# New α-Tetralonyl Glucosides from the Fruit of *Juglans mandshurica*

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**Five new α-tetralonyl glucosides, juglanosides A—E (1—5) were isolated from the fresh rejuvenated fruit of *Juglans mandshurica*. Their structures were elucidated as (4*S*)-4-hydroxy-α-tetralone 4-*O*-β-D-glucopyranoside (1), (4*S*)-4,5-dihydroxy-α-tetralone 4-*O*-β-D-glucopyranoside (2), (4*S*)-4,6-dihydroxy-α-tetralone 4-*O*-β-D-glucopyranoside (3), (4*S*)-4,5,8-trihydroxy-α-tetralone 4-*O*-β-D-glucopyranoside (4), and (4*S*)-4,5,8-trihydroxy-α-tetralone 5-*O*-β-D-glucopyranoside (5) on the basis of spectroscopic analysis and chemical evidence.**

**Key words** *Juglans mandshurica*; Juglandaceae; α-tetralonyl glucoside; juglanoside

*Juglans mandshurica* MAXIM. (Juglandaceae) is widely distributed throughout urban and rural areas in northeast of China. Its fresh rejuvenated fruit, commonly called "Qing Long Yi", has been used as a folk medicine for treatment of cancer and dermatosis and as an anodyne to relieve aches in China. Although phytochemical analyses were extensively carried out on not only the root[1—5] but also the stem bark[6] of *J. mandshurica*, little chemical work appears to have been done on the chemical composition of its fresh rejuvenated fruit. To our best knowledge, only two naphthalene glucosides, 4-hydroxynaphthalenyl β-D-glucopyranoside and 4,8-dihydroxy-1-naphthalenyl β-D-glucopyranoside have been isolated from the fruit of *J. mandshurica*.[7] The medicinal uses of "Qing Long Yi" prompted us to investigate its chemical constituents, resulting in the isolation of five new α-tetralonyl glucosides (**1**—**5**). This paper deals with the isolation and structural elucidation of the new compounds on the basis of spectroscopic analysis, including two-dimensional NMR spectroscopic data, and the results of hydrolysis.

## Results and Discussion

The fresh rejuvenated fruit of *J. mandshurica*, which was collected in a mountain area of Heilongjiang Province, China, was decocted twice with water and extracted with hexane, EtOAc and *n*-BuOH, successively. The *n*-BuOH extract was chromatographed on a Diaion HP-20 column to give water and 40% methanol eluate fraction. The 40% methanol eluate fraction was chromatographed on an ODS column, and subjected to a combination of silica gel, Lobar RP-$C_{18}$ column chromatography, and HPLC. Then, five new compounds, named juglanosides A—E (**1**—**5**) were isolated, and their structures were characterized as follows.

Juglanoside A (**1**) was isolated as an amorphous powder. Its molecular formula was determined to be $C_{16}H_{20}O_7$ by high-resolution (HR)-FAB-MS. On acid hydrolysis, **1** afforded D-glucose as a component sugar, which was identified by GLC analysis of its trimethylsilyl thiazolidine derivative. The $^1$H-NMR spectrum of **1** showed a set of proton signals due to two methylenes at $\delta$ 3.04 (1H, ddd, $J$=17.8, 9.5, 4.8 Hz) and 2.60 (1H, ddd, $J$=17.8, 6.7, 4.8 Hz), and 2.44 (1H, dddd, $J$=13.3, 9.5, 4.8, 3.4 Hz) and 2.36 (1H, dddd, $J$=13.3, 6.7, 6.2, 4.8 Hz), and an oxymethylene at $\delta$ 5.10 (1H, dd, $J$=6.2, 3.4 Hz). Moreover, the $^{13}$C-NMR spectrum, in combination with distortionless enhancement by polarization transfer (DEPT) and $^1$H-detected multiple quantum coherence (HMQC) experiments, showed signals for a carbonyl carbon at $\delta$ 200.3, two methylene carbons at $\delta$ 31.4 and 35.4, and a carbinylic carbon at $\delta$ 75.1. All above data indicated that **1** is an α-tetralone derivative.[6] In the $^1$H-NMR spectrum, proton signals due to an *ortho*-disubstituted aromatic ring at $\delta$ 7.71 (1H, dd, $J$=7.8, 1.4 Hz), 7.63 (1H, td, $J$=7.8, 1.4 Hz), 7.47 (1H, td, $J$=7.8, 1.4 Hz) and 7.97 (1H, dd, $J$=7.8, 1.4 Hz), suggested the 4-hydroxy-α-tetralone moiety in **1**. The carbinylic proton ($\delta$ 5.10) at C-4 could be deduced to be equatorial from its coupling constant value of 3.4 Hz with $H_{ax}$-3 ($\delta$ 2.44). The $^1$H- and $^{13}$C-NMR spectra also showed the presence of a glucopyranose moiety. The β-anomeric configuration for glucopyranose was determined from its large $^3J_{H1,H2}$ coupling constant value (7.8 Hz). The position of the sugar unit was indicated to be C-4 by heteronuclear multiple-bond correlations (HMBC) between the signals at $\delta_H$ 4.38 (Glc-H-1′) and $\delta_C$ 75.1 (C-4), and $\delta_H$ 5.10 (H-4) and $\delta_C$ 103.2 (Glc-C-1′). To determine the absolute configuration of the chiral center at C-4, **1** was hydrolyzed with naringinase to give the aglycon **1a**, which was identified to be (4*S*)-4-hydroxy-α-tetralone (**1a**) by comparing its MS, NMR and $[\alpha]_D$ data with those of the reference.[8] Based on the above evidence, the structure of juglanoside A (**1**) was established as (4*S*)-4-hydroxy-α-tetralone 4-*O*-β-D-glucopyranoside.

