 (C-2-$\underline{C}H_2CH_3$), 20.9 (C-9), 22.8 (C-12 and C-13), 27.9 (C-11), 28.8 (C-2-$CH_2\underline{C}H_3$), 39.2 (C-10), 98.9 (C-

8), 104.9 (C-4a), 106.9 (C-3), 108.0 (C-6), 156.1 (C-8a), 160.4 (C-5), 161.8 (C-7), 171.9 (C-2), 183.3 (C-4).

*2-Ethyl-5,7-dihydroxy-6-(3-methylbutyl)chromone (**8**)*

Pale yellow needles, mp 210 ˚C (decomp, *n*-hexane – Et_2O). EIMS *m/z* (rel. int.): 276 (M^+, 97 %), 233 (99), 221 (100), 219 (97). ^{1}H-NMR (acetone-d_6); δ 0.95 (6H, d, *J* = 6.6 Hz), 1.27 (3H, t, *J* = 7.5 Hz), 1.43 (2H, m), 1.58 (1H, m), 2.65 (4H, m), 6.04, 6.45 (each 1H, s), 13.14 (1H, s). ^{13}C-NMR (acetone-d_6): δ 11.2 (C-2-$\underline{C}H_2CH_3$), 20.8 (C-9), 22.9 (C-12 and C-13), 27.7 (C-11), 28.9 (C-2-$CH_2\underline{C}H_3$), 38.6 (C-10), 93.6 (C-8), 104.7 (C-4a), 107.1 (C-3), 113.0 (C-6), 156.6 (C-8a), 160.0 (C-5), 162.2 (C-7), 171.9 (C-2), 182.5 (C-4).

*2-Methyl-5,7-dihydroxy-8-(3-methylbutyl)chromone (**9**)*

Pale yellow needles, mp 191 ˚C (*n*-hexane – Et_2O). EIMS *m/z* (rel. int.): 262 (M^+, 21 %), 205 (100). ^{1}H-NMR (acetone-d_6); δ 0.94 (6H, d, *J* = 6.7 Hz), 1.42 (2H, m), 1.56 (1H, m), 2.40 (3H, s), 2.72 (2H, m), 6.05, 6.28 (each 1H, s), 12.81 (1H, s). ^{13}C-NMR (acetone-d_6): δ 19.5 (C-2-CH_3), 20.1 (C-9), 22.0 (C-12 and C-13), 27.9 (C-11), 38.4 (C-10), 98.4 (C-6), 104.2 (C-4a), 107.4 (C-8), 107.8 (C-3), 155.7 (C-8a), 160.0 (C-5), 161.4 (C-7), 167.3 (C-2), 182.8 (C-4).

*2-Methyl-5,7-dihydroxy-6-(3-methylbutyl)chromone (**10**)*

Pale yellow needles, mp 202 ˚C (*n*-hexane – Et_2O). EIMS *m/z* (rel. int.): 262 (M^+, 24 %), 219 (26), 206 (100), 205 (98). ^{1}H-NMR (acetone-d_6); δ 0.93 (6H, d, *J* = 6.7 Hz), 1.42 (2H, m), 1.57 (1H, m), 2.34 (3H, s), 2.64 (2H, m), 6.04, 6.42 (each 1H, s), 13.13 (1H, s). ^{13}C-NMR (acetone-d_6): δ 19.4 (C-2-CH_3), 20.0 (C-9), 22.1 (C-12 and C-13), 28.1 (C-11), 37.8 (C-10), 93.0 (C-8), 104.0 (C-4a), 108.0 (C-3), 112.5 (C-6), 156.1 (C-8a), 159.5 (C-5), 161.6 (C-7), 167.1 (C-2), 182.3 (C-4).

*General Procedure for Wessely-Moser Rearrangement Reaction of Compounds (**5** - **10**) using Hydroiodic Acid*

A mixture of the sample (10 mg), acetic anhydride (1 mL), and 57 % hydroiodic acid (1 mL) was heated at 170 ˚C for 2 h in a sealed tube. After cooling, to the solution 15 % sodium hydrogen sulfite was added and white precipitate was formed. The precipitate was extracted with Et_2O and the Et_2O layer was evaporated under reduced pressure to give a residue. Concentration ratio of 6-substituted and 8-substituted chromones was determined from a ratio of signal areas of the two products in the ^{1}H-NMR spectrum.

*Wessely-Moser Rearrangement Reaction of Compound (**6**) using Hydrochloric Acid and Hydrobromic Acid*

The reaction of compound (**6**) was carried out in the same procedure as the reaction using 57 % hydroiodic acid, excepting replace of hydroiodic acid by 35 % hydrochloric acid or 47 % hydrobromic acid. Concentration ratio of 6-substituted and 8-substituted chromones (**5** and **6**) was determined from a ratio of signal areas of the two products in the ^{1}H-NMR spectrum.

*Kinetic Analysis of Wessely-Moser Rearrangement Reaction of Compound (**5**)*

A mixture of **5** (1 mg), acetic anhydride (1 mL), and conc. HCl (1 mL) was heated at 85 ˚C in a sealed tube (10 tubes in total). Progress of the reaction was monitored quantitatively every each time by HPLC analysis (column, Inertsil ODS-3, 4.6 mm i.d. x 150 mm, solvent, CH_3CN - 0.1 % aq. phosphoric acid = 8 : 2, UV detector, 254 nm, flaw rate, 0.8 mL/min). Analogous experiments were carried out at 95 and 105 ˚C, respectively.

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