Water-Soluble Constituents of Fennel. IX. Glucides and Nucleosides

Junichi KITAJIMA,*[,a] Toru ISHIKAWA,[a] Yasuko TANAKA,[a] and Yoshiteru IDA[b]

Showa College of Pharmaceutical Sciences,[a] Higashi-Tamagawagakuen 3, Machida, Tokyo 194–8543, Japan and School of Pharmaceutical Sciences, Showa University,[b] Hatanodai, Shinagawa-ku, Tokyo 142–8555, Japan.
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From the water-soluble portion of the methanolic extract of fennel, seven new sugar alcohols (two deoxybutitols, four deoxypentitols and one deoxyhexitol) and a sugar lactone were isolated, together with seven known glucides, four nucleosides, (3*R*)-2-hydroxymethylbutane-1,2,3,4-tetrol and uracil. From the results of spectral investigation, the new compounds were characterized as 1-deoxythreitol (9), (2*R*)-butane-1,2,4-triol (10), 1-deoxy-D-ribitol (11), 1-deoxy-D-xylitol (12), 2-deoxy-D-ribitol (13), 3-deoxyarabinitol (14), 1-deoxy-D-glucitol (16) and 2-deoxy-D-ribono-1,4-lactone (15), respectively.

Key words fennel; *Foeniculum vulgare* fruit; glucide; sugar alcohol; sugar lactone; nucleoside

In previous papers, we reported the isolation and characterization of alkyl glycosides,[1] glycosides of aromatic compounds[2] and glycosides of monoterpenoids of different types[3] of fennel. In this paper we discuss the isolation and structural elucidation of glucides and nucleosides.

The methanolic extract of commercial fennel [prepared from the fruit of *Foeniculum vulgare* MILLER (Umbelliferae)] was treated as described in the Experimental section, and fourteen glucides, four nucleosides, (3*R*)-2-hydroxymethylbutane-1,2,3,4-tetrol (**8**)[4] and uracil (**21**) were isolated from the water-soluble portion. Molecular formulae of the new compounds were established from the accurate mass number of $[M+H]^+$ or $[M+Na]^+$ ion peaks in high-resolution positive FAB-MS.

Glucides **1**, **2**, **3**, **4**, **5**, **6** and **7** were identified as glycerol, erythritol,[5] D-threitol,[5] D-mannitol, D-glucose, D-fructose and sucrose by direct comparison with authentic compounds.

Glucides **9** (an amorphous powder, $[\alpha]_D^{23}$ +3.0°) and **10** (a colorless syrup, $[\alpha]_D^{23}$ +25.0°) had the same molecular formula: $C_4H_{10}O_3$. Glucide **9** was obtained as a mixture which included a trace of a compound which was considered to be the epimer of **9** (**9′**); however, this trace epimer was excluded in the isolation process. The ^{1}H-, ^{13}C- and ^{13}C–^{1}H correlation spectroscopy (COSY) NMR spectral data for **9** (Tables 1 and 2) revealed the presence of one *sec*-methyl, one hydroxymethyl, and two hydroxylated methines. From these data, **9** was characterized as butane-1,2,3-triol. The relation between C-2 and C-3 in **9** was considered to be *threo* by comparison of the methyl proton chemical-shift with that of **9′**. In the ^{1}H-NMR spectrum, the methyl proton signal of 1-deoxy-2,3-*threo*-alditols in pyridine-d_5 appeared in a higher field than those of 2,3-*erythro* isomers [fucitol (*threo*, δ 1.59),[6] quinovitol (*erythro*, δ 1.68)[6]; 1-deoxyglucitol (*threo*, δ 1.53), rhamnitol (*erythro*, δ 1.68)[6]; 1-deoxyxylitol (*threo*, δ 1.56), 1-deoxyarabinitol (threo, δ 1.60),[7] 1-deoxyribitol (*erythro*, δ 1.70)]. As the methyl proton signal of **9** appeared in a higher region than that of **9′** (**9** for δ 1.53, **9′** for δ 1.65), **9** was suggested to be 1-deoxythreitol.[8] However, the absolute configuration of **9** could not be established from the available data.

Glucide **10** was revealed to contain two hydroxymethyls, one hydroxylated methine and one methylene, and was concluded to be butane-1,2,4-triol from the analysis of the ^{1}H-, ^{13}C- and ^{13}C–^{1}H COSY NMR spectral data (Tables 1 and 2). As the synthesized (2*R*)-form of butane-1,2,4-triol was reported to have a positive optical rotation ($[\alpha]_D$ +27.9°),[9] the configuration at C-2 of **10** was revealed to be *R*.[10] Therefore, **10** was characterized as (2*R*)-butane-1,2,4-triol.