Juglanoside B (**2**) was isolated as an amorphous powder. Its molecular formula was determined to be $C_{16}H_{20}O_8$ by HR-FAB-MS. On acid hydrolysis, **2** afforded D-glucose as a component sugar. Besides the signals due to a β-glucopyranose moiety, the $^1$H- and $^{13}$C-NMR spectra also showed the

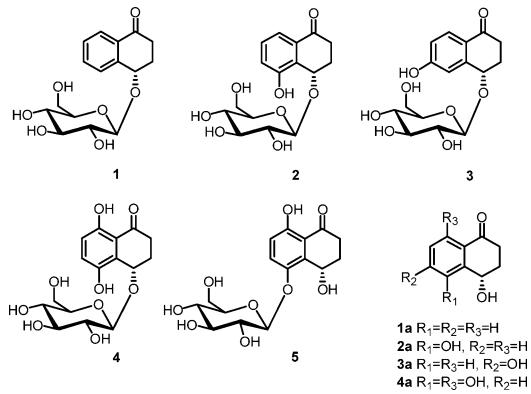


Chart 1

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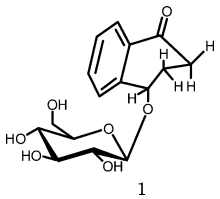
Table 1. $^1$H-NMR Spectral Data for **1**—**5** (500 MHz, $CD_3OD$)

| | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| $H_{ax}$-2 | 3.04, ddd (17.8, 9.5, 4.8) | 3.12, ddd (17.4, 14.0, 5.1) | 2.96, ddd (17.7, 9.7, 5.1) | 3.20, ddd (18.1, 13.8, 4.8) | 3.06, ddd (17.4, 13.1, 5.5) |
| $H_{eq}$-2 | 2.60, ddd (17.8, 6.7, 4.8) | 2.48, dt (17.4, 3.2) | 2.50, ddd (17.7, 6.4, 4.8) | 2.51, dt (18.1, 3.8) | 2.53, dt (17.4, 3.4) |
| $H_{ax}$-3 | 2.44, dddd (13.3, 9.5, 4.8, 3.4) | 2.19, tt (14.0, 3.2) | 2.38, dddd (13.5, 9.6, 4.8, 3.5) | 2.16, tdd (13.8, 3.8, 3.2) | 2.20, tt (13.9, 3.4) |
| $H_{eq}$-3 | 2.36, dddd (13.3, 6.7, 6.2, 4.8) | 2.56, ddt (14.0, 5.1, 3.2) | 2.31, dddd (13.5, 6.4, 6.2, 5.1) | 2.48, m | 2.24, ddt (13.9, 5.5, 3.4) |
| H-4 | 5.10, dd (6.2, 3.4) | 5.41, t (3.2) | 5.00, dd (6.2, 3.5) | 5.41, t (3.2) | 5.35, t (3.4) |
| H-5 | 7.71, dd (7.8, 1.4) | | 7.02, d (2.3) | | |
| H-6 | 7.63, td (7.8, 1.4) | 7.10, dd (7.9, 1.1) | | 7.09, d (9.0) | 7.51, d (9.1) |
| H-7 | 7.47, td (7.8, 1.4) | 7.28, t (7.9) | 6.83, dd (8.4, 2.3) | 6.79, d (9.0) | 6.86, d (9.1) |
| H-8 | 7.97, dd (7.8, 1.4) | 7.48, dd (7.9, 1.1) | 7.87, d (8.4) | | |
| Glc | | | | | |
| H-1′ | 4.38, d (7.8) | 4.60, d (7.8) | 4.38, d (7.8) | 4.53, d (7.8) | 4.78, d (7.8) |
| H-2′ | 3.24, dd (8.5, 7.8) | 3.18, dd (8.7, 7.8) | 3.25, dd (8.7, 7.8) | 3.16, dd (8.9, 7.8) | 3.52, dd (8.9, 7.8) |
| H-3′ | 3.32[a)] | 3.35[a)] | 3.33, t (8.7) | 3.30[a)] | 3.47, t (8.9) |
| H-4′ | 3.31[a)] | 3.36[a)] | 3.31[a)] | 3.31[a)] | 3.40[a)] |
| H-5′ | 3.32[a)] | 3.35[a)] | 3.30[a)] | 3.32[a)] | 3.39, m |
| H-6′ | 3.71, dd (11.8, 5.3) | 3.74, dd (12.2, 4.8) | 3.71, dd (11.8, 5.7) | 3.72, dd (11.9, 4.8) | 3.72, dd (12.2, 4.8) |
| | 3.94, dd (11.8, 1.0) | 3.91, dd (12.2, 1.8) | 3.94, dd (11.8, 1.5) | 3.90, dd (11.9, 1.8) | 3.90, dd (12.2, 1.4) |

