Furanodictine A and B: Amino Sugar Analogues Produced by Cellular Slime Mold *Dictyostelium discoideum* Showing Neuronal Differentiation Activity

Haruhisa Kikuchi,† Yoshinori Saito,† Jun Komiya,† Yoshiaki Takaya,† Shigeyoshi Honma,† Norimichi Nakahata,† Akira Ito,‡ and Yoshiteru Oshima*,†

Graduate School of Pharmaceutical Sciences, Tohoku University, Aoba-yama, Aoba-ku, Sendai 980-8578, Japan, and Kyorin Pharmaceutical Co., Ltd., 2-5 Kanda-Surugadai, Chiyoda-ku, Tokyo 101-0062, Japan

oshima@mail.pharm.tohoku.ac.jp

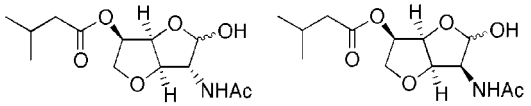
Received April 2, 2001

We investigated the constituents of *Dictyostelium discoideum* to clarify the diversity of secondary metabolites of *Dictyostelium* cellular slime molds and to explore biologically active substances that could be useful in the development of novel drugs. From a methanol extract of the multicellular fruit body of *D. discoideum*, we isolated two novel amino sugar analogues, furanodictine A (**1**) and B (**2**). They are the first 3,6-anhydrosugars to be isolated from natural sources. Their relative structures were elucidated by spectral means, and the absolute configurations were confirmed by asymmetric syntheses of **1** and **2**. These furanodictines potently induce neuronal differentiation of rat pheochromocytoma (PC-12) cells.

Introduction

Cellular slime molds are unique organisms with a two-stage life cycle: a unicellular animal-like feeding stage (a vegetative amoeba stage) and a multicellular plantlike fruit body stage (a reproductive fruit body stage). Spore germination produces unicellular amoebae that feed on bacteria, and when the amoebae starve, they aggregate by chemotaxis to relayed cyclic AMP signals to form fruit bodies consisting of spores and a multicellular stalk. Because of their unique characteristics, cellular slime molds are frequently used in biological studies of multicellular development.[1]

Differentiation-inducing factors (DIFs),[2] discadenine,[3] and several other compounds have been reported as the growth-regulating metabolites of the cellular slime molds. Recently, DIF-1 was found to inhibit proliferation and induce differentiation in mammalian cells, including murine erythroleukemia (B8) and human leukemia (K562) cell lines.[4] Furthermore, the intriguing experimental result suggesting that DIF-1 may induce differentiation of vascular smooth muscle cells in vitro could lead to novel strategies for the treatment of vascular diseases.[5] A chlorine-substituted aromatic compound, AB0022A, was also isolated as an antibacterial substance.[6] The chemical characteristics of cellular slime molds, however, remained uncertain. Recently, we have studied the secondary metabolites produced by cellular slime molds to explore their diversity as well as their physiological and pharmacological activities. Our investigation is leading to the utilization of cellular slime molds as a resource in novel drug development. We have isolated α-pyronoids and aromatics with unique structures,[7,8] which have demonstrated physiologically important activities such as control in cellular slime mold development.[8] In this paper, we outline the elucidation of the structure and the syntheses of two novel amino sugar analogues, furanodictine A (**1**) and B (**2**), as well as their ability to induce neurite outgrowth in rat pheochromocytoma (PC-12) cells.



Furanodictine A (**1**) Furanodictine B (**2**)

Results and Discussion

Isolation and Structure Elucidation. The fruit bodies of the cellular slime mold, *Dictyostelium discoideum*, were cultured on plates (wet wt, 109 g). They were extracted twice with methanol at room temperature to yield the extract (5.6 g), which was partitioned with ethyl acetate and water. The ethyl acetate soluble fraction (1.1 g) was separated by conventional column chromatography over silica gel and ODS to yield **1** (1.9 mg) and **2** (2.8 mg).

* To whom correspondence should be addressed. Phone: +81-22-217-6822. Fax: +81-22-217-6821.
† Tohoku University.
‡ Kyorin Pharmaceutical Co., Ltd.

(1) *Dictyostelium A Model System for Cell and Developmental Biology*; Maeda, Y., Inouye, K., Takeuchi, I., Eds.; Frontiers Science Series No. 21; Universal Academy Press, Inc.: Tokyo, 1997.
(2) (a) Morris, H. R.; Taylor, G. W.; Masento, M. S.; Jermyn, K. A.; Kay, R. R. *Nature* **1987**, *328*, 811−814. (b) Morris, H. R.; Masento, M. S.; Taylor, G. W.; Jermyn, K. A.; Kay, R. R. *Biochem. J.* **1988**, *249*, 903−906.
(3) Abe, H.; Uchiyama, M.; Tanaka, Y.; Saito, H. *Tetrahedron Lett.* **1976**, *42*, 3807−3810.
(4) Asahi, K.; Sakurai, A.; Takahashi, N.; Kubohara, Y.; Okamoto, K.; Tanaka, Y. *Biochem. Biophys. Res. Commun.* **1995**, *208*, 1036−1039.
(5) Miwa, Y.; Sasaguri, T.; Kosaka, C.; Taba, Y.; Ishida, A.; Abumiya, T.; Kubohara, Y. *Circ. Res.* **2000**, *86*, 68−75.
(6) Sawada, T.; Aono, M.; Asakawa, S.; Ito, A.; Awano, K. *J. Antibiot. (Tokyo)* **2000**, *53*, 959−966.
(7) Takaya, Y.; Kikuchi, H.; Terui, Y.; Komiya, J.; Furukawa, K.; Seya, K.; Motomura, S.; Ito, A.; Oshima, Y. *J. Org. Chem.* **2000**, *65*, 985−989.
(8) Takaya, Y.; Kikuchi, H.; Terui, Y.; Komiya, J.; Maeda, Y.; Ito, A.; Oshima, Y. *Tetrahedron Lett.* **2001**, *42*, 61−63.