Glucides **11** (a colorless syrup, $[\alpha]_D^{23}$ +6.5°), **12** (a colorless syrup, $[\alpha]_D^{23}$ −4.0°), **13** (a colorless syrup, $[\alpha]_D^{22}$ −17.0°) and **14** (a colorless syrup, $[\alpha]_D^{23}$ −34.5°) had the same molecular formula: $C_5H_{12}O_4$. The ^{1}H-, ^{13}C- and ^{13}C–^{1}H COSY NMR spectral data for **11** and **12** showed them to have one *sec*-methyl, one hydroxymethyl and three hydroxylated me-

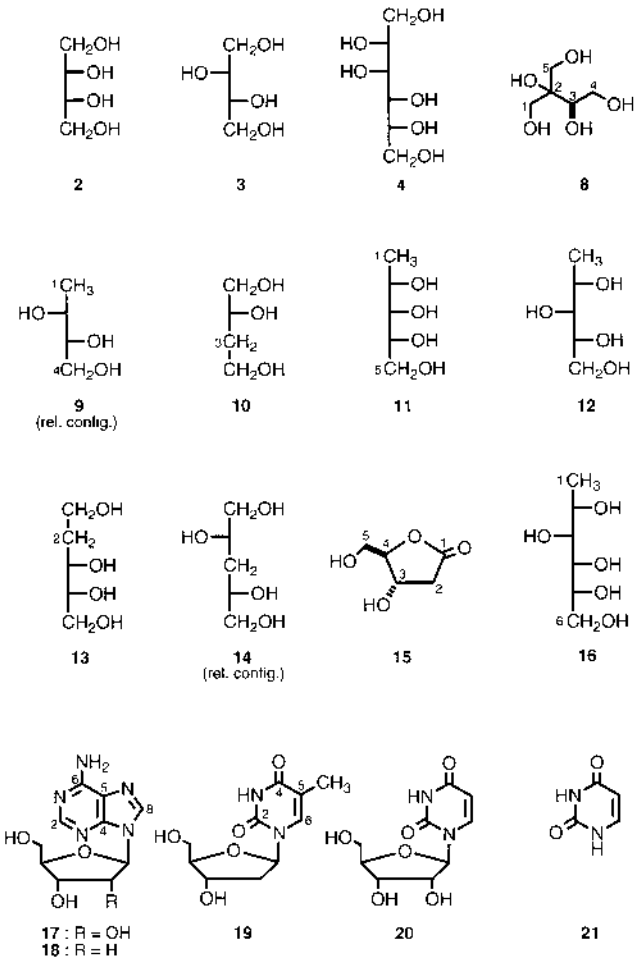

Fig. 1. Structures of **2**, **3**, **4**, **8**—**21**

∗ To whom correspondence should be addressed.

Table 1. ^{1}H-NMR Chemical Shifts of **2**, **3**, **8**—**16** (in Pyridine-d_5, 500 MHz)

	2	**3**	**9**	**10**
H-1	4.37 1H, dd (5.0, 11.0)	4.32 1H, dd (6.0, 11.0)	1.53 3H, d (6.5)	4.25 2H, m
	4.50 1H, dd (3.0, 11.0)	4.38 1H, dd (4.5, 11.0)	—	—
H-2	4.48 1H, ddd (3.0, 5.0, 7.5)	4.51 1H, ddd (4.5, 4.5, 6.0)	4.37 1H, dq (5.0, 6.5)	4.48 1H, m
H-3	4.48 1H, ddd (3.0, 5.0, 7.5)	4.51 1H, ddd (4.5, 4.5, 6.0)	4.05 1H, ddd (4.5, 5.0, 6.0)	2.19 1H, dddd (6.0, 6.0, 7.0, 14.0)
	—	—	—	2.27 1H, dddd (4.0, 6.0, 7.0, 14.0)
H-4	4.37 1H, dd (5.0, 11.0)	4.32 1H, dd (6.0, 11.0)	4.17 1H, dd (6.0, 11.0)	4.06 2H, br d (6.0)
	4.50 1H, dd (3.0, 11.0)	4.38 1H, dd (4.5, 11.0)	4.28 1H, dd (4.5, 11.0)	—
	11	**12**	**13**	**14**
H-1	1.70 3H, d (6.5)	1.56 3H, d (6.5)	4.32 1H, br dd (5.0, 11.0)	4.07 2H, br d (5.5)
	—	—	4.33 1H, br dd (6.0, 11.0)	—
H-2	4.64 1H, dq (6.0, 6.5)	4.52 1H, dq (4.0, 6.5)	2.32 1H, dddd (5.0, 6.0, 7.5, 14.0)	4.56 1H, br ddd (5.5, 8.5, 8.5)
	—	—	2.58 1H, dddd (3.0, 6.0, 7.5, 14.0)	—
H-3	4.27 1H, dd (6.0, 6.5)	4.08 1H, dd (3.5, 4.0)	4.54 1H, ddd (3.0, 7.5, 7.5)	2.19 1H, ddd (8.5, 8.5, 14.0)
	—	—	—	2.37 1H, ddd (5.5, 5.5, 14.0)
H-4	4.45 1H, ddd (4.0, 6.0, 6.5)	4.44 1H, ddd (3.5, 5.0, 6.0)	4.27 1H, ddd (4.0, 7.5, 7.5)	4.56 1H, br ddd (5.5, 8.5, 8.5)
H-5	4.38 1H, dd (6.0, 11.0)	4.33 1H, dd (6.0, 11.0)	4.34 1H, dd (7.5, 11.0)	4.07 2H, br d (5.5)
	4.55 1H, dd (4.0, 11.0)	4.36 1H, dd (5.0, 11.0)	4.44 1H, dd (4.0, 11.0)	—
	15	**8**	**16**	
H-1	—	4.46[a] 2H, d (9.5)	1.53 3H, d (6.0)	
H-2	2.86 1H, dd (2.5, 17.5)	—	4.52 1H, dq (6.0, 6.0)	
	3.33 1H, dd (6.5, 17.5)	—	—	
H-3	5.00 1H, ddd (2.0, 2.5, 6.5)	4.64 1H, dd (4.5, 6.0)	4.38 1H, br d (6.0)	
H-4	4.91 1H, ddd (2.0, 3.5, 3.5)	4.48 1H, dd (6.0, 11.5)	4.43 1H, br d (6.0)	
	—	4.55 1H, dd (4.5, 11.5)	—	
H-5	4.34 1H, dd (3.5, 12.0)	4.42[a] 2H, d (9.5)	4.61 1H, ddd (3.0, 6.0, 6.0)	
	4.13 1H, dd (3.5, 12.0)	—	—	
H-6	—	—	4.39 1H, dd (6.0, 12.0)	
	—	—	4.52 1H, dd (3.0, 12.0)	