*a*) Overlapped signals.



1

Chart 2

signals for two methylenes ($\delta_H$ 3.12, 2.48 and $\delta_C$ 34.1; $\delta_H$ 2.19, 2.56 and $\delta_C$ 30.1), an oxymethylene ($\delta_H$ 5.41, $\delta_C$ 69.9), and a carbonyl ($\delta_C$ 201.1), which were characteristic of those of 4-hydroxy-$\alpha$-tetralone. The $^1$H-NMR spectrum further showed the ABC-type aromatic proton signals at $\delta$ 7.10 (1H, dd, $J$=7.9, 1.1 Hz), 7.28 (1H, t, $J$=7.9 Hz) and 7.48 (1H, dd, $J$=7.9, 1.1 Hz), indicating the presence of a hydroxyl group on the aromatic ring. This was supported by the difference of 16 mass units between quasi-molecular ion peaks of **2** and **1** in the positive electrospray ionization (ESI)-MS spectrum. The position of the hydroxyl group on the aromatic ring was assigned to be C-5 by observation of the HMBC correlations between $\delta_H$ 5.41 (H-4) and $\delta_C$ 156.9 (C-5). The position of the sugar could be deduced to be C-4 by HMBC correlations between $\delta_H$ 4.60 (Glc-H-1′) and $\delta_C$ 69.9 (C-4), and $\delta_H$ 5.41 (H-4) and $\delta_C$ 69.9 (Glc-C-1′). Furthermore, **2** was enzymatic hydrolyzed to give 4,5-dihydroxy-$\alpha$-tetralone (**2a**), which afforded its dibenzoate **2b** on the following benzoylation. The absolute configuration of **2** was determined as 4*S* from the circular dichroism (CD) spectrum of **2a**, where a negative Cotton effect at 234 nm was observed. Thus, the structure of juglanoside B (**2**) was determined to be (4*S*)-4,5-dihydroxy-$\alpha$-tetralone 4-*O*-$\beta$-D-glucopyranoside.

Juglanoside C (**3**) was isolated as an amorphous powder. Its molecular formula was determined to be $C_{16}H_{20}O_8$ by HR-FAB-MS. Similarly to **1** and **2**, the $^1$H- and $^{13}$C-NMR spectra suggested **3** is also a 4-hydroxy-$\alpha$-tetralone $\beta$-glucopyranoside. However, in the $^1$H-NMR spectrum of **3**, the ABX-type aromatic proton signals at $\delta$ 7.02 (1H, d, $J$=2.3 Hz), 6.83 (1H, dd, $J$=8.4, 2.3 Hz) and 7.87 (1H, d, $J$=8.4 Hz) indicated a different substituted position of the hydroxyl group on the aromatic ring, comparing with that of

Table 2. $^{13}$C-NMR Data for **1**—**5** (125 MHz, $CD_3OD$)

| Carbon | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| 1 | 200.3 | 201.1 | 199.4 | 207.1 | 206.5 |
| 2 | 35.4 | 34.1 | 35.1 | 34.1 | 33.6 |
| 3 | 31.4 | 30.1 | 31.6 | 29.8 | 30.3 |
| 4 | 75.1 | 69.9 | 75.0 | 69.3 | 61.4 |
| 5 | 130.3 | 156.9 | 116.0 | 148.5 | 148.9 |
| 6 | 134.9 | 122.1 | 164.3 | 126.9 | 128.5 |
| 7 | 129.9 | 130.6 | 117.1 | 119.5 | 119.0 |
| 8 | 128.0 | 119.0 | 131.0 | 157.2 | 159.1 |
| 9 | 133.0 | 134.5 | 125.3 | 116.9 | 116.2 |
| 10 | 143.9 | 129.7 | 146.5 | 127.5 | 134.8 |
| Glc | | | | | |
| 1′ | 103.2 | 104.0 | 103.0 | 103.4 | 104.6 |
| 2′ | 75.3 | 75.4 | 75.3 | 75.4 | 75.4 |
| 3′ | 78.2 | 78.1 | 78.2 | 78.2 | 78.0 |
| 4′ | 71.8 | 71.6 | 71.9 | 71.7 | 71.3 |
| 5′ | 78.1 | 78.1 | 78.0 | 78.1 | 78.4 |
| 6′ | 63.0 | 62.8 | 63.0 | 62.8 | 62.6 |

