Indonesian Medicinal Plants. XI.[1] Chemical Structures of Caesaldekarins a and b, Two New Cassane-Type Furanoditerpenes from the Roots of *Caesalpinia major* (Fabaceae)

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Five new cassane-type furanoditerpenes named caesaldekarins a (1), b (2), c, d, and e were isolated from the roots of *Caesalpinia major* (Fabaceae), an Indonesian medicinal plant. The chemical structures of 1 and 2 have been elucidated on the bases of physicochemical evidence and chemical derivations. The major diterpenoid caesaldekarin a (1) was shown to inhibit mitogen responses of mouse spleen cells and interleukin-1 production.

Keywords Indonesian medicinal plant; *Caesalpinia major*; Fabaceae; cassane diterpene; furanoditerpene; caesaldekarin

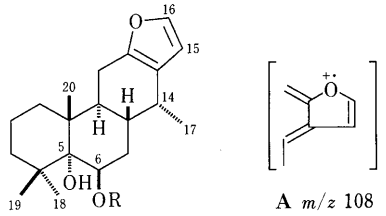
Caesalpinia major DANDY (Fabaceae) is a medium-sized tree (5—15 m) growing in forests and forest borders at 50—1000 m altitude in Indonesia. It is called "dekar" in the Ruteng area of Flores Island,[2] and the decoction of the roots has been traditionally used as a tonic and an anthelmintic, and also for treatment of rheumatism and back-ache.[3] During our second scientific expedition to investigate Indonesian medicinal plants in 1988,[3] the roots were collected and subjected to pharmacochemical investigation. Through bioactivity-directed fractionation and separation of the extract of the roots, we have isolated five new cassane-type furanoditerpenes designated caesaldekarins a (**1**), b (**2**), c, d, and e. In this paper, we present a full account of the structure elucidation of caesaldekarins a (**1**) and b (**2**).[4]

The methanol extract of the roots was partitioned into an ethyl acetate and water mixture to provide the ethyl acetate-soluble portion (6.6% yield from the root). In a preliminary examination, the ethyl acetate-soluble portion was found to contain a constituent(s) that inhibits the production of interleukin-1.[5] Thus, the ethyl acetate-soluble portion was subjected to silica gel column chromatography and high-performance liquid chromatography (HPLC) to isolate caesaldekarins a (**1**, 0.86% from the roots, the principal constituent), b (**2**, 0.05%), c (0.06%), d (0.01%), and e (0.06%).

Caesaldekarin a (1) Caesaldekarin a (**1**), obtained as colorless needles, colored reddish purple with the Ehrlich reagent. The mass spectrum (MS) showed a molecular ion peak at *m/z* 360, the composition $C_{22}H_{32}O_4$ being determined by high-resolution MS, as well as the base peak at *m/z* 108 which was characteristically assigned to an ion **A** derivable from a furanoterpenoid.[6] The infrared (IR) spectrum of **1** showed absorption bands ascribable to a hydroxyl group (3600 cm^{-1}), an acetoxyl group (1728 cm^{-1}), and a furan ring (1510, 860 cm^{-1}). Furthermore, the ultraviolet (UV) spectrum of **1** showed a maximum at 219 nm (ε=7500) which suggested the presence of a furan ring in **1**.

The proton nuclear magnetic resonance (^{1}H-NMR) spectrum of caesaldekarin a (**1**) showed the presence of three *tertiary* methyl groups [δ 1.00, 1.25, 1.35 (all s)], one *secondary* methyl group [δ 0.99 (d, J=7.0 Hz)], one acetoxyl group [δ 2.07 (s)], and adjacent α and β protons [δ 7.23 (d, J=1.8 Hz), δ 6.19 (d, J=1.8 Hz)] on a furan ring. One methine proton geminal to the acetoxyl group was observed as a triplet (J=3.0 Hz) at δ 5.23, which suggested this proton to be equatorial. Furthermore, the coupling pattern of another methine proton signal observed at δ 2.58 (dq, J=6.7, 7.0 Hz) was changed to a doublet (J=6.7 Hz) upon irradiation of the signal (δ 0.99) of the *secondary* methyl group.

The carbon-13 nuclear magnetic resonance (^{13}C-NMR) spectrum of caesaldekarin a (**1**) showed the presence of one *quaternary* carbon [δ_C 76.2 (s)] and one *secondary* carbon [δ_C 72.3 (d)], both bearing a hydroxyl group. Finally, ^{1}H–^{1}H and ^{1}H–^{13}C correlation spectroscopy (COSY) together with an incredible natural abundance



caesaldekarin a (1) : R=Ac
caesaldekarin b (2) : R=H

A *m/z* 108

Fig. 1

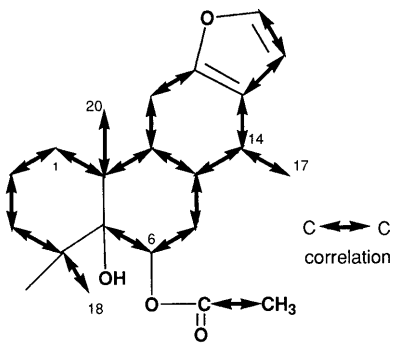


Fig. 2. INADEQUATE for Caesaldekarin a (**1**)

double quantum transfer (INADEQUATE) experiment and correlation spectroscopy *via* long-range coupling (COLOC), led us to the cassane skeleton[7] of caesaldekarin a (**1**) (Figs. 2, 3).