10.1021/jo015657x CCC: $20.00
Published on Web 09/21/2001

Table 1. ^{13}C and ^{1}H NMR Spectral Data of Furanodictine A (1)

	α-anomer (**1a**)		β-anomer (**1b**)	
positions	^{13}C	^{1}H	^{13}C	^{1}H
1	98.2	5.56 (1H, dd, J = 4.7, 3.7 Hz)	103.6	5.24 (1H, d, J = 9.5 Hz)
2	58.8	4.38−4.45 (1H, m)	60.9	4.38−4.45 (2H, m)
3	87.0	4.58 (1H, dd, J = 5.4, 4.0 Hz)	86.7	
4	78.0	4.91 (1H, t, J = 5.4 Hz)	81.9	4.89−4.92[a] (1H)
5	72.3	5.00 (1H, ddd, J = 7.4, 5.4, 6.3 Hz)	73.2	5.12 (1H, td, J = 5.8, 3.9 Hz)
6	68.6	4.07 (1H, dd, J = 9.4, 6.3 Hz)	71.2	4.13 (1H, dd, J = 10.2, 3.9 Hz)
		3.82 (1H, dd, J = 9.4, 7.4 Hz)		3.90 (1H, dd, J = 10.2, 5.8 Hz)
1′	172.6		172.7	
2′	43.0	2.22−2.30 (2H, m)	42.9	2.22−2.30 (2H, m)
3′	25.7	2.07−2.16 (1H, m)	25.5	2.07−2.16 (1H, m)
4′	22.4[b]	0.97 (3H, d, J = 6.7 Hz)	22.4[c]	0.99 (3H, d, J = 6.7 Hz)
5′	22.3[b]	0.97 (3H, d, J = 6.7 Hz)	22.3[c]	0.98 (3H, d, J = 6.7 Hz)
1″	170.6		170.1	
2″	23.2	2.04 (3H, s)	23.1	2.00 (3H, s)
1-OH		3.36 (1H, d, J = 3.7 Hz)		3.53 (1H, d, J = 9.5 Hz)
2-NH		6.03 (1H, d, J = 7.1 Hz)		5.49 (1H, br.s)

[a] Multiplicity was obscure because of overlap with the signal of H-4 in α-anomer. [b,c] These signals were not distinguishable.

Table 2. ^{13}C and ^{1}H NMR Spectral Data of Furanodictine B (2)

	α-anomer (**2a**)		β-anomer (**2b**)	
positions	^{13}C	^{1}H	^{13}C	^{1}H
1	103.8	5.22 (1H, br.s)	96.7	5.36 (1H, dd, J = 6.8, 5.3 Hz)
2	59.3	4.20 (1H, td, J = 6.3, 4.2 Hz)	54.8	4.43 (1H, dt, J = 8.4, 5.3 Hz)
3	80.4	4.59 (1H, dd, J = 6.3, 5.0 Hz)	81.0	4.51 (1H, dd, J = 5.3, 4.8 Hz)
4	79.9	4.97 (1H, t, J = 5.0 Hz)	81.0	4.82 (1H, dd, J = 5.4, 4.8 Hz)
5	73.0	5.15 (1H, td, J = 6.0, 5.0 Hz)	73.6	5.10 (1H, td, J = 6.2, 5.4 Hz)
6	70.8	4.05 (1H, dd, J = 9.5, 6.0 Hz)	70.3	4.08 (1H, dd, J = 9.5, 6.2 Hz)
		3.80 (1H, dd, J = 9.5, 6.0 Hz)		3.95 (1H, dd, J = 9.5, 6.2 Hz)
1′	172.2		172.3	
2′	43.1	2.26 (1H, dd, J = 15.0, 7.3 Hz)	43.0	2.28 (1H, dd, J = 15.0, 7.3 Hz)
		2.22 (1H, dd, J = 15.0, 7.0 Hz)		2.24 (1H, dd, J = 15.0, 7.0 Hz)
3′	25.7	2.08−2.15 (1H, m)	25.6	2.08−2.15 (1H, m)
4′	22.5[a]	0.95 (3H, d, J = 6.6 Hz)	22.5[b]	0.96 (3H, d, J = 6.6 Hz)
5′	22.4[a]	0.95 (3H, d, J = 6.6 Hz)	22.4[b]	0.96 (3H, d, J = 6.6 Hz)
1″	171.0		170.2	
2″	23.2	2.03 (3H, s)	23.2	2.04 (3H, s)
1-OH		3.80−3.82 (1H, br.s)		3.31 (1H, d, J = 6.8 Hz)
2-NH		6.15 (1H, d, J = 6.3 Hz)		6.12 (1H, d, J = 8.4 Hz)

[a,b] These signals were not distinguishable.

The ^{1}H and ^{13}C NMR spectra of **1** suggested that **1** is an equilibrium mixture of two stereoisomers (**1a** and **1b**) in a ratio of 7:1. The molecular formula $C_{13}H_{21}NO_6$ indicated for **1** was established by HREI-MS (m/z 288.1429 $[M + H]^+$) and ^{1}H and ^{13}C NMR spectra (Table 1). We first analyzed NMR signals assignable to the major isomer (**1a**). The ^{13}C NMR spectrum of **1a** revealed the presence of two carbonyls, an acetal, three oxymethines, an oxymethylene, a nitrogen-adjacent methine, a methine, a methylene, and three methyls. ^{1}H NMR spectrum of **1a** exhibited signals due to the protons of an acetal (δ 5.56 (1H, dd, J = 4.7, 3.7 Hz)), three oxymethines (δ 5.00 (1H, ddd, J = 7.4, 6.3, 5.4 Hz), 4.91 (1H, t, J = 5.4 Hz), and 4.58 (1H, dd, J = 5.4, 4.0 Hz)), an oxymethylene (δ 4.07 (1H, dd, J = 9.4, 6.3 Hz) and 3.82 (1H, dd, J = 9.4, 7.4 Hz)), and a nitrogen-adjacent methine (δ 4.38−4.45 (1H, m)). $^{1}H-^{1}H$ COSY unambiguously gave the sequence of the protons suggesting that **1a** is an analogue of an amino sugar. $^{1}H-^{1}H$ COSY also pointed out the presence of an isovaleryloxy group. In the heteronuclear multiple-bond correlation (HMBC) spectrum, two carbonyl carbons (δ 170.6 and 172.6) were correlated through three σ-bonds with the nitrogen-adjacent methine (δ 4.41) and oxymethine (δ 5.00) protons, respectively, while the long-range C−H correlations indicated the presence of the acetamide and isovaleryloxy groups at C-2 and C-5 (Figure 1). The 3,6-anhydrohexofuranose carbon skeleton of **1a** was deduced by long-range C−H couplings of C-3−H-6, C-6−H-3, and C-4−H-1 (Figure 1). NOESY spectrum exhibited cross peaks as follows: H-1−H-2, H-3−H-4, and H-4−H-5 (Figure 2), indicating that the acetal, nitrogen-adjacent methine, and oxymethine protons at C-1 to C-5 are situated spatially as β, β, α, α, and α, respectively. The relative stereostructure of **1a** is, therefore, represented as shown in the formula, which is thought to be biotransformed from *N*-acetylglucosamine (Figure 2). **1b** was deduced to be a β-anomer using a $^{1}H-^{1}H$ COSY and NOESY spectrum.