**2**. The downfield shifted proton signal at $\delta$ 7.87 could be assigned to be H-8, which was also supported by the HMBC correlation between $\delta_H$ 7.87 and $\delta_C$ 199.4 (C-1). Furthermore, in the $^{13}$C-NMR spectrum of **3**, the C-6 signal was shifted downfield by 29.4 ppm, C-5 and C-7 signals were shifted upfield by 14.3 and 12.8 ppm than those of **1**. All these results confirmed the presence of a hydroxyl group at C-6. On acid hydrolysis, **3** afforded the D-glucose as a component sugar. The connectivity of the sugar was the same as that of **2** by the HMBC experiment. The absolute configuration of the chiral center at C-4 was determined to be *S* by CD spectral analysis of its aglycon, (4*S*)-4,6-dihydroxy-$\alpha$-tetralone (**3a**), which was obtained from enzymatic hydrolysis. Thus, the structure of juglanoside C (**3**) was elucidated to be (4*S*)-4,6-dihydroxy-$\alpha$-tetralone 4-*O*-$\beta$-D-glucopyranoside.

Juglanoside D (**4**) was isolated as an amorphous powder. The molecular formula was determined to be $C_{16}H_{20}O_9$ by HR-FAB-MS. Its $^1$H- and $^{13}$C-NMR spectra, coupled with the result from acid hydrolysis, suggested **4** is a 4-hydroxy-$\alpha$-tetralone 4-*O*-$\beta$-D-glucopyranoside. In the $^1$H-NMR spectrum, comparing to those of **3**, the proton signals due to an aromatic ring was changed from ABX type to AB type at $\delta$

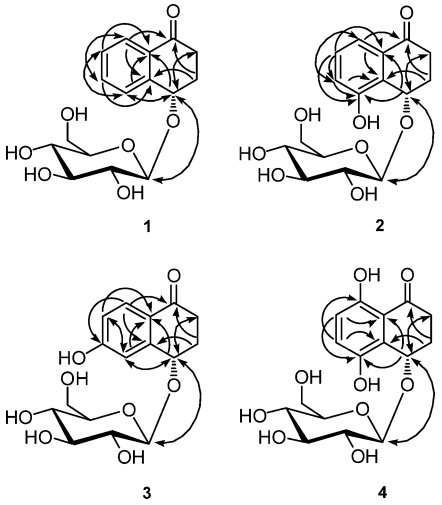



Fig. 1. Key HMBC Correlations of **1**—**4**

7.09 (1H, d, $J$=9.0 Hz) and 6.79 (1H, d, $J$=9.0 Hz). Further analysis of the HMBC correlations as shown in Fig. 1 suggested the aglycon of **4** is (4*S*)-4,5,8-trihydroxy-$\alpha$-tetralone (**4a**), which was confirmed by enzymatic hydrolysis and comparison of the NMR and CD spectral data and the $[\alpha]_D$ value with those of the reference.[6] Thus, the structure of juglanoside D (**4**) was determined to be (4*S*)-4,5,8-trihydroxy-$\alpha$-tetralone 4-*O*-$\beta$-D-glucopyranoside.

Juglanoside E (**5**) was isolated as an amorphous powder. Its molecular formula, $C_{16}H_{20}O_9$, which is the same as that of **4**, was determined by HR-FAB-MS. Enzymatic hydrolysis of **5** gave the same aglycon **4a** as that of **4**, and acid hydrolysis gave D-glucose as a component sugar. Comparison of the $^1$H- and $^{13}$C-NMR spectra of **5** with those of **4** suggested a different position of glycosylation between **5** and **4**. Namely, the chemical shift of H-6 of **5** at $\delta$ 7.51 was shifted downfield by 0.42 ppm, and C-4 at $\delta$ 61.4 was shifted upfield by 7.9 ppm than those of **4**, respectively, suggesting the $\beta$-D-glucopyranose is located at C-5. Thus, the structure of juglanoside E (**5**) was determined to be (4*S*)-4,5,8-trihydroxy-$\alpha$-tetralone 5-*O*-$\beta$-D-glucopyranoside.