In order to elucidate the stereochemical connectivities of the A/B and B/C rings in caesaldekarin a (**1**), we next carried out a nuclear Overhauser enhancement and exchange spectroscopy (NOESY) experiment in the ^{1}H-NMR. Correlations were observed between the 10-methyl protons and 6β-acetoxyl protons and 11β-proton, between the 11β-proton and 8β-proton, between the 4β-methyl protons and 6β-acetoxyl protons, between the 4α-methyl protons and 6α-proton, and also between the 14α-methyl protons and 7α- and 14β-protons (Fig. 4). These findings demonstrate that the junctions of the A/B and B/C rings in **1** are *trans-anti-trans*.

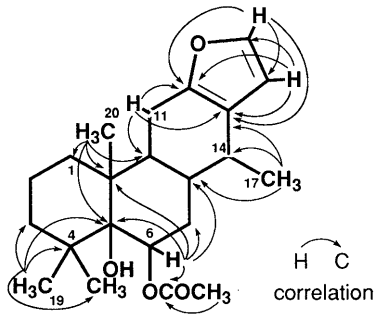


Fig. 3. COLOC for Caesaldekarin a (**1**)

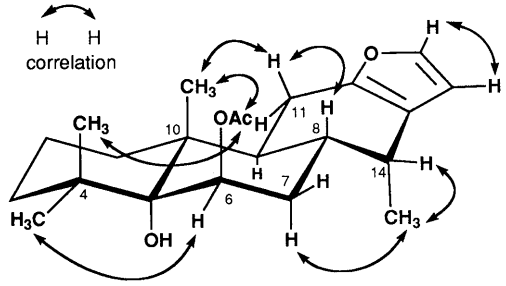


Fig. 4. NOESY for Caesaldekarin a (**1**)

Finally, in order to confirm the above-proposed structure of caesaldekarin a (**1**), we attempted to prepare a heavy atom derivative suitable for X-ray crystallographic analysis. After several attempts, we found that treatment of **1** with *N*-bromosuccinimide (NBS) in chloroform at $-40\,^\circ$C afforded two products, a fairly unstable unidentified compound **3** (40% yield)[8] and a dimeric derivative **4** (15% yield).

The minor bisfuranoditerpene derivative **4** was obtained as colorless needles and gave a molecular ion peak at *m/z* 718 ($C_{44}H_{62}O_8$) in the MS spectrum. In the ^{1}H-NMR spectrum of **4**, no signal due to an α-proton on the furan ring of **1** was observed. The dimeric compound **4** was subjected to X-ray crystallographic analysis to determine the structure, and perspective drawings are shown in Fig. 5. Consequently, the structure of caesaldekarin a (**1**) has been substantiated.

Caesaldekarin b (2) Caesaldekarin b (**2**), obtained as colorless needles, colored reddish purple with the Ehrlich reagent. It gave a molecular ion peak at *m/z* 318 of the composition $C_{20}H_{30}O_3$, together with a base peak ion at *m/z* 108 (**A**) in the MS. The IR spectrum of **2** showed absorption bands due to a hydroxyl group (3600 cm^{-1}) and a furan ring (1460, 870 cm^{-1}), while the UV spectrum