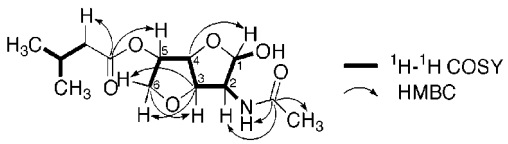


Figure 1. Planar structure of α-anomer of furanodictine A (**1a**).

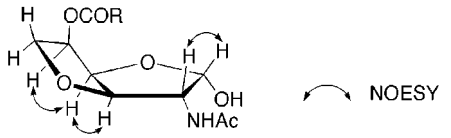
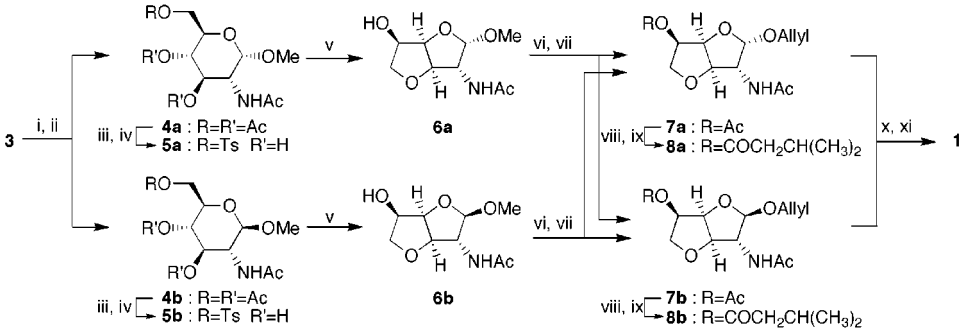


Figure 2. Relative structure of α-anomer of furanodictine A (**1a**).

Scheme 1[a]

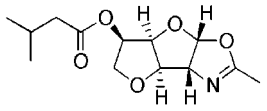


[a] Reagents and conditions: (i) MeOH, cat. H_2SO_4, reflux; (ii) Ac_2O, pyridine, rt; (iii) NaOMe, MeOH, rt; (iv) *p*-TsCl, pyridine, 0 °C; (v) NaOMe, MeOH, reflux; (vi) allyl alcohol, cat. H_2SO_4, reflux; (vii) Ac_2O, pyridine, rt; (viii) NaOMe, MeOH, rt; (ix) isovaleric acid, EDCI, DMAP, CH_2Cl_2, rt; (x) Wilkinson's catalyst, DABCO, EtOH−H_2O (9:1), reflux; (xi) microencapsulated OsO_4, NMO, H_2O−acetonitrile−acetone (1:1:1), rt

The HREI-MS of **2** gave the same molecular formula, $C_{13}H_{21}NO_6$, as that of **1**. As in the case of **1**, **2** is composed of two stereoisomers (**2a** and **2b**), which equilibrate in a ratio of 2:3. Both the stereoisomers (**2a** and **2b**) showed similar correlations of H-2−H-3, H-3−H-4, and H-4−H-5 in the NOESY spectrum, indicating that H-2 to H-5 are oriented in the same plane. The observation of NOE between H-1 and H-2 only in **2b** helped to determine that **2a** and **2b** are α- and *β*-anomers, respectively, and that they might be derived from *N*-acetylmannosamine.

Synthesis and Absolute Configuration. To determine the absolute configurations of **1** and **2**, total syntheses of these compounds were carried out (Scheme 1).

The anomeric mixture of *N*-acetyl-D-glucosamine (**3**) was used as a starting material in the synthesis of **1**. The treatment of **3** in 5% sulfuric acid−methanol gave a mixture of α- and *β*-anomers of the methyl glycoside and their deacetylated products. Acetylation of the mixture of the compounds with acetic anhydride−pyridine afforded α- and *β*-anomers (**4a** and **4b**) of the tetraacetylated compound. Deacetylation of the α-anomer (**4a**), using sodium methoxide, and subsequent tosylation, with *p*-tosyl chloride in pyridine, gave 6-*O*-tosylate (**5a**). 3,6-Anhydroglucofuranoside (**6a**) prepared from **5a** with sodium methoxide was refluxed in 5% sulfuric acid−allyl alcohol to obtain the mixture of 3,6-anhydroglucofuranoside and its deacetylated product. Acetylation of this mixture gave α- and *β*-anomers (**7a** and **7b**) of the allyl glycoside. **4b** was also converted into **7a** and **7b** by the same sequential treatment as the α-anomer (**4a**). Deacetylation of the α-anomer (**7a**), using sodium methoxide, and subsequent esterification, with isovaleric acid in the presence of EDCI and DMAP, gave an isovalerate (**8a**). Deallylation of **8a** using $PdCl_2$[9] did not give **1** but oxazoline (**9**) as a major product. The treatment of **8a** with Wilkinson's catalyst in 10% aqueous ethanol followed by oxidative cleavage of 1-propenyl glycoside with microencapsulated osmium tetroxide[10,11] allowed us to complete the synthesis of **1**. The *β*-anomer (**7b**) was also converted into **1** by the similar sequential treatment as the α-anomer (**7a**).



9

2 was synthesized from an anomeric mixture of *N*-acetyl-D-mannosamine (**10**) in a similar manner as **1**, but the α- and *β*-anomers of allyl glycoside (**14a** and **14b**) could not be separated by silica gel chromatography.

All of the spectral data on synthetic furanodictine A and B, including their respective specific rotations, were identical with those of their respective natural compounds. From this result, the absolute configurations of **1** and **2** were determined to be 2*R*, 3*R*, 4*S*, 5*R* and 2*S*, 3*R*, 4*S*, 5*R*, which are the same as those of *N*-acetyl-D-glucosamine (**3**) and *N*-acetyl-D-mannosamine (**10**), respectively.

Biological Evaluation.PC-12 cells were used to evaluate the potency of the effects of the compounds on neuronal differentiation. These cells were cultivated in Dulbecco's modified Eagle's medium (DMEM) containing 0.5% FCS with **1** or **2** at the concentrations of 0.5−50 *μ*M for 4 days. This was followed by the observation of neurite outgrowth of the cells under a phase-contrast microscope. **2** caused the PC-12 cells to change in morphology and extend neurites in a concentration-dependent manner with an EC_{50} value of about 2 *μ*M. The number of cells bearing neurites increased from 10 to 18% upon the addition of **2** at a concentration of 20 *μ*M. Despite the apparent activity of **2**, **1** only weakly induced the morphological differentiation. However, both **1** and **2** at concentrations of 0.5−5 *μ*M caused a great extent of neurite extension in the presence of 2 ng mL^{-1} of nerve growth factor (NGF). These results indicate that furanodictines have the ability to cause neuronal differentiation.