## Experimental

**General Experimental Procedures** The UV spectra were obtained with a Shimadzu UV-160 spectrophotometer, whereas the IR spectra were measured with a JASCO FT/IR-300E (by a KBr disk method) spectrometer. Optical rotations were measured with a JASCO DIP-370 digital polarimeter in a 0.5-dm cell, while the CD spectra were recorded on a JASCO J-720W spectropolarimeter. The ESIMSs were taken on an LCQ mass analyzer. The HR-FAB-MS was taken on a JEOL Mstation spectrometer. The $^1$H- and $^{13}$C-NMR spectra were measured with a JEOL ECP-500 spectrometer with TMS as the internal reference, and chemical shifts are expressed in $\delta$ (ppm). For HPLC, a JASCO PU-2080 HPLC system, equipped with a Shodex RI-101 Differential Refractometer detector, was used. Reversed-phase column chromatography (CC) was accomplished with RP-$C_{18}$ silica gel (Chromatotex DM1020T ODS, Fuji silysia Chemical LTD.). Silica gel CC was carried out using Kieselgel 60 (E. Merck). TLC was conducted in Kieselgel 60 $F_{254}$ plates (E. Merck). GLC was carried out on a PerkinElmer Clarus 500 GC-MS instrument.

**Plant Material** The fresh rejuvenated fruit of *J. mandshurica* MAXIM. was collected in August 2002 at a mountain area of Wuchang, Heilongjiang Province, China. A voucher specimen (QLY 2002008) is preserved at the department of Chinese Traditional Medicine, Heilongjiang Provincial Institute for Drug Control.

**Extraction and Isolation** The fresh rejuvenated fruit of *J. mandshurica* (5 kg) was decocted twice with water (10 l) for 6 h. The aqueous layer was concentrated and the resulting precipitates were filtered off. The filtrate was extracted with the same volume of hexane, EtOAc and *n*-BuOH, successively. The *n*-BuOH extract (50 g) was loaded on a Diaion HP-20 column (60×11 cm) and the column was eluted with $H_2O$, 40% MeOH, 80% MeOH and MeOH. The 40% MeOH fraction was evaporated to dryness (4 g) and loaded on a reverse-phase column (36×2.5 cm, ODS) with 40% MeOH, 60% MeOH, 80% MeOH and MeOH. The 40% MeOH fraction was evaporated to dryness (3 g) and passed through a Lobar RP-C18 column (32×2 cm, 30% MeOH) to give four fractions A—D. The fraction B (246 mg) from Lobar RP-C18 column was loaded on a silica gel column (34×2 cm) and the column was eluted with $CHCl_3$–MeOH (84 : 16). The major fraction 6 (348 mg) from the column was further purified on preparative HPLC (20×150 mm, Senshupak pegasil ODS) with 25% MeOH, affording **3** (5 mg) and **4** (2 mg). Fraction C (530 mg) from Lobar RP-$C_{18}$ column was loaded on a silica gel column (30×2 cm) and the column was eluted with $CHCl_3$–MeOH (88 : 12). The major fraction 6 (348 mg) from the column was chromatographed on preparative HPLC with 25% MeOH and the subfractions 5, 7 and 8 were further purified on preparative HPLC with 15% MeCN, affording **5** (52 mg), **2** (54 mg) and **1** (13 mg).

Juglanoside A (**1**): Amorphous powder, $[\alpha]_D^{25}$ −77° ($c$=0.9, MeOH). UV (MeOH) $\lambda_{max}$ (log $\varepsilon$): 247.2 (4.1), 284.8 (3.3). IR (KBr) $\nu_{max}$: 3415, 1729, 1589, 1386, 1074, 649. CD ($c$=2.99×10$^{-5}$, MeOH, 25 °C): $[\theta]_{246}$ −7912.2, $[\theta]_{290}$ −6023.3. $^1$H-NMR ($CD_3OD$, 500 MHz): see Table 1. $^{13}$C-NMR ($CD_3OD$, 125 MHz): see Table 2. ESI-MS (positive) $m/z$ 347.1 $[M+Na]^+$; HR-FAB-MS (positive) $m/z$ 347.1101 $[M+Na]^+$ (Calcd for $C_{16}H_{20}O_7Na$ 347.1107).

Juglanoside B (**2**): Amorphous powder, $[\alpha]_D^{25}$ −13° ($c$=0.5, MeOH). UV (MeOH) $\lambda_{max}$ (log $\varepsilon$): 220.6 (4.3), 256.4 (3.9), 316.8 (3.5). IR (KBr) $\nu_{max}$: 3415, 1730, 1595, 1382, 1284, 1076, 661. CD ($c$=2.35×10$^{-5}$, MeOH, 25 °C): $[\theta]_{232}$ −6017.3. $^1$H-NMR ($CD_3OD$, 500 MHz): see Table 1. $^{13}$C-NMR ($CD_3OD$, 125 MHz): see Table 2. ESI-MS (positive) $m/z$ 363.1 $[M+Na]^+$ HR-FAB-MS (positive) $m/z$ 363.1050 $[M+Na]^+$ (Calcd for $C_{16}H_{20}O_8Na$ 363.1056).