δ in ppm from TMS [coupling constants (J) in Hz are given in parentheses]. *a*) Assignments may be interchanged.

Table 2. ^{13}C-NMR Chemical Shifts of **2**—**4**, **8**—**16** (in Pyridine-d_5, 125 MHz)

	2	**3**	**9**	**9′**	**10**	**11**	**12**	**13**	**14**	**15**	**8**	**16**	**4**
C-1	65.19	64.67	20.24	20.34	67.65	19.59	20.44	60.25	67.61	177.11	64.61[a]	20.32	64.13
C-2	74.29	73.50	68.52	69.43	70.99	69.91	69.23	37.35	72.16	39.46	76.46	70.01	70.37
C-3	74.29	73.50	77.02	77.17	37.79	76.77	75.95	72.04	38.22	69.23	75.16	74.03	71.90
C-4	65.19	64.67	64.63	65.13	59.84	75.07	74.03	76.28	72.16	89.76	63.69	74.86	71.90
C-5						65.31	64.81	65.15	67.61	62.07	65.33[a]	73.21	70.37
C-6												65.23	64.13

δ in ppm from TMS. *a*) Assignments may be interchanged.

Table 3. ^{1}H-NMR Chemical Shifts of **17**—**21** (in Pyridine-d_5, 500 MHz)

	17	**18**	**19**[a]	**20**	**21**
H-2	8.73 1H, s	8.74 1H, s	—	—	—
H-5	—	—	—	5.81 1H, d (8.0)	5.82 1H, d (8.0)
H-6	—	—	8.17 1H, d (1.0)	8.55 1H, d (8.0)	7.55 1H, d (8.0)
H-8	8.61 1H, s	8.71 1H, s	—	—	—
CH_3	—	—	1.88 3H, d (1.0)	—	—
NH_2	8.37 2H, s	8.43 2H, s	—	—	—
Sug-1	6.73 1H, d (6.0)	7.01 1H, dd (6.0, 7.5)	7.05 1H, d (6.5)	6.83 1H, d (4.0)	
Sug-2	5.50 1H, dd (3.5, 6.0)	2.82 1H, ddd (3.0, 6.0, 13.0)	2.66 2H, m	4.92 1H, dd (4.0, 9.0)	
	—	3.23 1H, ddd (6.0, 7.5, 13.0)	—	—	
Sug-3	5.07 1H, dd (3.5, 6.0)	5.25 1H, ddd (3.0, 3.0, 6.0)	5.05 1H, m	4.91 1H, dd (4.5, 9.0)	
Sug-4	4.78 1H, ddd (3.0, 3.0, 6.0)	4.69 1H, ddd (3.0, 3.0, 3.0)	4.48 1H, ddd (3.0, 3.0, 3.0)	4.67 1H, ddd (2.5, 2.5, 4.5)	
Sug-5	4.15 1H, dd (3.0, 12.0)	4.20 1H, dd (3.0, 12.0)	4.15 1H, dd (3.0, 12.0)	4.21 1H, dd (2.5, 12.0)	
	4.33 1H, dd (3.0, 12.0)	4.31 1H, dd (3.0, 12.0)	4.24 1H, dd (3.0, 12.0)	4.32 1H, dd (2.5, 12.0)	

δ in ppm from TMS [coupling constants (J) in Hz are given in parentheses]. *a*) Measured at 67.5 MHz.

Table 4. ^{1}H-NMR Chemical Shifts of **17**—**21** (in Pyridine-d_5, 125 MHz)

	17	18	19[a)]	20	21
C-2	153.30	153.28	151.96	152.20	153.24
C-4	150.00	150.15	164.99	164.44	165.83
C-5	121.44	121.11	110.46	102.38	101.23
C-6	157.67	157.53	136.65	141.11	142.18
C-8	140.58	140.07	—	—	—
CH_3	—	—	12.76	—	—
Sug-1	90.83	85.99	85.30	90.27	
Sug-2	75.54	41.24	41.39	76.04	
Sug-3	72.40	72.20	71.45	71.14	
Sug-4	87.80	89.77	88.87	86.19	
Sug-5	63.03	63.13	62.31	61.66	

δ in ppm from TMS. *a*) Measured at 67.5 MHz.