Conclusion

To the best of our knowledge, **1** and **2** are the first examples of amino sugar analogues that bear a 3,6-anhydrohexofuranose carbon skeleton and are derived from natural sources. Their isolation may draw attention as amino sugars rarely occur as free compounds or as simple derivatives. The *Streptomyces* family of molds is a particularly abundant source of a variety of amino sugars, thus becoming the popular source of various

(9) Ogawa, T.; Kitajima, T.; Nukada, T. *Carbohydr. Res.* **1983**, *123*, C5−C7.
(10) Lamberth, C.; Bernarski, M. D. *Tetrahedron Lett.* **1991**, *32*, 7369−7372.
(11) Nagayama, S.; Endo, M.; Kobayashi, S. *J. Org. Chem.* **1998**, *63*, 6094−6095.

antibiotics containing amino sugars.[12] The isolation of α-pyrones and aromatic compounds from *Dictyostelium* cellular slime molds previously described[7,8] implies that cellular slime molds may have a diversity of secondary metabolites as the *Streptomyces* family. Furthermore, our study demonstrating that **2**, derived from *N*-acetylmannosamine ocurring in glycoproteins but to rather limited extent compared to *N*-acetylglucosamine,[12] shows a strong neuronal differentiation activity suggests that the activity can be a focus in the biological study of the functions of amino sugars.

Experimental Section

General Methods. Analytical TLC was performed on silica gel 60 F_{254} (Merck). Column chromatography was carried out on silica gel 60 (70−230 mesh, Merck). Chemical shifts for ^{1}H and ^{13}C NMR are given in parts per million (δ) relative to internal standards.

Organism and Culture Conditions. Cellular slime mold, *D. discoideum* NC-4, was kindly supplied by Professor Y. Maeda, Tohoku University. Spores were cultured at 22 °C with *Escherichia coli* Br on A-medium consisting of 0.5% glucose, 0.5% polypeptone, 0.05% yeast extract, 0.225% KH_2PO_4, 0.137% $Na_2HPO_4 \cdot 12H_2O$, 0.05% $MgSO_4 \cdot 7H_2O$, and 1.5% agar. When the fruit body was formed in 5 days, they were harvested for extraction.

Isolation of 1 and 2. The cultured fruit body (wet wt 109 g) of *D. discoideum* was extracted twice with methanol at room temperature to give the extract (5.6 g). This extract was partitioned with ethyl acetate and water to yield ethyl acetate solubles (1.1 g). The ethyl acetate solubles were chromatographed over SiO_2, and the column was eluted with *n*-hexanes−ethyl acetate mixtures with increasing polarity. Ethyl acetate eluent (130 mg) was further chromatographed over ODS using a methanol−water mixture to give crude furanodictines. The crude sample was purified by SiO_2 column chromatography (chloroform−methanol, 27:1) to give **1** (1.9 mg) and **2** (2.8 mg). **1**: $[\alpha]^{25}_D$ +100.4 (*c* 0.233, $CHCl_3$); a colorless oil; ^{1}H NMR and ^{13}C NMR data are shown in Table 1; EI-MS *m/z* 288 $[M + H]^+$, 270, 258, 244, 227, 60 (base), 43; HREI-MS *m/z* 288.1429 (288.1446 calcd for $C_{13}H_{22}NO_6$). **2**: $[\alpha]^{25}_D$ +85.6 (*c* 0.250, $CHCl_3$); a colorless oil; ^{1}H NMR and ^{13}C NMR data are shown in Table 2; EI-MS *m/z* 288 $[M + H]^+$, 270, 258, 244, 227, 60 (base), 43; HREI-MS *m/z* 288.1455 (288.1446 calcd for $C_{13}H_{22}NO_6$).

Methyl 2-acetamido-3,4,6-*O*-triacetyl-2-deoxy-α-D-glucopyranoside (4a) and methyl 2-acetamido-3,4,6-*O*-triacetyl-2-deoxy-β-D-glucopyranoside (4b). *N*-Acetyl-D-glucosamine (2-acetamido-2-deoxy-D-glucopyranose) (**3**) (5.00 g, 22.6 mmol) was dissolved in methanol (40 mL), and sulfuric acid (0.8 mL) was added to this solution. After being refluxed for 3 h, the mixture was neutralized with Dowex 1 × 8 (OH^-) until the pH reached 10. The solvent was evaporated to give a residue which was the mixture of methyl 2-acetamido-2-deoxy-D-glucopyranoside and methyl 2-amino-2-deoxy-D-glucopyranoside. This mixture was treated with an excess of acetic anhydride (10 mL) in pyridine (25 mL). After 10 h, the mixture was poured into 0.1 M hydrochloric acid (100 mL) and extracted three times with ethyl acetate. The organic layer was washed with saturated sodium bicarbonate solution, water, and brine, dried over anhydrous sodium sulfate, and evaporated. The residue was purified by SiO_2 column chromatography to give **4a** (3.08 g, 38%), which was eluted by chloroform, and **4b** (1.98 g, 24%), which was eluted by chloroform−methanol (99:1). **4a**: a colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.67 (1H, d, *J* = 9.5 Hz), 5.17 (1H, dd, *J* = 10.5, 9.6 Hz), 5.08 (1H, dd, *J* = 10.1, 9.6 Hz), 4.69 (1H, d, *J* = 3.7 Hz), 4.31 (1H, ddd, *J* = 10.6, 9.6, 3.7 Hz), 4.20 (1H, dd, *J* = 12.4, 4.7 Hz), 4.07 (1H, dd, *J* = 12.4, 2.4 Hz), 3.88 (1H, ddd, *J* = 10.1, 4.7, 2.4 Hz), 3.37 (3H, s), 2.06 (3H, s), 1.99 (3H, s), 1.98 (3H, s), 1.92 (3H, s); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 171.3, 170.6, 169.8, 169.2, 98.3, 71.3, 68.1, 67.6, 62.0, 55.4, 51.8, 23.1, 20.7 (2C), 20.5; EI-MS *m/z* 362 $[M + H]^+$, 330, 302, 43 (base); HREI-MS *m/z* 362.1454 (362.1452 calcd for $C_{15}H_{24}NO_9$). **4b**: a colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.68 (1H, d, *J* = 8.8 Hz), 5.28 (1H, dd, *J* = 10.5, 9.6 Hz), 5.08 (1H, t, *J* = 9.6 Hz), 4.60 (1H, d, *J* = 8.3 Hz), 4.28 (1H, dd, *J* = 12.3, 4.8 Hz), 4.15 (1H, dd, *J* = 12.3, 2.4), 3.88 (1H, dt, *J* = 10.5, 8.6 Hz), 3.72 (1H, ddd, *J* = 10.0, 4.8, 2.4 Hz), 3.50 (3H, s), 2.09 (3H, s), 2.03 (3H, s), 2.03 (3H, s), 1.96 (3H, s); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 170.9, 170.7, 170.2, 169.3, 101.6, 72.4, 71.8, 68.7, 62.1, 56.7, 54.6, 23.3, 20.7, 20.6, 20.6; EI-MS *m/z* 362 $[M + H]^+$,346, 330, 302, 288, 43 (base); HREI-MS *m/z* 362.1477 (362.1452 calcd for $C_{15}H_{24}NO_9$).