Juglanoside C (**3**): Amorphous powder, $[\alpha]_D^{25}$ −36° ($c$=0.4, MeOH). UV (MeOH) $\lambda_{max}$ (log $\varepsilon$): 224.4 (4.1), 281.4 (4.0). IR (KBr) $\nu_{max}$: 3421, 1730, 1589, 1468, 1380, 1279, 1078, 650. CD ($c$=3.44×10$^{-5}$, MeOH, 25 °C): $[\theta]_{295}$ −1107.0. $^1$H-NMR ($CD_3OD$, 500 MHz): see Table 1. $^{13}$C-NMR ($CD_3OD$, 125 MHz): see Table 2. ESI-MS (positive) $m/z$ 363.1 $[M+Na]^+$; HR-FAB-MS (positive) $m/z$ 363.1050 $[M+Na]^+$ (Calcd for $C_{16}H_{20}O_8Na$ 363.1056).

Juglanoside D (**4**): Amorphous powder, $[\alpha]_D^{25}$ −45° ($c$=0.2, MeOH). UV (MeOH) $\lambda_{max}$ (log $\varepsilon$): 231.8 (4.1), 261.8 (3.8), 368.2 (3.6). IR (KBr) $\nu_{max}$: 3423, 1728, 1589, 1467, 1381, 1038, 613. CD ($c$=3.34×10$^{-5}$, MeOH, 25 °C): $[\theta]_{264}$ −7745.5. $^1$H-NMR ($CD_3OD$, 500 MHz): see Table 1. $^{13}$C-NMR ($CD_3OD$, 125 MHz): see Table 2. ESI-MS (positive) $m/z$ 379.1 $[M+Na]^+$; HR-FAB-MS (positive) $m/z$ 379.0997 $[M+Na]^+$ (Calcd for $C_{16}H_{20}O_9Na$ 379.1005).

Juglanoside E (**5**): Amorphous powder, $[\alpha]_D^{25}$ −65° ($c$=1.1, MeOH). UV (MeOH) $\lambda_{max}$ (log $\varepsilon$): 224.8 (4.4), 259.2 (4.1), 349.6 (3.8). IR (KBr) $\nu_{max}$: 3413, 1728, 1597, 1468, 1385, 1264, 1074, 648. CD ($c$=1.85×10$^{-5}$, MeOH, 25 °C): $[\theta]_{260}$ −5492.2. $^1$H-NMR ($CD_3OD$, 500 MHz): see Table 1. $^{13}$C-NMR ($CD_3OD$, 125 MHz): see Table 2. ESI-MS (positive) $m/z$ 379.1 $[M+Na]^+$; HR-FAB-MS (positive) $m/z$ 379.1002 $[M+Na]^+$ (Calcd for $C_{16}H_{20}O_9Na$ 379.1005).

**Acid Hydrolysis and Determination of the Absolute Configuration of Sugars in 1—5** Each solution of **1**—**5** (each 1 mg), in 1 M HCl (dioxane–$H_2O$, 1 : 1, 200 $\mu$l) was heated at 100 °C for 1 h under an Ar atmosphere. After dioxane was removed, the solution was extracted with EtOAc (1 ml×3) to remove the aglycon. The aqueous layer was neutralized by passing through an ion-exchange resin (Amberlite MB-3, Organo, Tokyo, Japan) column, concentrated under reduced pressure to dryness, to give a residue of the sugar fraction. The residue was dissolved in pyridine (1 ml), to which 0.1 M L-cysteine methyl ester hydrochloride in pyridine (2 ml) was added. The mixture was kept at 60 °C for 1.5 h. After the reaction mixture was dried *in vacuo*, the residue was trimethylsilylated with 1-trimethylsilylimidazole (0.2 ml) for 2 h. The mixture was partitioned between hexane and $H_2O$ (0.3 ml each) and the hexane extract was analyzed by gas-liquid chromatography (GLC) under following conditions: capillary column, EQUITY$^{TM}$-1 (30 m×0.25 mm×0.25 $\mu$m, Supelco), column temperature, 230 °C; injection temperature, 250 °C; carrier $N_2$ gas. In the acid hydrolysate of **1**—**5**, D-glucose was confirmed by comparison of the retention times of their derivatives with those of D-glucose and L-glucose derivatives prepared in a similar way, which showed retention times of 11.79 and 11.33 min, respectively.

**Enzymatic Hydrolysis of 1—5** A solution of **1**—**5** (2—5 mg) in 0.1 M

acetate buffer (pH 4.0, 1.0 ml) was treated with naringinase (Sigma Chemical Co., 3 mg) and then the reaction mixture was stirred at 40 °C for 12 h. The reaction mixture was passed through a Sep-Pak $C_{18}$ cartridge using $H_2O$ and MeOH. The MeOH elute was further purified by preparative TLC [$CHCl_3$–MeOH (88 : 12)] to give the aglycones **1a**—**4a** in 50—60% yields.