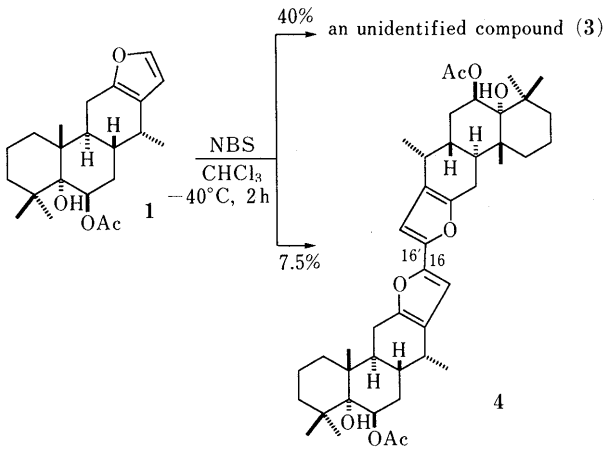


Chart 1

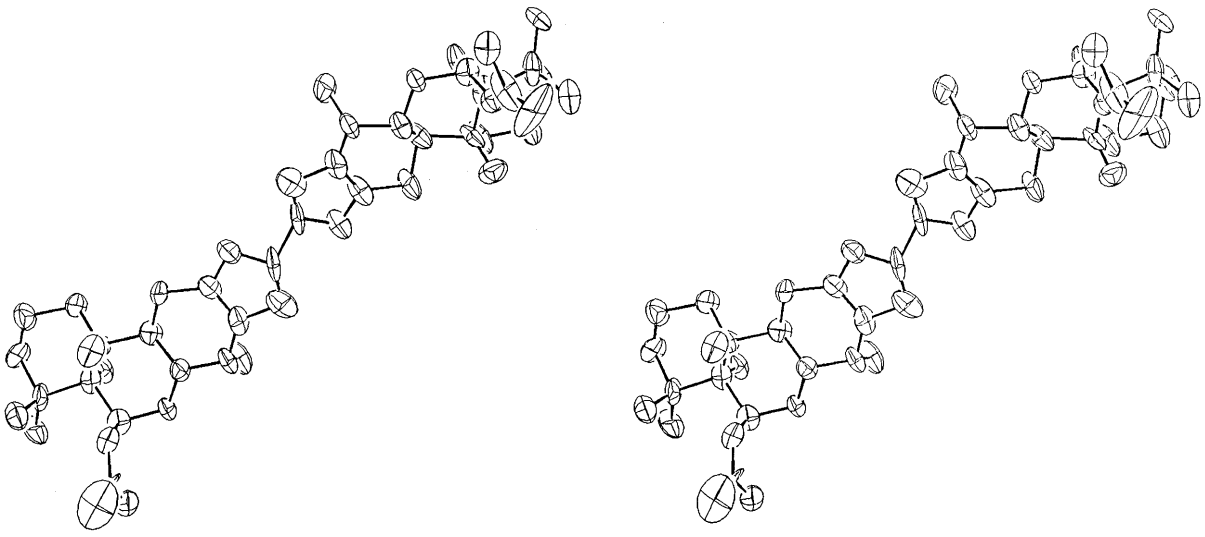


Fig. 5. Perspective Drawings of **4**

showed a maximum at 220 nm ($\varepsilon = 6500$) attributable to a furan ring. ^{1}H- and ^{13}C-NMR spectral analyses, including COSY and COLOC experiments, led us to presume that caesaldekarin b (**2**) is a deacetyl derivative of caesaldekarin a (**1**).

In order to corroborate this, we next attempted deacetylation of caesaldekarin a (**1**). Due to its β-axial configuration, the acetoxyl moiety resisted ordinary deacetylation. Finally, it was found that treatment of **1** with 20% KOH in methanol at 40 °C effected the deacetylation to provide caesaldekarin b (**2**, 70%), together with a 5,6-epoxide **5** (20%) which was presumably formed by the attack of the 5α-oxygen function from the α-side of the 6β-acetoxyl moiety. Conversely, caesaldekarin a (**1**) was recovered by acetylation of **2** with acetic anhydride in pyridine containing 4-dimethylaminopyridine (DMAP). Consequently, the structure of caesaldekarin b (**2**) was concluded to be as shown.

In order to determine the absolute configurations of caesaldekarins a (**1**) and b (**2**), we conducted the following chemical derivation starting from caesaldekarin b (**2**) to synthesize a triol (**8**) suitable for applying the advanced Mosher's method.

Oxidation of **2** with *m*-chloroperbenzoic acid (*m*-CPBA) furnished an aldehydic derivative **6** in 77% yield. The aldehyde **6** was then transformed into a silylated ketone **7** in 40% yield, by reduction with sodium borohydride (1.1 eq) and subsequent treatment with *tertiary*-butyldimethylsilyl chloride (TBDMSCl) and imidazole. Reduction of **7** again with sodium borohydride at -10 °C in the presence of cerous chloride gave the triol **8** in 55% yield. The ^{1}H-NMR spectrum of the triol **8** exhibited the signal attributable to the 12α-proton at δ 4.38 (dd, $J = 4.5$, 11.5 Hz), which was spatially correlated with the 14α-methyl protons (δ 0.99) and 9α-proton (δ 2.05) in nuclear Overhauser effect (NOE) experiments. These findings indicate β-equatorial configuration of the 12-hydroxyl group of **8**. Furthermore, the correlation between the signals of the 15-proton (δ 5.45) and 14β-proton (δ 2.25), observed in the NOE experiments on **8**, have substantiated the geometry of the double bond at C-13, 15. Consequently, the structure of the triol **8** has been confirmed to be as shown.

The triol **8** was then treated with (+)-α-methoxy-α-(trifluoromethyl)phenylacetic acid (MTPA) [or (−)-MTPA] and 1,3-dicyclohexylcarbodiimide (DCC) in

Table I. Comparisons of the ^{1}H-NMR Data for **9a** and **9b** (at 270 MHz in $CDCl_3$)

Proton(s)	**9a** δ(+)-MTPA	**9b** δ(−)-MTPA	Δ_δ[a]
6	4.11 (br s)	4.12 (t-like, $J=3$)	+0.01
7	1.26 (m)	1.22 (m)	−0.04
	2.07 (m)	2.06 (m)	−0.01
8	1.97 (m)	1.93 (m)	−0.04
9	1.67 (m)	1.74 (m)	+0.07
11	1.13 (m)	1.34 (m)	+0.21
	1.97 (m)	1.99 (m)	+0.02
12	5.64 (dd, $J=4$, 11)	5.64 (dd, $J=3.5$, 11)	0
14	2.36 (dq, $J=5$, 7)	2.33 (dq, $J=5$, 7)	−0.03
15	5.26 (t, $J=4.5$)	5.17 (t, $J=4.5$)	−0.09
16	4.15 (dd, $J=4.5$, 7.5)	3.56 (dd, $J=5.5$, 7)	−0.59
	4.23 (dd, $J=4.5$, 7.5)	4.20 (dd, $J=5.5$, 7)	−0.03
17	1.03 (d, $J=7$)	1.00 (d, $J=7$)	−0.03
18	0.99 (s)	0.99 (s)	0
19	1.42 (s)	1.43 (s)	+0.01
20	1.22 (s)	1.27 (s)	+0.05
Si–CH_3	−0.05 (s)	−0.05 (s)	0
Si–$C(CH_3)_3$	0.84 (s)	0.84 (s)	0

a) $\Delta_\delta = \delta$(−)-MTPA−δ(+)-MTPA.