thines (Tables 1 and 2), and suggested them to be diastereomers of pentane-1,2,3,4-tetrol. Since the ^{1}H-NMR spectra of **11** and **12** in deuterium oxide showed identical patterns with those of tetrols which were obtained in the reduction of ribose and xylose,[11] they were concluded to be 1-deoxyribitol and 1-deoxyxylitol, respectively. The absolute configuration of **11** was revealed to be a D-form since 1-deoxy-D-ribitol was reported to have a positive $[M]_D$ value in water (+14°,[12] +12.9° for **11**). On the other hand, the absolute configuration of **12** could not be assigned by consideration of the $[M]_D$ value, as the D-form of 1-deoxyxylitol was reported to show zero $[M]_D$ value in water.[12] However, **12** was considered to be a D-form since only the D-form of xylose is known in nature. From the above facts, **11** and **12** were characterized as 1-deoxy-D-ribitol and 1-deoxy-D-xylitol, respectively.

The ^{1}H-, ^{13}C- and ^{13}C–^{1}H COSY NMR spectral data for **13** showed the presence of two hydroxymethyls, one methylene and two hydroxylated methines (Tables 1 and 2), and were indicated to be pentane-1,2,3,5-tetrol. The absolute configuration of this sugar alcohol was confirmed by direct comparison with tetrol obtained by $NaBH_4$ reduction of 2-deoxy-D-ribose. Therefore, **13** was characterized as 2-deoxy-D-ribitol.

The ^{13}C-NMR spectrum of **14** showed only three signals, but analysis of the ^{1}H- and ^{13}C–^{1}H COSY NMR spectral data revealed the presence of one methylene, one pair of hydroxymethyl and one pair of hydroxylated methine (Tables 1 and 2). So, **14** was suggested to be pentane-1,2,4,5-tetrol, which has an intermolecular symmetry plane or center. The relation between C-2 and C-4 was considered to be *threo* since **14** showed a negative optical rotation. Therefore, **14** was characterized as deoxyarabinitol. However, the absolute configuration of **14** could not be established from the available data.

Glucide **15** ($C_5H_8O_4$, a colorless syrup, $[\alpha]_D^{22}$ +3.5°) showed $[2M+H]^+$, $[M+K]^+$, $[M+Na]^+$, $[M+H]^+$, $[M-H_2O]^+$, $[M-2H_2O]^+$ ion peaks at *m/z* 265, 171, 155, 133, 115, 97 in the positive FAB-MS, and $[2M+H]^+$, $[M+H]^+$, $[M-H_2O]^+$ ion peaks at *m/z* 265, 133, 115 in the CI-MS. The ^{1}H-, ^{13}C- and ^{13}C–^{1}H COSY NMR spectral data for **15** (Tables 1 and 2) revealed the presence of one hydroxymethyl, one methylene and two oxygenated methines and one carbonyl carbon. From the heteronuclear multiple-bond correlation (HMBC) spectrum, which showed H–C long-range correlations between the methylene protons (H_2-2) and the C-1, C-3, C-4 carbons, and between the hydroxymethyl protons (H_2-5) and the C-3, C-4 carbons, and from the unsaturation degree of this compound, **15** was indicated to be 3,5-dihydroxypentono-1,4-lactone. Han *et al.*[13] prepared some pentonolactones, and the ^{13}C-NMR data in deuterium oxide was identical with those of 2-deoxy-D-ribono-1,4-lactone which was prepared from 2-deoxy-D-ribose. As the synthetic lactone was reported to have a positive optical rotation in water ($[\alpha]_D$ +19.9°,[13] $[\alpha]_D^{22}$ +13.5° for **15**), glucide **15** was identified as 2-deoxy-D-ribono-1,4-lactone.

Glucide **16** ($C_6H_{12}O_5$, mp 123—126 °C, $[\alpha]_D^{23}$ −3.0°) was observed to have one *sec*-methyl, one hydroxymethyl and four hydroxylated methines from the NMR spectral data (Tables 1 and 2). So, **16** was suggested to be 6-deoxyhexitol. And the ^{1}H-NMR spectrum in deuterium oxide was identical with that of 1-deoxyglucitol, which was prepared from a reduction of D-glucose.[11] Since the 1-deoxy-D-glucitol was reported to have a positive $[M]_D$ value in water (+7°,[12] +8.3° for **16**) and a negative $[M]_D$ value in methanol (−2°,[12] −5.0° for **16**), **16** was characterized as 1-deoxy-D-glucitol. This characterization was also supported by the fact that the ^{1}H- and ^{13}C-NMR spectra of deoxyhexitols which were obtained by the $NaBH_4$ reduction of quinovitol, rhamnose and fucose were not identical with that of **16**.

Nucleosides **17**, **18**, **19** and **20** were identified as adenosine, 2′-deoxyadenosine, thymidine and uridine, respectively.

This is the first paper to present the isolation of sugar alcohols corresponding to deoxytetrose, deoxypentose and deoxyhexose, and a sugar lactone corresponding to deoxypentose from natural sources.