(4*S*)-4-Hydroxy-$\alpha$-tetralone (**1a**): Yellow amorphous powder, $[\alpha]_D^{25}$ +21° ($c$=0.3, $CHCl_3$). CD ($c$=1.70×10$^{-4}$, MeOH, 25 °C): $[\theta]_{290}$ −2291.7, $[\theta]_{244}$ −2686.9. $^1$H-NMR ($CDCl_3$, 500 MHz) $\delta$: 2.13 (1H, m, H-3), 2.35 (1H, m, H-3), 2.55 (1H, ddd, $J$=17.8, 9.6, 4.8 Hz, H-2), 2.88 (1H, ddd, $J$=17.8, 7.5, 4.6 Hz, H-2), 4.93 (1H, dd, $J$=8.1, 3.9 Hz, H-4), 7.35 (1H, m, H-7), 7.54 (2H, m, H-5 and H-6), 7.97 (1H, br d, $J$=7.8 Hz, H-8). ESI-MS (positive) $m/z$ 185.1 $[M+Na]^+$.

(4*S*)-4,5-Dihydroxy-$\alpha$-tetralone (**2a**): Yellow amorphous powder, $[\alpha]_D^{25}$ +35° ($c$=0.2, $CHCl_3$). CD ($c$=1.32×10$^{-4}$, MeOH, 25 °C): $[\theta]_{234}$ −1440.6. $^1$H-NMR ($CDCl_3$, 500 MHz) $\delta$: 2.21 (1H, m, H-3), 2.52 (1H, m, H-3), 2.58 (1H, ddd, $J$=17.5, 13.6, 4.6 Hz, H-2), 2.83 (1H, dt, $J$=17.5, 4.6 Hz, H-2), 5.35 (1H, dd, $J$=10.0, 4.8 Hz, H-4), 7.11 (1H, br d, $J$=7.9 Hz, H-6), 7.31 (1H, t, $J$=7.9 Hz, H-7), 7.60 (1H, br d, $J$=7.9 Hz, H-8). ESI-MS (positive) $m/z$ 201.1 $[M+Na]^+$.

(4*S*)-4,6-Dihydroxy-$\alpha$-tetralone (**3a**): Yellow amorphous powder, $[\alpha]_D^{25}$ +19° ($c$=0.1, $CHCl_3$). CD ($c$=6.01×10$^{-5}$, MeOH, 25 °C): $[\theta]_{294}$ −6143.3. $^1$H-NMR ($CDCl_3$, 500 MHz) $\delta$: 2.06 (1H, m, H-3), 2.30 (1H, m, H-3), 2.49 (1H, ddd, $J$=17.3, 10.5, 4.8 Hz, H-2), 2.78 (1H, ddd, $J$=17.3, 6.4, 4.4 Hz, H-2), 4.82 (1H, dd, $J$=8.7, 4.1 Hz, H-4), 6.93 (1H, d, $J$=2.6 Hz, H-5), 6.76 (1H, dd, $J$=8.5, 2.6 Hz, H-7), 7.88 (1H, d, $J$=8.5 Hz, H-8). $^{13}$C-NMR ($CDCl_3$, 125 MHz) $\delta$: 31.4 (C-3), 34.2 (C-2), 67.1 (C-4), 111.6 (C-5), 114.7 (C-7), 123.4 (C-9), 129.1 (C-8), 147.3 (C-10), 160.6 (C-6), 195.1 (C-1). ESI-MS (positive) $m/z$ 201.1 $[M+Na]^+$.

(4*S*)-4,5,8-Trihydroxy-$\alpha$-tetralone (**4a**): Yellow amorphous powder, $[\alpha]_D^{25}$ +12° ($c$=0.3, EtOH). CD ($c$=7.68×10$^{-5}$, MeOH, 25 °C): $[\theta]_{266}$ −2418.8. $^1$H-NMR ($CDCl_3$, 500 MHz) $\delta$: 2.24 (2H, m, $H_2$-3), 2.58 (1H, dt, $J$=17.0, 5.0 Hz, H-2), 3.01 (1H, ddd, $J$=17.0, 9.1, 6.0 Hz, H-2), 5.27 (1H, t, $J$=4.4 Hz, H-6), 6.77 (1H, d, $J$=9.0 Hz, H-7), 7.07 (1H, d, $J$=9.0 Hz, H-6). ESI-MS (positive) $m/z$ 217.1 $[M+Na]^+$.

**Benzoylation of 1a—4a** Benzoyl chloride (100 $\mu$l) was added to a solution of **1a**—**4a** (1 mg) in pyridine (100 $\mu$l) and the reaction mixture was kept overnight at room temperature. The mixture was evaporated to give a residue, which was purified by preparative TLC on silica gel with hexane–acetone (3 : 1) to give **2b** (0.63 mg) and **3b** (0.71 mg), **1b** and **4b** fraction was then further purified by HPLC, eluated with 50% MeCN and 80% MeOH, respectively, to give **1b** (0.49 mg) and **4b** (0.63 mg).