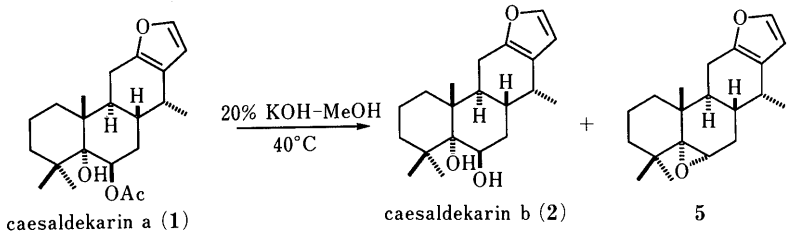


Chart 2

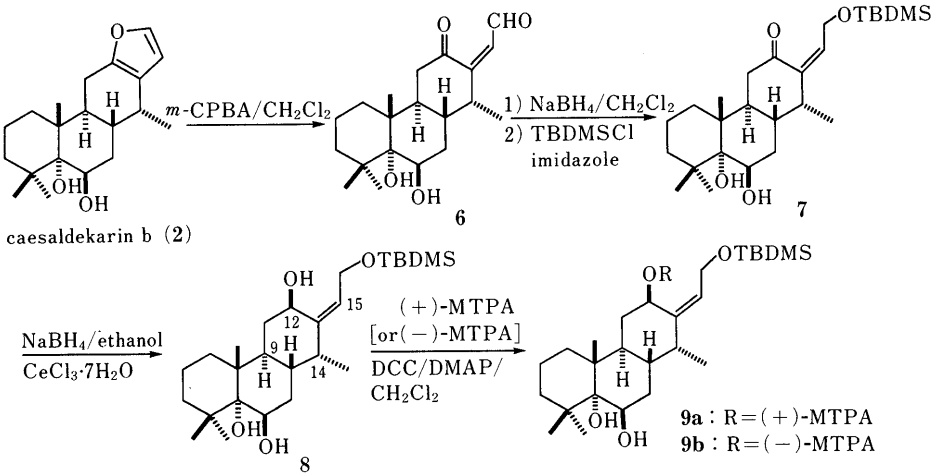


Chart 3

DMAP to prepare the corresponding (+)-MTPA ester (**9a**) or (−)-MTPA ester (**9b**). Detailed comparisons of the chemical shifts in the ^{1}H-NMR spectra of **9a** and **9b** and resulting $\Delta\delta$ values (Table I)[9] established that the absolute configuration at C-12 of **8** is *R*. Thus, the absolute stereostructures of caesaldekarins a (**1**) and b (**2**) have been determined to be as shown.

Among the five furanoditerpenoids isolated from the roots, the principal constituent, caesaldekarin a (**1**), showed an inhibitory effect on mitogen responses of spleen cell from BALB/C mice (IC_{50} 10 μg/ml) and caused 80% inhibition of interleukin-1 production at 10 μg/ml concentration.[5]

The structure elucidation of caesaldekarins c, d, and e will be reported in a forthcoming paper.

Experimental

The instruments used to obtain physical data and the experimental conditions for chromatography were the same as in our previous paper.[1c]

Plant Materials The roots of *Caesalpinia major* (Fabaceae) were collected in the Ruteng area of Flores Island, Province Nusa Tenggara Timur, Indonesia, in August 1988. The plant was identified at Herbarium Bogoriense, Research and Development Centre for Biology-LIPI, Indonesia. Voucher specimens have been deposited at the Herbarium Bogoriense and the Faculty of Pharmaceutical Sciences, Osaka University.

Isolation of Caesaldekarins Dried roots (cut, 2.5 kg) of *Caesalpinia major* (Fabaceae) were extracted with MeOH under reflux and the solvent was evaporated off under reduced pressure to give the MeOH extract (250 g). The MeOH extract (150 g) was partitioned into a 1 : 1 mixture of EtOAc and H_2O. The EtOAc phase was taken and concentrated under reduced pressure to afford the EtOAc extract (100 g), while the water phase was concentrated under reduced pressure to afford the water extract (46 g). The EtOAc extract (50 g) was subjected to column chromatography (SiO_2 4 kg, *n*-hexane : EtOAc = 10 : 1 → 1 : 1) to afford caesaldekarin a (**1**, 6.43 g, 0.86% from the roots), caesaldekarin b (**2**, 373 mg, 0.05%), caesaldekarin d (81 mg, 0.01%), caesaldekarin e (460 mg, 0.06%), and a fraction (598 mg) containing caesaldekarin c, which was purified by HPLC (Zorbax SIL, *n*-hexane : EtOAc = 10 : 1) to afford caesaldekarin c (450 mg, 0.06%).

Caesaldekarin a (**1**): Colorless needles, mp 152—153 °C (*n*-hexane–EtOAc), $[\alpha]_D$ −5.4° (*c* = 1.91 in $CHCl_3$, at 20 °C). IR ν_{max}^{KBr} cm^{-1}: 3600, 1728, 1510, 1240, 860. UV λ_{max}^{EtOH} nm (ε): 219 (7500). ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 0.99 (3H, d, *J* = 7.0 Hz, 17-H_3), 1.00 (3H, s, 18-H_3), 1.15 (1H, m, 3-H_a), 1.25 (3H, s, 19-H_3), 1.35 (3H, s, 20-H_3), 1.45 (1H, m, 1-H_a), 1.50 (2H, m, 2-H_a, 7β-H), 1.55 (1H, m, 1-H_b), 1.70 (2H, m, 2-H_b, 3-H_b), 2.01 (1H, m, 8-H), 2.07 (3H, s, OAc), 2.21 (1H, ddd, *J* = 3.0, 13.0, 13.0 Hz, 7α-H), 2.35 (1H, m, 9-H), 2.44 (1H, dd, *J* = 10.0, 17.0 Hz, 11β-H), 2.51 (1H, dd, *J* = 8.0, 17.0 Hz, 11α-H), 2.58 (1H, dq, *J* = 6.7, 7.0 Hz, 14-H), 5.23 (1H, t, *J* = 3.0 Hz, 6-H), 6.19 (1H, d, *J* = 1.8 Hz, 15-H), 7.23 (1H, d, *J* = 1.8 Hz, 16-H). ^{13}C-NMR (125 MHz, $CDCl_3$) δ_C: 16.5 (q, 20-C), 17.6 (q, 17-C), 18.2 (t, 2-C), 21.7 (t, 11-C), 21.8 (q, $-OCO\underline{C}H_3$), 25.7 (q, 19-C), 27.6 (q, 18-C), 30.4 (d, 8-C), 31.1 (d, 14-C), 31.4 (t, 7-C), 34.6 (t, 1-C), 37.9 (d, 9-C), 38.1 (t, 3-C), 38.9 (s, 4-C), 41.4 (s, 10-C), 72.3 (d, 6-C), 76.2 (s, 5-C), 109.4 (d, 15-C), 122.3 (s, 13-C), 140.3 (d, 16-C), 149.5 (s, 12-C), 169.8 (s, $-O\underline{C}OCH_3$). MS *m/z* (%): 360 (M^+, 29), 108 (100). High-resolution MS *m/z*: Calcd for $C_{22}H_{32}O_4$: 360.2329. Found: 360.2299. *Anal.* Calcd for $C_{22}H_{32}O_4$: C, 73.30; H, 8.95. Found: C, 73.14; H, 8.80.