Experimental

NMR spectra in deuterium oxide were taken with 3-(trimethylsilyl)-1-propane sulfonic acid sodium salt, while FAB-MS spectra of **9**, **10**, **13**, **15** and **16** were recorded without a matrix. The instruments used and the other experimental conditions for obtaining spectral data and for chromatography were the same as in the preceding paper.[1]

Extraction and Isolation of 1 to 21 As reported in the previous paper, commercial fennel (2.0 kg) was extracted with MeOH. The MeOH extract (329.4 g) was partitioned into Et_2O/H_2O and then EtOAc/H_2O, and the resulting aqueous portion was subjected to Amberlite XAD-II (H_2O→MeOH). The Amberlite XAD-II MeOH eluate (29.5 g) was chromatographed over Sephadex LH-20 (MeOH) to give seven fractions (frs. A—G). Fraction C (16.9 g) was chromatographed over silica gel [$CHCl_3$–MeOH–H_2O (4 : 1 : 0.1)→MeOH] to give fifteen fractions (frs. C_1—C_{15}). Fraction C_5 (1.7 g) was subjected to a Lobar RP-8 column [CH_3CN–H_2O (3 : 17)] to give twelve fractions (frs. $C_{5\text{-}1}$—$C_{5\text{-}12}$). Fraction $C_{5\text{-}2}$ was subjected to HPLC [carbohydrate analysis (Waters), CH_3CN–H_2O (14 : 1)] to give **19** (20 mg). Fraction E (1.8 g) was subjected to a Lobar RP-8 column [CH_3CN–H_2O (1 : 19→1 : 9)] to give six fractions (frs. E_1—E_6). Fraction E_4 was chromatographed over Sephadex LH-20 (MeOH) to give **17** (150 mg). Fraction E_5 was chromatographed over silica gel [$CHCl_3$–MeOH–H_2O (7 : 3 : 0.5)] to give **18** (5 mg).

The Amberlite XAD-II water eluate (71.5 g) was chromatographed over Sephadex LH-20 [MeOH–H_2O (9 : 1)] to give six fractions (frs. H—M). Fraction I (56.9 g) was chromatographed over silica gel [$CHCl_3$–MeOH–H_2O (17 : 3 : 0.2→4 : 1 : 0.1→7 : 3 : 0.5→MeOH] to give eleven fractions (frs. I_1—I_{11}). Fraction I_4 (0.3 g) was subjected to a Lobar RP-8 column [CH_3CN–H_2O (1 : 19)] to give four fractions (frs. $I_{4\text{-}1}$—$I_{4\text{-}4}$). Fraction $I_{4\text{-}2}$ was subjected to HPLC [carbohydrate analysis, CH_3CN–H_2O (99 : 1)] to give **15** (35 mg) and **21** (20 mg). Fraction $I_{4\text{-}3}$[14] was acetylated with Ac_2O and pyridine, and the acetylated fraction was subjected to HPLC [ODS, MeOH–H_2O (2 : 3)] to give four fractions (frs. $I_{4\text{-}3\text{-}1}$—$I_{4\text{-}3\text{-}4}$). Fraction $I_{4\text{-}3\text{-}3}$ was deacetylated by heating in a water bath with 5% NH_4OH–MeOH for 2 h to give **9** (3 mg). Fraction I_5 (0.2 g) was subjected to a Lobar RP-8 column [CH_3CN–H_2O (1 : 99)] to give four fractions (frs. $I_{5\text{-}1}$—$I_{5\text{-}4}$). Fraction $I_{5\text{-}3}$[14] was acetylated with Ac_2O and pyridine, and the acetylated fraction was subjected to HPLC [ODS, MeOH—H_2O (2 : 3)] to give four fractions (frs. $I_{5\text{-}2\text{-}1}$—$I_{5\text{-}2\text{-}4}$). Fraction $I_{5\text{-}2\text{-}2}$ was deacetylated by heating in a water bath (80 °C) with 5% NH_4OH–MeOH for 2 h to give **10** (3 mg). Fraction I_6 (0.7 g) was subjected to a Lobar RP-8 column [CH_3CN–H_2O (1 : 99→1 : 19)] to give seven fractions (frs.