Methyl 2-acetamido-2-deoxy-6-*O*-tosyl-α-D-glucopyranoside (5a). 4a (2.97 g, 8.23 mmol) in methanol (40 mL) was treated with sodium methoxide (2.00 g, 37.0 mmol) at room temperature for 3 h. The mixture was neutralized with Dowex 50w (H^+) until the pH reached 3. The solvent was evaporated to give a white solid which was methyl 2-acetamido-2-deoxy-α-D-mannopyranoside. This solid was dissolved in pyridine (20 mL), and this solution was cooled to 0 °C. *p*-Toluenesulfonyl chloride (1.73 g, 0.905 mmol) was added to the solution. After 3 h, the reaction was quenched by the use of methanol (10 mL). The mixture was poured into 0.1 M hydrochloric acid (100 mL) and extracted three times with ethyl acetate. The organic layer was washed with saturated sodium bicarbonate solution, water, and brine, dried over anhydrous sodium sulfate, and evaporated. The residue was purified by SiO_2 column chromatography (chloroform−methanol, 96:4) to give **5a** (1.22 g, 38%). **5a**: colorless needles; ^{1}H NMR (CD_3OD, 500 MHz) δ 7.79 (2H, d, *J* = 8.2 Hz), 7.43 (2H, d, *J* = 8.2 Hz), 4.52 (1H, d, *J* = 3.6 Hz), 4.32 (1H, dd, *J* = 10.8, 1.8 Hz), 4.18 (1H, dd, *J* = 10.8, 6.0 Hz), 3.81 (1H, dd, *J* = 10.7, 3.6 Hz), 3.65 (1H, ddd, *J* = 10.0, 6.0, 1.8 Hz), 3.55 (1H, dd, *J* = 10.7, 8.8 Hz), 3.28 (3H, s), 3.24 (1H, dd, *J* = 10.0, 8.8 Hz), 2.44 (3H, s), 1.95 (3H, s); ^{13}C NMR (CD_3OD, 125 MHz) δ 173.4, 146.5, 134.5, 131.0 (2C), 129.1 (2C), 99.7, 72.8, 71.9, 71.1, 71.0, 55.6, 55.1, 22.5, 21.6; EI-MS *m/z* 389 $[M]^+$, 357, 60 (base), 43; HREI-MS *m/z* 389.1112 (389.1149 calcd for $C_{16}H_{23}NO_8S$).

Methyl 2-acetamido-2-deoxy-6-*O*-tosyl-β-D-glucopyranoside (5b). By the use of **4b** (1.87 g, 5.18 mmol) as a substrate, **5b** (746 mg, 37%) was afforded in the same manner as the synthesis of **5a**. **5b**: colorless needles; ^{1}H NMR (CD_3OD, 500 MHz) δ 7.79 (2H, d, *J* = 8.4 Hz), 7.43 (2H, d, *J* = 8.4 Hz), 4.34 (1H, dd, *J* = 10.8, 2.0 Hz), 4.24 (1H, d, *J* = 8.5 Hz), 4.16 (1H, dd, *J* = 10.8, 6.0 Hz), 3.55 (1H, dd, *J* = 10.3, 8.5 Hz), 3.35−3.42 (2H, m), 3.34 (3H, s), 3.22 (1H, dd, *J* = 9.8, 8.9 Hz), 2.44 (3H, s), 1.94 (3H, s); ^{13}C NMR (CD_3OD, 125 MHz) δ 173.8, 146.5, 134.4, 131.0 (2C), 129.1 (2C), 103.3, 75.9, 75.0, 71.6, 70.8, 57.1, 56.9, 22.9, 21.6; EI-MS *m/z* 389 $[M]^+$, 357, 43 (base); HREI-MS *m/z* 389.1178 (389.1149 calcd for $C_{16}H_{23}NO_8S$).

Methyl 2-acetamido-3,6-anhydro-2-deoxy-α-D-glucofuranoside (6a). 5a (1.20 g, 3.08 mmol) in methanol (30 mL) was treated with sodium methoxide (500 mg, 9.26 mmol) and stirred for 3 h at 65 °C. After being cooled, the mixture was acidified with Dowex 50w (H^+) until the pH reached 3. The solvent was evaporated, and the residue was purified by SiO_2 column chromatography (chloroform−methanol 96:4) to give **6a** (494 mg, 79%). **6a**: colorless and amorphous; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 6.00 (1H, br.s), 5.09 (1H, d, *J* = 4.3 Hz), 4.55 (1H, t, *J* = 5.4 Hz), 4.44−4.48 (2H, m), 4.18−4.23 (1H, m), 3.97 (1H, dd, *J* = 9.4, 6.0 Hz), 3.62 (1H, dd, *J* = 9.4, 7.5 Hz), 3.42 (3H, s), 2.51 (1H, d, *J* = 8.5 Hz), 2.02 (3H, s); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 169.8, 104.2, 87.1, 78.8, 71.5, 71.0, 58.4, 55.3, 23.2; EI-MS *m/z* 218 $[M + H]^+$, 185, 158, 128, 43 (base); HREI-MS *m/z* 218.1036 (218.1027 calcd for $C_9H_{16}NO_5$).