Caesaldekarin b (**2**): Colorless needles, mp 160—161 °C (*n*-hexane–EtOAc), $[\alpha]_D$ +4.1° (*c* = 0.35 in $CHCl_3$, at 20 °C). IR ν_{max}^{KBr}cm^{-1}: 3600, 1460, 870. UV λ_{max}^{EtOH} nm (ε): 220 (6500). ^{1}H-NMR (270 MHz, $CDCl_3$) δ: 1.00 (3H, d, *J* = 7.0 Hz, 17-H_3), 1.03 (3H, s, 18-H_3), 1.12 (1H, m, 3-H_a), 1.35 (1H, m, 2-H_a), 1.36 (3H, s, 20-H_3), 1.39 (2H, m, 1-H_2), 1.41 (1H, m, 7-H_a), 1.47 (3H, s, 19-H_3), 1.59 (1H, m, 2-H_b), 1.77 (1H, m, 3-H_b), 2.14 (1H, m, 8-H), 2.27 (1H, m, 7-H_b), 2.33 (1H, m, 9-H), 2.43 (2H, m, 11-H_2), 2.59 (1H, dq, *J* = 5.6, 7.0 Hz, 14-H), 4.17 (1H, br s, 6-H), 6.19 (1H, d, *J* = 2.0 Hz, 15-H), 7.23 (1H, d, *J* = 2.0 Hz, 16-H). ^{13}C-NMR (67.5 MHz, $CDCl_3$) δ_C: 16.7 (q, 20-C), 17.7 (q, 17-C), 18.1 (t, 2-C), 21.8 (t, 11-C), 26.1 (q, 19-C), 27.8 (q, 18-C), 29.9 (d, 8-C), 31.3 (d, 14-C), 35.1 (t, 1-C), 35.4 (t, 7-C), 38.1 (t, 3-C), 38.2 (d, 9-C), 39.0 (s, 4-C), 40.9 (s, 10-C), 71.7 (d, 6-C), 76.5 (s, 5-C), 109.5 (d, 15-C), 122.4 (s, 13-C), 140.3 (d, 16-C), 149.7 (s, 12-C). MS *m/z* (%): 318 (M^+, 73), 108 (100). High-resolution MS *m/z*: Calcd for $C_{20}H_{30}O_3$: 318.2195. Found: 318.2205 (M^+).

Treatment of Caesaldekarin a (1) with NBS A solution of **1** (100 mg, 0.28 mmol) in $CHCl_3$ (5.0 ml) was treated with NBS (49 mg) and the mixture was stirred at −40 °C for 2 h. It was poured into water and the whole was extracted with $CHCl_3$. The $CHCl_3$ extract was washed with water and brine, then dried over $MgSO_4$. The solvent was removed under reduced pressure to give a product, which was purified by column chromatography (SiO_2 20 g, *n*-hexane : EtOAc = 5 : 1) to afford an unidentified compound (**3**, 49 mg, 40%) and a bisfuranoditerpene derivative (**4**, 15 mg, 15%).

3: A colorless glassy solid (unstable), $[\alpha]_D$ −67° (*c* = 0.78 in $CHCl_3$, at 20 °C). IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1745, 1450, 940. ^{1}H-NMR (270 MHz, $CDCl_3$) δ: 0.97, 0.99 (3H each, both s), 1.12 (3H, d, *J* = 7.0 Hz), 2.01 (3H, s), 2.69 (1H, dq, *J* = 3.6, 7.0 Hz), 5.00 (1H, d, *J* = 3.6 Hz), 5.15 (1H, d-like, *J* = 5.5 Hz), 6.25 (1H, d, *J* = 2.0 Hz), 7.36 (1H, d, *J* = 2.0 Hz).

4: Colorless needles, mp 207—208 °C (*n*-hexane–EtOAc), $[\alpha]_D$ +4.4° (*c* = 0.12 in $CHCl_3$, at 20 °C). IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 3550, 1737, 1722, 1450, 940. ^{1}H-NMR (270 MHz, $CDCl_3$) δ: 0.89 (6H, d, *J* = 6.0 Hz, 17,17′-H_3), 1.23, 1.25 (totally 12H, both s, 18,19,18′,19′-H3), 1.34 (6H, s, 20,20′-H_3), 2.03 (2H, m, 8,8′-H), 2.06 (6H, s, $-OCOCH_3 \times 2$), 2.34 (2H, m, 9,9′-H), 5.22 (2H, br s, 6,6′-H), 6.24 (2H, s, 15,15′-H). FAB-MS *m/z*: 718 (M^+). High-resolution FAB-MS *m/z*: Calcd for $C_{44}H_{62}O_8$: 718.4444. Found: 718.4413.