$I_{6\text{-}1}$—$I_{6\text{-}7}$). Fraction $I_{6\text{-}5}$ was subjected to HPLC [carbohydrate analysis, CH_3CN–H_2O (24 : 1)] to give **20** (110 mg). Fraction I_7 (11.5 g) was subjected to a Lobar RP-8 column [CH_3CN–H_2O (1 : 99)] to give four fractions (frs. $I_{7\text{-}1}$—$I_{7\text{-}4}$). Fraction $I_{7\text{-}2}$ was subjected to HPLC [carbohydrate analysis, CH_3CN–H_2O (97 : 3)] to give **1** (3 g) and other fractions (frs. $I_{7\text{-}2\text{-}2}$—$I_{7\text{-}2\text{-}4}$). Fraction $I_{7\text{-}2\text{-}2}$[14] was acetylated with Ac_2O and pyridine, and the acetylated fraction was subjected to HPLC [symmetryprep C_{18} (Waters), MeOH–H_2O (1 : 1)] to give four fractions (frs. $I_{7\text{-}2\text{-}2a}$—$I_{7\text{-}2\text{-}2d}$). Fractions $I_{7\text{-}2\text{-}2c}$ and $I_{7\text{-}2\text{-}2d}$ were each deacetylated by heating in a water bath (80 °C) with 5% NH_4OH–MeOH for 2 h to give **12** (2 mg) and **11** (3 mg). Fraction $I_{7\text{-}2\text{-}3}$[14] was acetylated with Ac_2O and pyridine, and the acetylated fraction was subjected to HPLC [symmetryprep C_{18}, MeOH–H_2O (1 : 1)] to give two fractions (frs. $I_{7\text{-}2\text{-}3a}$ and $I_{7\text{-}2\text{-}3b}$). Fractions $I_{7\text{-}2\text{-}3a}$ and $I_{7\text{-}2\text{-}3b}$ were deacetylated by heating with 5% NH_4OH–MeOH for 2 h in a water bath (80 °C) to give **14** (2 mg) and **13** (4 mg). Fraction I_8 was subjected to a Lobar RP-8 column [CH_3CN–H_2O (1 : 99)] to give four fractions (frs. $I_{8\text{-}1}$—$I_{8\text{-}4}$), respectively. Fraction $I_{8\text{-}2}$ was subjected to HPLC [carbohydrate analysis, CH_3CN–H_2O (97 : 3)] to give four fractions (frs. $I_{8\text{-}2\text{-}1}$—$I_{8\text{-}2\text{-}4}$). Fraction $I_{8\text{-}2\text{-}3}$[14] was acetylated with Ac_2O and pyridine, and the acetylated fraction was subjected to HPLC [symmetryprep C_{18}, MeOH–H_2O (1 : 1)] to give two fractions (frs. $I_{8\text{-}2\text{-}3a}$ and $I_{8\text{-}2\text{-}3b}$). Fractions $I_{8\text{-}2\text{-}3a}$ and $I_{8\text{-}2\text{-}3b}$ were deacetylated by heating with 5% NH_4OH–MeOH for 2 h in a water bath (80 °C) to give **3** (20 mg) and **2** (15 mg), respectively. Fraction $I_{8\text{-}2\text{-}4}$[14] was acetylated with Ac_2O and pyridine, and the acetylated fraction was subjected to HPLC [symmetryprep C_{18}, MeOH–H_2O (3 : 2)] and was deacetylated by heating with 5% NH_4OH–MeOH for 2 h in a water bath (80 °C) to give **16** (30 mg). Fraction I_9 was subjected to a Lobar RP-8 column [CH_3CN–H_2O (1 : 99)] to give four fractions (frs. $I_{9\text{-}1}$—$I_{9\text{-}4}$). Fraction $I_{9\text{-}2}$ was subjected to HPLC [carbohydrate analysis, CH_3CN–H_2O (19 : 1)] to give **8** (45 mg). Fraction I_{10} was treated with hot MeOH to give a MeOH soluble portion and insoluble crystal **4** (1.5 g). The MeOH soluble portion was subjected to a Lobar RP-8 column [CH_3CN–H_2O (1 : 99)] to give three fractions (frs. $I_{10\text{-}1}$—$I_{10\text{-}3}$). Fraction $I_{10\text{-}2}$ was subjected to HPLC [carbohydrate analysis, CH_3CN–H_2O (17 : 3)] to give **6** (100 mg), **5** (1 g) and **7** (2 g).

Glycerol (1) A colorless syrup, $[\alpha]_D^{21}$ 0°(c=1.0, H_2O). ^{13}C-NMR (pyridine-d_5, 125 MHz) δ: 64.87 (C-1,3), 74.09 (C-2).

Erythritol (2) An amorphous powder, $[\alpha]_D^{23}$ 0°(c=0.7, MeOH).

D-Threitol (3) An amorphous powder, $[\alpha]_D^{23}$ +4.0° (c=0.9, H_2O), $[\alpha]_D^{23}$ −7.0°(c=0.9, MeOH).

D-Mannitol (4) Colorless needles (MeOH), mp 168—169 °C, $[\alpha]_D^{22}$ −30.0° (c=1.0, pyridine).

D-Glucose (5) Colorless needles (MeOH), mp 80—83 °C, $[\alpha]_D^{22}$ +49.0° (c=1.3, H_2O).

D-Fructose (6) A colorless syrup, $[\alpha]_D^{22}$ −93.0° (c=1.0, H_2O).

Sucrose (7) A colorless syrup, $[\alpha]_D^{22}$ +66.0° (c=1.2, H_2O).

(3*R*)-2-Hydroxymethylbutane-1,2,3,4-tetrol (8) A colorless syrup, $[\alpha]_D^{25}$ +4.4° (c=0.5, MeOH).

1-Deoxythreitol (9) An amorphous powder, $[\alpha]_D^{23}$ +3.0° (c=0.1, MeOH). Positive FAB-MS m/z: 137 $[M+CH_3O]^+$ (base), 129.0543 $[M+Na]^+$ (Calcd for $C_4H_{10}O_3Na$; 129.0528), 89 $[M-H_2O+H]^+$, 71 $[M-2H_2O+H]^+$, 53 $[M-3H_2O+H]^+$. Epimer of **9** (**9′**) ^{1}H-NMR (pyridine-d_5, 270 MHz) δ: 1.65 (3H, d, J=6.5 Hz, H_3-1).