Methyl 2-acetamido-3,6-anhydro-2-deoxy-β-D-glucofuranoside (6b). By the use of **5b** (741 mg, 1.90 mmol) as a substrate, the reaction was carried out in the same manner as the synthesis of **6a**. The crude product was purified by SiO_2 column chromatography to give **6a** (24 mg, 6%), which was

(12) *Comprehensive Organic Chemistry The Synthesis and Reactions of Organic Compounds*; Haslam, E., Ed.; Pergamon Press: Oxford, 1979; Vol. 5.

eluted by chloroform−methanol (96:4), and **6b** (329 mg, 86%), which was eluted by chloroform−methanol (90:10). **6b**: colorless and amorphous; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.80 (1H, br.s), 4.99 (1H, s), 4.83 (1H, t, J = 5.7 Hz), 4.40 (1H, d, J = 5.5 Hz), 4.31 (1H, d, J = 7.4 Hz), 4.22 (1H, dq, J = 10.2, 5.7 Hz), 3.82 (2H, d, J = 5.7 Hz), 3.49 (3H, s), 2.86 (1H, d, J = 10.2 Hz), 2.01 (3H, s); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 169.7, 110.8, 86.3, 84.1, 73.7, 71.2, 61.7, 56.4, 23.1; EI-MS *m*/*z* 218 $[M + H]^+$, 185, 158, 128, 43 (base); HREI-MS *m*/*z* 218.1024 (218.1027 calcd for $C_9H_{16}NO_5$).

Allyl 2-acetamido-5-*O*-acetyl-3,6-anhydro-2-deoxy-α-D-glucofuranoside (7a) and allyl 2-acetamido-5-*O*-acetyl-3,6-anhydro-2-deoxy-*β*-D-glucofuranoside (7b). Sulfuric acid (0.3 mL) was added to a solution of **6a** (478 mg, 2.19 mmol) in allyl alcohol (10 mL). After being stirred at 80 °C for 2 h, the mixture was neutralized with Dowex 1 × 8 (OH^-) until the pH reached 10. The solvent was evaporated to give a residue which was the mixture of allyl 2-acetamido-3,6-anhydro-2-deoxy-D-glucofuranoside and allyl 2-amino-3,6-anhydro-2-deoxy-D-glucofuranoside. This mixture was treated with an excess of acetic anhydride (1.3 mL) in pyridine (10 mL). After 10 h, the mixture was poured into 0.1 M hydrochloric acid (40 mL) and extracted three times with ethyl acetate. The organic layer was washed with saturated sodium bicarbonate solution, water, and brine, dried over anhydrous sodium sulfate, and evaporated. The residue was purified by SiO_2 column chromatography to give **7a** (337 mg, 54%), which was eluted by chloroform−methanol (99:1), and **7b** (190 mg, 30%), which was eluted by chloroform−methanol (95:5).

By the use of **6b** (320 mg, 1.47 mmol) as a substrate, **7a** (202 mg, 48%) and **7b** (122 mg, 29%) were afforded in the same manner described above. **7a**: a colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 6.05 (1H, d, J = 7.5 Hz), 5.87 (1H, dddd, J = 17.2, 10.4, 6.1, 5.3 Hz), 5.26 (1H, dq, J = 17.2, 1.5 Hz), 5.20−5.22 (1H, m), 5.20 (1H, d, J = 4.3 Hz), 4.99 (1H, dt, J = 7.5, 6.0 Hz), 4.75 (1H, t, J = 5.3 Hz), 4.47−4.52 (2H, m), 4.22 (1H, ddt, J = 12.8, 5.3, 1.5 Hz), 4.06 (1H, dd, J = 9.3, 6.3 Hz), 4.01 (1H, ddt, J = 12.8, 6.1, 1.2 Hz), 3.82 (1H, dd, J = 9.3, 7.8 Hz), 2.13 (3H, s), 2.02 (3H, s); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 170.3, 169.8, 133.6, 117.7, 102.5, 87.3, 77.7, 72.2, 68.5, 68.2, 58.2, 23.1, 20.6; EI-MS *m*/*z* 286 $[M + H]^+$, 244, 226, 202, 43 (base); HREI-MS *m*/*z* 286.1268 (286.1289 calcd for $C_{13}H_{20}NO_6$). **7b**: a colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 6.06 (1H, br.s), 5.92 (1H, dddd, J = 17.2, 10.4, 6.0, 5.2 Hz), 5.30 (1H, dq, J = 17.2, 1.7 Hz), 5.20 (1H, dq, J = 10.4, 1.5 Hz), 5.03 (1H, s), 4.93−4.97 (2H, m), 4.53 (1H, d, J = 4.6 Hz), 4.37 (1H, d, J = 7.5 Hz), 4.26 (1H, ddt, J = 12.7, 5.2, 1.5 Hz), 3.98−4.07 (3H, m), 2.13 (3H, s), 1.99 (3H, s); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 170.3, 169.7, 133.5, 117.4, 107.6, 86.6, 81.1, 73.2, 68.6, 68.6, 62.3, 23.0, 20.6; EI-MS *m*/*z* 286 $[M + H]^+$, 244, 226, 202, 43 (base); HREI-MS *m*/*z* 286.1329 (286.1289 calcd for $C_{13}H_{20}NO_6$).

Allyl 2-acetamido-3,6-anhydro-2-deoxy-5-*O*-isovaleryl-α-D-glucofuranoside (8a). 7a (517 mg, 1.81 mmol) in methanol (10 mL) was treated with sodium methoxide (120 mg, 2.22 mmol) at room temperature for 2 h. The mixture was neutralized with Dowex 50w (H^+) until the pH reached 3. The solvent was evaporated to give a white solid which was allyl 2-acetamido-3,6-anhydro-2-deoxy-α-D-glucofuranoside. This solid was dissolved in dichloromethane (10 mL), and the solution was cooled at 0 °C. Isovaleric acid (240 μL, 2.20 mmol), 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide hydrochloride (694 mg, 3.62 mmol), and DMAP (221 mg, 1.81 mmol) were added to this solution. After being stirred for 3 h, the mixture was poured into 0.1 M hydrochloric acid (40 mL) and extracted three times with ethyl acetate. The organic layer was washed with saturated sodium bicarbonate solution, water, and brine, dried over anhydrous sodium sulfate, and evaporated. The residue was purified by SiO_2 column chromatography (chloroform−methanol, 99:1) to give **8a** (399 mg, 67%). **8a**: a colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 6.05 (1H, d, J = 7.6 Hz), 5.87 (1H, dddd, J = 17.2, 10.4, 6.0, 5.3 Hz), 5.25 (1H, dq, J = 17.2, 1.4 Hz), 5.18−5.22 (1H, m), 5.18 (1H, d, J = 4.6 Hz), 4.99 (1H, dt, J = 7.5, 6.0 Hz), 4.77 (1H, t, J = 5.3 Hz), 4.47−4.52 (2H, m), 4.20(1H, ddt, J = 12.8, 5.3, 1.5 Hz), 4.06 (1H, dd, J = 9.3, 6.3 Hz), 4.00 (1H, ddt, J = 12.8, 6.3, 1.2 Hz), 3.83 (1H, dd, J = 9.3, 7.8 Hz), 2.28 (1H, dd, J = 14.7, 7.5 Hz), 2.24 (1H, dd, J = 14.7, 6.8 Hz), 2.08−2.16 (1H, m), 2.02 (3H, s), 0.98 (6H, d, J = 6.6 Hz); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 172.4, 169.8, 133.5, 117.8, 102.3, 87.4, 77.7, 72.0, 68.5, 68.3, 58.2, 43.0, 25.7, 23.2, 22.2, 22.2; EI-MS *m*/*z* 328 $[M + H]^+$, 286, 268, 202, 85 (base), 57, 43; HREI-MS *m*/*z* 328.1805 (328.1759 calcd for $C_{16}H_{26}NO_6$).