Crystallographic Data for the Crystals Prepared from 4 Composition: $(C_{22}H_{31}O_4 \cdot C_4H_8O_2)_2$, M = 807.08. Orthorhombic, *a* = 9.351(1) Å, *b* = 20.660(3) Å, *c* = 24.581(4) Å, *v* = 4748 Å^3. Space group $C222_1$, *z* = 4, D_x = 1.13 g cm^{-3}, $\mu(CuK_\alpha)$ = 4.83 cm^{-1}. Crystal size 0.8 × 0.2 × 0.1 mm.

X-Ray Analysis Intensity data were measured at 286 K with graphite-monochromated CuK_α radiation on a Rigaku AFC-5R diffractometer. In the $\omega-2\theta$ scanning mode, the intensities of 2126 independent reflections with $\sin\theta/\lambda < 0.58$ Å^{-1} were obtained. The structure was solved by direct and difference Fourier methods and refined by the full-matrix least-squares method with anisotropic temperature factors for non-H atoms of **4** and with isotropic temperature factors for non-H atoms of ethyl acetate. The final *R* value was 0.0957 for 674 reflections with $F_O > 3\delta(F_O)$.

Alkaline Treatment of Caesaldekarin a (1) A solution of **1** (600 mg) in MeOH (5 ml) was treated with 20% KOH–MeOH (100 ml) and the mixture was stirred at 40 °C for 20 min. It was poured into ice-water and extracted with EtOAc. The EtOAc extract was washed with brine and dried over $MgSO_4$. Removal of the solvent under reduced pressure gave a product. Purification of the product by column chromatography (SiO_2 50 g, *n*-hexane : EtOAc = 7 : 1) afforded **2** (370 mg, 70%), which was identified by comparisons of physical data (IR, UV, and ^{1}H-NMR) with those of caesaldekarin b, and an epoxide **5** (100 mg, 20%).

5: Colorless needles, mp 90—91 °C, $[\alpha]_D$ +2.2° (*c* = 0.1 in $CHCl_3$, at 20 °C). IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1450, 900. UV λ_{max}^{MeOH} nm (ε): 218 (6000). ^{1}H-NMR (500 MHz, $CDCl_3$) δ: 0.76 (3H, s, 18 or 19-H_3), 1.09 (3H, d, *J* = 6.7 Hz, 17-H_3), 1.13 (3H, s, 20-H_3), 1.16 (3H, s, 18 or 19-H_3), 1.30 (1H, m, 1-H_a), 1.42 (1H, m, 3-H_a), 1.49 (1H, dd, *J* = 4.0, 13.5 Hz, 3-H_b), 1.55 (1H, m, 2-H_a), 1.58 (1H, m, 1-H_b), 1.72 (1H, m, 2-H_b), 1.86 (1H, m, 8-H), 2.01 (1H, ddd, *J* = 3.0, 3.0, 16.5 Hz, 7-H_a), 2.08 (1H, ddd, *J* = 1.5, 11.0, 16.5 Hz, 7-H_b), 2.23 (1H, t-like, *J* = 11.5 Hz, 9-H), 2.29 (1H, m, 11-H_a), 2.42 (1H, dd, *J* = 4.3, 14.6 Hz, 11-H_b), 2.49 (1H, dq, *J* = 6.7, 6.7 Hz, 14-H), 3.11 (1H, br s, 6-H), 6.14 (1H, d, *J* = 1.8 Hz, 15-H), 7.18 (1H, d, *J* = 1.8 Hz, 16-H). ^{13}C-NMR (125 MHz, $CDCl_3$) δ_C: 16.1 (q, 20-C), 17.4 (q, 17-C), 18.2 (t, 2-C), 24.0 (t, 11-C), 25.0 (t, 7-C), 26.6, 26.7 (both q, 18,19-C), 32.8 (d, 14-C), 33.2 (d, 8-C), 34.4 (s, 4-C), 35.2 (t, 1-C), 36.5 (s, 10-C), 37.1 (d, 9-C), 38.4 (t, 3-C), 54.7 (d, 6-C), 66.3 (s, 5-C), 109.6 (d, 15-C), 122.8 (s, 13-C), 140.5 (d, 16-C), 149.8 (s, 12-C). MS *m/z* (%): 300 (M^+, 44), 108 (100). High-resolution MS *m/z*: Calcd for $C_{20}H_{28}O_2$: 300.2095. Found: 300.2085 (M^+).

Acetylation of Caesaldekarin b (2) Giving Caesaldekarin a (1) A solution of **2** (10 mg) in pyridine (0.1 ml) was treated with acetic anhydride (0.1 ml) and 4-dimethylaminopyridine (3 mg), and the whole mixture was left standing at 40 °C for 30 min. After cooling, the reaction mixture was poured into ice-water, and extracted with EtOAc. Work-up of the EtOAc extract in a usual manner gave a product, which was purified by column chromatography (SiO_2, 1 g, *n*-hexane : EtOAc = 10 : 1) to afford **1** (5 mg, 46%). The physical data including the specific rotation of **1** were identical with those of caesaldekarin a isolated from the roots.