(2*R*)-Butane-1,2,4-triol (10) A colorless syrup, $[\alpha]_D^{23}$ +25.0° (c=0.1, MeOH). Positive FAB-MS m/z: 129.0519 $[M+Na]^+$ (base; Calcd for $C_4H_{10}O_3Na$; 129.0528), 107 $[M+H]^+$, 89 $[M-H_2O+H]^+$, 71 $[M-2H_2O+H]^+$, 53 $[M-3H_2O+H]^+$.

1-Deoxy-D-ribitol (11) A colorless syrup, $[\alpha]_D^{22}$ +9.5° (c=0.2, H_2O), $[\alpha]_D^{22}$ +6.5° (c=0.2, MeOH). Positive FAB-MS m/z: 175 $[M+K]^+$, 159 $[M+Na]^+$, 137.0801 $[M+H]^+$ (base, Calcd for $C_5H_{13}O_4$; 137.0814), 119 $[M-H_2O+H]^+$, 101 $[M-2H_2O+H]^+$. ^{1}H-NMR (D_2O, 500 MHz) δ: 1.18 (3H, d, J=6.4 Hz, H_3-1), 3.57 (1H, dd, J=4.6, 7.7 Hz, H-3), 3.62 (1H, dd, J=6.7, 11.3 Hz, H-5a), 3.66 (1H, ddd, J=2.2, 6.7, 7.7 Hz, H-4), 3.80 (1H, dd, J=2.2, 11.3 Hz, H-5b), 3.99 (1H, dq, J=4.6, 6.4 Hz, H-2). ^{13}C-NMR (D_2O, 125 MHz) δ: 18.63 (C-1), 65.49 (C-5), 70.26 (C-2), 74.84 (C-4), 77.13 (C-3).

1-Deoxy-D-xylitol (12) A colorless syrup, $[\alpha]_D^{22}$ 0° (c=0.1, H_2O), $[\alpha]_D^{22}$ −4.0° (c=0.1, MeOH). Positive FAB-MS m/z: 273 $[2M+H]^+$, 159 $[M+Na]^+$, 137.0826 $[M+H]^+$ (base, Calcd for $C_5H_{13}O_4$; 137.0814), 119 $[M-H_2O+H]^+$, 101 $[M-2H_2O+H]^+$. ^{1}H-NMR (D_2O, 500 MHz) δ: 1.20 (3H, d, J=6.4 Hz, H_3-1), 3.40 (1H, dd, J=3.7, 5.8 Hz, H-3), 3.63 (1H, dd, J=7.0, 11.6 Hz, H-5a), 3.69 (1H, dd, J=4.6, 11.6 Hz, H-5b), 3.78 (1H, ddd, J=3.7, 4.6, 7.0 Hz, H-4), 3.90 (1H, dq, J=5.8, 6.4 Hz, H-2). ^{13}C-NMR (D_2O, 125 MHz) δ: 21.02 (C-1), 65.60 (C-5), 70.79 (C-2), 74.43 (C-4), 77.45 (C-3).

2-Deoxy-D-ribitol (13) A colorless syrup, $[\alpha]_D^{22}$ −20.0° (c=0.3, H_2O), $[\alpha]_D^{22}$ −17.0° (c=0.3, MeOH). Positive FAB-MS m/z: 159.0618 $[M+Na]^+$ (base, Calcd for $C_5H_{12}O_4Na$; 159.0633).

$NaBH_4$ Reduction of 2-Deoxy-D-ribose 2-Deoxy-D-ribose (Kanto Chemical Co. Inc., lot No. 812S4166, 40 mg) was dissolved in methanol (7.5 ml) and stirred with $NaBH_4$ (10 mg) for 5 h at room temperature. After the usual work-up, the residue was purified by silica gel [$CHCl_3$–MeOH (11 : 9)] to give 2-deoxy-D-ribitol (35 mg); a colorless syrup, $[\alpha]_D^{22}$ −20.5° (c=1.3, H_2O), $[\alpha]_D^{22}$ −18.0° (c=1.3, MeOH). The results of ^{1}H- and ^{13}C-NMR were identical with those of **13**.

3-Deoxyarabinitol (14) A colorless syrup, $[\alpha]_D^{22}$ −11.0° (c=0.1, H_2O), $[\alpha]_D^{22}$ −34.5° (c=0.1, MeOH). Positive FAB-MS m/z: 229 $[M+H+glycerol]^+$, 159 $[M+Na]^+$, 137.0802 $[M+H]^+$ (base, Calcd for $C_5H_{13}O_4$; 137.0814).

2-Deoxy-D-ribono-1,4-lactone (15) A colorless syrup, $[\alpha]_D^{22}$ +3.5° (c=0.8, MeOH), $[\alpha]_D^{22}$ +13.5° (c=0.8, H_2O). Positive FAB-MS m/z: 265 $[2M+H]^+$, 171 $[M+K]^+$, 155 $[M+Na]^+$ (base), 133.0500 $[M+H]^+$ (Calcd for $C_5H_9O_4$; 133.0501), 115 $[M-H_2O+H]^+$, 97 $[M-2H_2O+H]^+$, CI-MS (isobutane) m/z: 265 $[2M+H]^+$, 133 $[M+H]^+$ (base), 115 $[M-H_2O+H]^+$. ^{13}C-NMR (D_2O, 67.5 MHz) δ: 37.52 (C-2), 60.03 (C-5), 68.03 (C-3), 88.74 (C-4), 179.23 (C-1).