Allyl 2-acetamido-3,6-anhydro-2-deoxy-5-*O*-isovaleryl-*β*-D-glucofuranoside (8b). By the use of **7b** (299 mg, 1.05 mmol) as a substrate, **8b** (264 mg, 77%) was afforded in the same manner as the synthesis of **8a**. **8b**: a colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.85−5.96 (2H, m), 5.30 (1H, dq, J = 17.2, 1.7 Hz), 5.20 (1H, dq, J = 10.4, 1.5 Hz), 5.03 (1H, s), 4.93−4.98 (2H, m), 4.53 (1H, d, J = 4.7 Hz), 4.38 (1H, d, J = 7.6 Hz), 4.26 (1H, ddt, J = 12.8, 5.2, 1.5 Hz), 3.96−4.08 (3H, m), 2.25−2.27 (2H, m), 2.09−2.17 (1H, m), 1.99 (3H, s), 0.99 (6H, d, J = 6.6 Hz); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 172.5, 169.6, 133.6, 117.4, 107.5, 86.5, 81.1, 73.1, 68.6, 68.5, 62.3, 43.1, 25.7, 23.1, 22.4, 22.3; EI-MS *m*/*z* 328 $[M + H]^+$, 286, 268, 253, 85 (base), 57, 43; HREI-MS *m*/*z* 328.1780 (328.1759 calcd for $C_{16}H_{26}NO_6$).

2-Acetamido-3,6-anhydro-2-deoxy-5-*O*-isovaleryl-D-glucofuranose (furanodictine A) (1). Chlorotris(triphenylphosphine)rhodium(I) (157 mg, 0.170 mmol) and DABCO (19.1 mg, 0.170 mmol) were added to a solution of **8a** (278 mg, 0.849 mmol) in ethanol−water (9:1) (7 mL). After being refluxed for 2 h, the mixture was filtered with ethyl acetate, and the filtrate was evaporated. The residue was purified by SiO_2 column chromatography (ethyl acetate−methanol, 39:1) to give 1-propenyl glycoside. This glycoside was dissolved in water−acetonitrile−acetone (1:1:1) (7 mL). *N*-Methylmorpholine *N*-oxide (129 mg, 1.10 mmol) and microencapsulated osmium tetroxide (110 mg, it contains 10% osmium tetroxide; Wako Pure Chemicals, Osaka) were added to this solution. After being stirred at room temperature for 9 h, the mixture was filtered with methanol, and the filtrate was evaporated. The residue was purified by SiO_2 column chromatography (ethyl acetate−methanol, 9:1) to give **1** (137 mg, 56% from **8a**). By the use of **8b** (140 mg, 0.426 mmol) as a substrate, **1** (85.1 mg, 69% from **8b**) was afforded in the same manner as described above.Synthetic **1**: $[\alpha]^{25}_D$ +118.5 (*c* 0.437, $CHCl_3$); other spectral data were identical with those of the natural product.

Methyl 2-acetamido-3,4,6-*O*-triacetyl-2-deoxy-α-D-mannopyranoside (11a) and methyl 2-acetamido-3,4,6-*O*-triacetyl-2-deoxy-*β*-D-mannopyranoside (11b). By the use of *N*-acetyl-D-mannosamine (2-acetamido-2-deoxy-D-mannopyranose) monohydrate (**10**) (233 mg, 0.974 mmol) as a substrate, the reaction was carried out in the same manner as the synthesis of **4a** and **4b**. The crude product was purified by SiO_2 column chromatography to give **11a** (197 mg, 56%), which was eluted by chloroform, and **11b** (118 mg, 34%), which was eluted by chloroform−methanol (99:1). **11a**: a colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 6.00 (1H, d, J = 9.1 Hz), 5.32 (1H, dd, J = 10.2, 4.5 Hz), 5.10 (1H, t, J = 10.2 Hz), 4.66 (1H, d, J = 1.4 Hz), 4.62 (1H, ddd, J = 9.1, 4.5, 1.4 Hz), 4.28 (1H, dd, J = 12.2, 5.8 Hz), 4.08 (1H, dd, J = 12.2, 2.4 Hz), 3.97 (1H, ddd, J = 10.2, 5.8, 2.4 Hz), 3.40 (3H, s), 2.11 (3H, s), 2.05 (3H, s), 2.05 (3H, s), 1.99 (3H, s); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 170.5, 170.0, 169.8, 169.8, 100.0, 69.0, 67.8, 66.1, 62.5, 55.1, 50.1, 23.1, 20.6 (2C), 20.5; EI-MS *m*/*z* 362 $[M + H]^+$, 346, 330, 302, 43 (base); HREI-MS *m*/*z* 362.1451 (362.1452 calcd for $C_{15}H_{24}NO_9$). **11b**: a colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 6.15 (1H, d, J = 8.8 Hz), 5.57 (1H, dd, J = 5.5, 3.5 Hz), 5.19 (1H, ddd, J = 9.5, 5.5, 2.4 Hz), 4.88 (1H, d, J = 4.1 Hz), 4.69 (1H, ddd, J = 8.8, 5.5, 4.1 Hz), 4.53 (1H, dd, J = 12.2, 2.4 Hz), 4.34 (1H, dd, J = 9.5, 3.5 Hz), 4.14 (1H, dd, J = 12.2, 5.5 Hz), 3.38 (3H, s), 2.08 (3H, s), 2.07 (3H, s), 2.01 (3H, s), 1.99 (3H, s); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 170.6, 169.8, 169.7, 169.2, 107.6, 76.4, 71.5, 67.7, 63.0, 56.9, 55.7, 22.9, 20.7, 20.6, 20.4; EI-MS *m*/*z* 362 $[M + H]^+$, 330, 302, 288, 43 (base); HREI-MS *m*/*z* 362.1459 (362.1452 calcd for $C_{15}H_{24}NO_9$).