Treatment of Caesaldekarin b (2) with *m*-CPBA A solution of **2** (202 mg) in CH_2Cl_2 (5 ml) was treated with 70% *m*-CPBA (108 mg). The whole mixture was stirred at room temperature for 30 min, then treated with 5% aqueous $Na_2S_2O_3$ for 10 min to terminate the reaction. The whole was extracted with $CHCl_3$. The $CHCl_3$ extract was washed with aqueous saturated $NaHCO_3$ and brine, then dried over $MgSO_4$. Removal of the solvent under reduced pressure gave a product, which was purified by column chromatography (SiO_2 50 g, *n*-hexane : EtOAc = 2 : 3) to afford an aldehyde **6** (165 mg, 77%).

6: Colorless needles, mp 155—156 °C (*n*-hexane–EtOAc), $[\alpha]_D$ −12.4° (c = 0.37 in $CHCl_3$, at 20 °C). IR ν_{max}^{KBr} cm^{-1}: 3530, 1680. UV λ_{max}^{MeOH} nm (ε): 245 (1800). ^{1}H-NMR (270 MHz, $CDCl_3$) δ: 1.02 (3H, s, 18-H_3), 1.04 (3H, d, J = 7.2 Hz, 17-H_3), 1.19 (1H, m, 3-H_a), 1.26 (2H, m, 1-H_2), 1.36 (3H, s, 20-H_3), 1.41 (1H, m, 7-H_a), 1.47 (3H, s, 19-H_3), 1.59 (1H, m, 2-H_a), 1.62 (1H, m, 3-H_b), 1.67 (1H, m, 2-H_b), 2.28 (1H, m, 7-H_b), 2.41 (1H, dd, J = 3.6, 12.5 Hz, 11-H_a), 2.49 (1H, m, 9-H), 2.51 (2H, m, 8-H, 11-H_b), 2.67 (1H, dq, J = 7.2, 7.2 Hz, 14-H), 4.20 (1H, br s, 6-H), 5.84 (1H, d, J = 7.9 Hz, 15-H), 9.72 (1H, d, J = 7.9 Hz, 16-H). ^{13}C-NMR (67.5 MHz, $CDCl_3$) δ_C: 13.7 (q, 17-C), 16.1 (q, 20-C), 18.0 (t, 2-C), 26.0 (q, 19-C), 27.7 (q, 18-C), 33.6 (d, 9-C), 34.5 (t, 1-C), 34.7 (t, 7-C), 38.0 (t, 3-C), 38.9 (s, 10-C), 40.7 (d, 8-C), 41.1 (s, 4-C), 43.0 (t, 11-C), 44.7 (d, 14-C), 71.4 (d, 6-C), 76.2 (s, 5-C), 127.6 (d, 15-C), 164.8 (s, 13-C), 192.3 (d, 16-C), 205.0 (s, C-12). MS m/z (%): 334 (M^+, 31), 108 (18), 55 (100). High-resolution MS m/z: Calcd for $C_{20}H_{30}O_4$: 334.2144. Found: 334.2155.

Preparation of a Silylated Ketone 7 from the Aldehyde 6 A solution of **6** (165 mg) in dry CH_2Cl_2 (1.0 ml) was treated with $NaBH_4$ (20 mg, 1.1 eq) at −10 °C for 3 h. The reaction mixture was then treated with imidazole (5.1 mg) and *tertiary*-butyldimethylsilyl chloride (4.5 mg) at room temperature for 1 min. The whole was poured into ice-water and extracted with EtOAc. The EtOAc extract was washed with aqueous 5% HCl, aqueous saturated $NaHCO_3$, and brine, then dried over $MgSO_4$. Removal of the solvent under reduced pressure gave a product, which was purified by column chromatography (SiO_2 15 g, *n*-hexane : EtOAc = 6 : 1) to afford **7** (88 mg, 40%).

7: Colorless needles, mp 142—143 °C (*n*-hexane–EtOAc), $[\alpha]_D$ −14.7° (c = 0.97 in $CHCl_3$, at 20 °C). IR ν_{max}^{KBr} cm^{-1}: 3580, 1680, 1100, 840. UV λ_{max}^{MeOH} nm (ε): 230 (4900). ^{1}H-NMR (270 MHz, $CDCl_3$) δ: 0.05 [6H, s, $-OSi(C\underline{H}_3)_2C(CH_3)_3$], 0.89 [9H, s, $-OSi(CH_3)_2C(C\underline{H}_3)_3$], 0.96 (3H, d, J = 7.2 Hz, 17-H_3), 1.05 (3H, s, 18-H_3), 1.11 (1H, m, 3-H_a), 1.27 (2H, m, 1-H_2), 1.31 (3H, s, 20-H_3), 1.35 (1H, m, 7-H_a), 1.44 (2H, m, 2-H_2), 1.45 (3H, s, 19-H_3), 1.65 (1H, m, 3-H_b), 2.21 (1H, m, 9-H), 2.23 (1H, m, 7-H_b), 2.33 (1H, m, 11-H_a), 2.39 (2H, m, 8-H, 11-H_b), 2.47 (1H, m, 14-H), 4.17 (1H, br s, 6-H), 4.40 (2H, d, J = 5.3 Hz, 16-H_2), 5.68 (1H, t, J = 5.3 Hz, 15-H). ^{13}C-NMR (67.5 MHz, $CDCl_3$) δ_C: −5.2 [totally 2C, q, $-OSi(\underline{C}H_3)_2C(CH_3)$], 15.7 (q, 17-C), 16.1 (q, 20-C), 18.0 (t, 2-C), 18.4 [s, $-OSi(CH_3)_2\underline{C}(CH_3)_3$], 25.4 [totally 3C, q, $-OSi(CH_3)_2C(\underline{C}H_3)_3$], 25.9 (q, 19-C), 27.7 (q, 18-C), 32.3 (d, 9-C), 34.4 (t, 1-C), 35.2 (t, 7-C), 38.1 (t, 3-C), 38.9 (s, 10-C), 39.3 (d, 8-C), 40.8 (s, 4-C), 40.9 (t, 11-C), 42.9 (d, 14-C), 61.4 (t, 16-C), 71.6 (d, 6-C), 76.4 (s, 5-C), 136.6 (d, 15-C), 142.5 (s, 13-C), 205.4 (s, 12-C). MS m/z (%): 450 (M^+, 27), 75 (100). High-resolution MS m/z: Calcd for $C_{26}H_{46}O_4Si$: 450.3166. Found: 450.3165.