1-Deoxy-D-glucitol (16) Colorless needles (MeOH), mp 123—126 °C, $[\alpha]_D^{23}$ −3.0° (c=0.5, MeOH), $[\alpha]_D^{23}$ +5.0° (c=0.5, H_2O). Positive FAB-MS m/z: 189.0733 $[M+Na]^+$ (base, Calcd for $C_6H_{14}O_5Na$; 189.0739). ^{1}H-NMR (D_2O, 500 MHz) δ: 1.49 (3H, d, J=6.4 Hz, H3-1), 3.60 (1H, dd, J=1.8, 7.0 Hz, H-3), 3.62 (1H, dd, J=1.8, 8.5 Hz, H-4), 3.64 (1H, dd, J=6.4, 11.8 Hz, H-6a), 3.75 (1H, ddd, J=3.0, 6.4, 8.5 Hz, H-5), 3.82 (1H, dd, J=3.0, 11.8 Hz, H-6b), 3.90 (1H, dq, J=6.4, 7.0 Hz, H-2). ^{13}C-NMR (D_2O, 125 MHz) δ: 20.90 (C-1), 65.66 (C-6), 71.53 (C-2), 73.42 (C-5), 73.66 (C-3), 76.55 (C-4).

Adenosine (17) Colorless needles (MeOH), mp 233—235 °C. $[\alpha]_D^{21}$ −62.0° (c=1.2, H_2O).

2′-Deoxyadenosine (18) Colorless needles (MeOH), mp 187—189 °C, $[\alpha]_D^{23}$ −53.7° (c=0.2, MeOH).

Thymidine (19) Colorless needles (MeOH), mp 186—187 °C, $[\alpha]_D^{21}$ +24.3° (c=0.7, MeOH).

Uridine (20) Colorless needles (MeOH), mp 164—166°C, $[\alpha]_D^{22}$ +4.0° (c=1.8, MeOH).

Urasil (21) Colorless needles (MeOH), mp>300 °C, $[\alpha]_D^{22}$ 0° (c=0.4, pyridine).

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References and Notes

1) Kitajima J., Ishikawa T., Tanaka Y., *Chem. Pharm. Bull.*, **46**, 1643—1646 (1998).
2) *a*) Kitajima J., Ishikawa T., Tanaka T., Ono M., Ito Y., Nohara T., *Chem. Pharm. Bull.*, **46**, 1587—1590 (1998); *b*) Kitajima J., Ishikawa T., Tanaka Y., *ibid.*, **46**, 1591—1594 (1998).
3) Ono M., Ito Y., Ishikawa T., Kitajima J., Tanaka Y., Niiho Y., Nohara T., *Chem. Pharm. Bull.*, **44**, 337—342 (1996); Ishikawa T., Kitajima J., Tanaka Y., *ibid.*, **46**, 1599—1602 (1998); *idem*, *ibid.*, **46**, 1603—1606 (1998); *idem*, *ibid.*, **46**, 1748—1751 (1998); Ishikawa T., Kitajima J., Tanaka Y., Ono M., Ito Y., Nohara T., *ibid.*, **46**, 1738—1742 (1998); Ishikawa T., Tanaka Y., Kitajima J., Ida Y., *ibid.*, **47**, 805—808 (1999).
4) Kitajima J., Suzuki N., Ishikawa T., Tanaka Y., *Chem. Pharm. Bull.*, **46**, 1583—1586 (1998).
5) Ritchie R. G. S., Cyr N., Korch B., Koch H. J., Perlin A. S., *Can. J. Chem.*, **53**, 1424—1433 (1975); Hawkes G. E., Lewis D., *J. Chem. Soc., Perkin Trans. 2*, **1984**, 2073—2078.
6) Prepared by $NaBH_4$ reduction from the corresponding aldoses.
7) 1-Deoxyarabinitol was isolated from the fruit of *Carum ajowan* by us.
8) Synthetic 1-deoxythreitol was obtained by Chaby *et al*., but the NMR data was not reported; Chaby R., Szabo L., *Tetrahedron*, **27**, 3197—3205 (1971).
9) Yamada O., Ogasawara K., *Synthesis*, **1995**, 1291—1294.
10) (2*S*)-form ($[\alpha]_D$ −29°) was synthesized from (*S*)-malic acid; Hungerbuhler E., Seebach D., Wasmuth D., *Angew. Chem., Int. Ed. Engl.*, **18**,

953 (1979).
11) Gillies D. G., Lewis D., *J. Chem. Soc., Perkin Trans. 2*, **1985**, 1155—1159.
12) Lewis D., *J. Chem. Soc., Perkin Trans. 2*, **1991**, 197—200.
13) Han S. Y., Joullie M. M., Petasis N. A., Bigorra J., Font J., Ortuno R. M., *Tetrahedron*, **49**, 349—362 (1993); Han S. Y., Joullie M. M., Fokin V. V., Petasis N. A., *Tetrahedron: Asymmetry*, **5**, 2535—2562 (1994).
14) No acetoxyl group was detectable by NMR spectral data for these fractions.