(4*S*)-4-Benzoyloxy-$\alpha$-tetralone (**1b**): Amorphous powder, $[\alpha]_D^{25}$ −38° ($c$=0.05, $CHCl_3$). CD ($c$=1.84×10$^{-5}$, MeOH, 25 °C): $[\theta]_{290}$ −8872.81, $[\theta]_{244}$ −30435.3. $^1$H-NMR ($CDCl_3$, 500 MHz) $\delta$: 2.47 (1H, m, H-3), 2.54 (1H, m, H-3), 2.75 (1H, ddd, $J$=17.4, 7.3, 4.6 Hz, H-2), 3.03 (1H, ddd, $J$=17.4, 9.4, 4.8 Hz, H-2), 6.40 (1H, dd, $J$=6.5, 3.7 Hz, H-4), 7.43—7.61 (6H, m), 8.05—8.11 (3H, m).

(4*S*)-4,5-Dibenzoyloxy-$\alpha$-tetralone (**2b**): Amorphous powder, $[\alpha]_D^{25}$ +50° ($c$=0.06, $CHCl_3$). CD ($c$=1.65×10$^{-5}$, MeOH, 25 °C): $[\theta]_{282}$ −6208.85, $[\theta]_{240}$ 46515. $^1$H-NMR ($CDCl_3$, 500 MHz) $\delta$: 2.47 (1H, m, H-3), 2.55 (1H, m, H-3), 2.71 (1H, dt, $J$=17.4, 4.0 Hz, H-2), 3.00 (1H, ddd, $J$=17.4, 13.3, 4.9 Hz, H-2), 6.60 (1H, t, $J$=3.3 Hz, H-4), 7.34—7.40 (4H, m), 7.50—7.58 (3H, m), 7.61 (1H, t, $J$=7.9 Hz, H-7), 7.84 (2H, dd, $J$=8.4, 1.2 Hz), 7.98 (2H, dd, $J$=8.4, 1.2 Hz), 8.08 (1H, dd, $J$=7.9, 1.4 Hz, H-8).

(4*S*)-4,6-Dibenzoyloxy-$\alpha$-tetralone (**3b**): Amorphous powder, $[\alpha]_D^{25}$ +58° ($c$=0.07, $CHCl_3$). CD ($c$=1.86×10$^{-5}$, MeOH, 25 °C): $[\theta]_{290}$ −6990.67, $[\theta]_{238}$ 22194.1. $^1$H-NMR ($CDCl_3$, 500 MHz) $\delta$: 2.46 (1H, m, H-3), 2.58 (1H, m, H-3), 2.79 (1H, ddd, $J$=17.6, 7.9, 4.8 Hz, H-2), 3.04 (1H, ddd, $J$=17.4, 9.0, 4.8 Hz, H-2), 6.40 (1H, dd, $J$=7.0, 3.8 Hz, H-4), 7.36 (1H, dd, $J$=8.6, 2.4 Hz, H-7), 7.43 (1H, d, $J$=2.4 Hz, H-5), 7.45 (2H, tt, $J$=7.7, 1.6 Hz), 7.51 (2H, tt, $J$=7.7, 1.6 Hz), 7.58 (1H, tt, $J$=7.7, 1.6 Hz), 7.65 (1H, tt, $J$=7.7, 1.6 Hz), 8.07 (2H, dd, $J$=7.7, 1.6 Hz), 8.19 (2H, dd, $J$=7.7, 1.6 Hz).

(4*S*)-4,5,8-Tribenzoyloxy-$\alpha$-tetralone (**4b**): Amorphous powder, $[\alpha]_D^{25}$ −25° ($c$=0.1, $CHCl_3$). CD ($c$=1.25×10$^{-5}$, MeOH, 25 °C): $[\theta]_{283}$ −14801.0, $[\theta]_{254}$ −10175.6. $^1$H-NMR ($CDCl_3$, 500 MHz) $\delta$: 2.49 (2H, m, $H_2$-3), 2.61 (1H, dt, $J$=17.0, 3.3 Hz, H-2), 2.98 (1H, ddd, $J$=17.0, 13.4, 5.7 Hz, H-2), 6.61 (1H, t, $J$=3.3 Hz, H-4), 7.34—7.41 (5H, m), 7.51—7.61 (5H, m), 7.66 (1H, tt, $J$=7.5, 1.3 Hz), 7.85 (2H, dd, $J$=8.2, 1.3 Hz), 7.99 (2H, dd, $J$=8.2, 1.3 Hz), 8.25 (2H, dd, $J$=8.2, 1.1 Hz).

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