Reduction of 7 with $NaBH_4$ Giving a Triol 8 A solution of **7** (40 mg) in EtOH (2 ml) was treated with $CeCl_3 \cdot 7H_2O$ (33 mg) and $NaBH_4$ (5 mg, 1.5 eq), and the mixture was stirred at −10 °C for 30 min. It was poured into ice-water and the whole was extracted with EtOAc. Work-up of the EtOAc in a usual manner gave a product, which was purified by column chromatography (SiO_2 10 g, *n*-hexane : EtOAc = 4 : 1) to afford **8** (22 mg, 55%).

8: Colorless needles, mp 150—151 °C (*n*-hexane–EtOAc), $[\alpha]_D$ −36.7° (c = 1.1 in $CHCl_3$, at 20 °C). IR ν_{max}^{KBr} cm^{-1}: 3550—3380 (br), 1070, 835. ^{1}H-NMR (270 MHz, $CDCl_3$) δ: 0.10 [6H, s, $-OSi(C\underline{H}_3)_2C(CH_3)_3$], 0.91 [9H, s, $-OSi(CH_3)_2C(C\underline{H}_3)_3$], 0.99 (3H, d, J = 6.3 Hz, 17-H_3), 1.00 (3H, s, 18-H_3), 1.14 (1H, m, 3-H_a), 1.22 (2H, m, 1-H_2), 1.25 (1H, m, 11-H_a), 1.28 (3H, s, 20-H_3), 1.41 (1H, m, 7-H_a), 1.44 (3H, s, 19-H_3), 1.47 (2H, m, 2-H_2), 1.67 (1H, m, 3-H_b), 1.87 (1H, m, 8-H), 1.90 (1H, m, 11-H_b), 2.05 (1H, m, 9-H), 2.10 (1H, m, 7-H_b), 2.25 (1H, dq, J = 4.6, 6.3 Hz, 14-H), 4.13 (1H, t-like, J = 3.0 Hz, 6-H), 4.26 (2H, d, J = 6.3 Hz, 16-H_2), 4.38 (1H, dd, J = 4.5, 11.5 Hz, 12-H), 5.45 (1H, t, J = 6.3 Hz, 15-H). ^{13}C-NMR (67.5 MHz, $CDCl_3$) δ_C: −5.0 [totally 2C, q, $-OSi(\underline{C}H_3)_2C(CH_3)_3$], 15.0 (q, 17-C), 16.6 (q, 20-C), 18.3 [s, $-OSi(CH_3)_2\underline{C}(CH_3)_3$], 18.3 (t, 2-C), 25.8 [totally 3C, q, $-OSi(CH_3)_2C(\underline{C}H_3)_3$], 26.0 (q, 19-C), 27.9 (q, 18-C), 34.4 (d, 8-C), 34.8, 34.9 (both t, 1-,7-C), 36.7 (t, 11-C), 38.2 (t, 3-C), 38.9 (s, 10-C), 39.9 (d, 9-C), 40.5 (s, 4-C), 45.2 (d, 14-C), 59.2 (t, 16-C), 70.3 (d, 12-C), 71.8 (d, 6-C), 76.5 (s, 5-C), 117.8 (d, 15-C), 152.7 (s, 13-C). FAB-MS m/z: 475 $(M+Na)^+$, 459 $(M+Li)^+$. High-resolution FAB-MS m/z: Calcd for $C_{26}H_{47}O_4Si$: 451.3244. Found: 451.3225 $(M-H)^+$.

Preparation of the (+)-MTPA Ester 9a from 8 A solution of the triol **8** (5 mg) in dry CH_2Cl_2 (5 ml) was treated with *R*-(+)-α-methoxy-α-(trifluoromethyl)phenylacetic acid (31 mg), 1,3-dicyclohexylcarbodiimide (31 mg), and 4-dimethylaminopyridine (10 mg), and the mixture was stirred at room temperature for 30 min. It was poured into ice-water and the whole was extracted with EtOAc. Work-up of the EtOAc extract in a usual manner gave a product. Purification of the product by column chromatography (SiO_2 10 g, *n*-hexane : EtOAc = 4 : 1) afforded the (+)-MTPA ester **9a** (6 mg, 64%).

9a: A white powder. FAB-MS m/z: 691 $(M+Na)^+$. High-resolution FAB-MS m/z: Calcd. for $C_{36}H_{55}F_3O_6NaSi$: 691.3618. Found: 691.3666 $(M+Na)^+$. The ^{1}H-NMR data are given in Table I.

Preparation of the (−)-MTPA Ester 9b from 8 The (−)-MTPA ester **9b** (7 mg, 60%) was obtained from the triol **8** (6.0 mg) through the same procedure as used for the preparation of **9a** from **8**.

9b: A white powder. FAB-MS m/z: 691 $(M+Na)^+$. High-resolution FAB-MS m/z: Calcd for $C_{36}H_{55}F_3O_6NaSi$: 691.3618. Found: 691.3666 $(M+Na)^+$. The ^{1}H-NMR data are given in Table I.

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