Methyl 2-acetamido-2-deoxy-6-*O*-tosyl-α-D-mannopyranoside (12a). By the use of **11a** (101.1 mg, 0.280 mmol) as a substrate, **12a** (60.1 mg, 55%) was afforded in the same

manner as the synthesis of **5a**. **12a**: colorless needles; ^{1}H NMR (CD_3OD, 500 MHz) δ 7.80 (2H, d, J = 8.2 Hz), 7.43 (2H, d, J = 8.2 Hz), 4.48 (1H, d, J = 1.4 Hz), 4.36 (1H, dd, J = 10.7, 1.9 Hz), 4.21 (1H, dd, J = 5.2, 1.4 Hz), 4.20 (1H, dd, J = 10.7, 7.0 Hz), 3.84 (1H, dd, J = 9.6, 5.2 Hz), 3.64 (1H, ddd, J = 9.9, 7.0, 1.9 Hz), 3.45 (1H, t, J = 9.8 Hz), 3.27 (3H, s), 2.44 (3H, s), 1.98 (3H, s); ^{13}C NMR (CD_3OD, 125 MHz) δ 174.0, 146.5, 134.4 (2C), 131.0 (2C), 129.1, 101.4, 71.7, 71.2, 70.3, 68.3, 55.3, 54.2, 22.5, 21.6; EI-MS m/z 389 $[M]^+$, 358, 340, 43 (base); HREI-MS m/z 389.1158 (389.1149 calcd for $C_{16}H_{23}NO_8S$).

Methyl 2-acetamido-2-deoxy-6-*O*-tosyl-β-D-mannopyranoside (12b). By the use of **11b** (99.8 mg, 0.276 mmol) as a substrate, **12b** (41.7 mg, 40%) was afforded in the same manner as the synthesis of **5a**. **12b**: colorless needles; ^{1}H NMR (CD_2Cl_2, 500 MHz) δ 7.78 (2H, d, J = 8.4 Hz), 7.37 (2H, d, J = 8.4 Hz), 4.76 (1H, d, J = 3.9 Hz), 4.29 (1H, dd, J = 5.4, 3.3 Hz), 4.21−4.24 (2H, m), 4.02−4.08 (2H, m), 3.89 (1H, dd, J = 8.0, 3.3 Hz), 3.26 (3H, s), 2.42 (3H, s), 1.97 (3H, 2); ^{13}C NMR (CD_2Cl_2, 125 MHz) δ 172.0, 145.7, 133.0, 130.3 (2C), 128.3 (2C), 108.3, 79.6, 72.5, 70.9, 67.9, 58.7, 55.6, 22.8, 21.6; EI-MS m/z 372 $[M - H_2O + H]^+$, 340, 172, 91 (base), 43; HREI-MS m/z 372.1093 (389.1116 calcd for $C_{16}H_{22}NO_7S$); FAB-MS m/z 390 $[M + H]^+$.

Methyl 2-acetamido-3,6-anhydro-2-deoxy-β-D-mannofuranoside (13). 12a (40.4 mg, 0.104 mmol) in methanol (1 mL) was treated with sodium methoxide (22.4 mg, 0.415 mmol) and stirred for 4 h at room temperature. The mixture was acidified with Dowex 50w (H^+), until the pH reached 3, and stirred for 3 h. The solvent was evaporated, and the residue was purified by SiO_2 column chromatography (chloroform−methanol, 95:5) to give **13** (16.8 mg, 74%).

By the use of **12b** (31.2 mg, 0.080 mmol) as a substrate, **13** (15.3 mg, 88%) was afforded in the same manner as described above. **13**: colorless needles; ^{1}H NMR (CD_2Cl_2, 500 MHz) δ 4.84 (1H, d, J = 2.1 Hz), 4.59−4.64 (2H, m), 4.18−4.24 (2H, m), 3.89 (1H, dd, J = 9.3, 5.2 Hz), 3.73 (1H, dd, J = 9.3, 5.2 Hz), 3.34 (3H, s), 1.96 (3H, s); ^{13}C NMR (CD_2Cl_2, 125 MHz) δ 171.7, 111.0, 82.3, 80.7, 74.4, 71.4, 57.1, 55.5, 22.8; EI-MS m/z 218 $[M + H]^+$, 185, 158, 128, 43 (base); HREI-MS m/z 218.1043 (218.1027 calcd for $C_9H_{16}NO_5$).

Allyl 2-acetamido-5-*O*-acetyl-3,6-anhydro-2-deoxy-D-mannofuranoside (14). By the use of **13** (201 mg, 0.925 mmol) as a substrate, **14** (mixture of α and β-anomers, 1:1, 252 mg, 95%) was afforded in the same manner as the synthesis of **7a** and **7b**. **14**: a colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 6.14 (0.5H, br.s), 6.13 (0.5H, br.s), 5.85−5.96 (1H, m), 5.29 (0.5H, dq, J = 17.2, 1.5 Hz), 5.27 (0.5H, dq, J = 17.3, 1.5 Hz), 5.16−5.22 (1.5H, m), 5.08 (0.5H, d, J = 1.9 Hz), 5.07 (0.5H, d, J = 5.6 Hz), 5.01 (0.5H, ddd, J = 9.3, 7.9, 5.6 Hz), 4.85 (0.5H, t, J = 5.2 Hz), 4.83 (0.5H, t, J = 5.0 Hz), 4.72 (0.5H, dd, J = 6.5, 5.0 Hz), 4.61 (0.5H, dd, J = 5.6, 4.9 Hz), 4.49 (0.5H, dt, J = 8.9, 5.6 Hz), 4.34 (0.5H, td, J = 6.5, 1.9 Hz), 4.28 (0.5H, ddt, J = 12.8, 5.2, 1.5 Hz), 4.16 (0.5H, ddt, J = 12.9, 5.2, 1.5 Hz), 4.11 (0.5H, dd, J = 9.3, 5.9 Hz), 4.08 (0.5H, t, J = 8.0 Hz), 3.99−4.05 (1H, m), 3.96 (0.5H, dd, J = 9.3, 8.2 Hz), 3.88 (0.5H, dd, J = 9.3, 6.2 Hz), 2.14 (1.5H, s), 2.13 (1.5H, s), 2.05 (1.5H, s), 2.03 (1.5H, s); ^{13}C NMR ($CDCl_3$, 125 MHz, all signals correspond to 0.5C) δ 170.1, 170.0, 169.9, 169.9, 133.8, 133.6, 117.3, 117.2, 108.8, 100.3, 80.6, 80.1, 80.0, 79.6, 73.5, 72.6, 70.7, 68.7, 68.6, 68.4, 57.0, 54.7, 23.1, 23.0, 20.6, 20.5; EI-MS m/z 286 $[M + H]^+$, 244, 226, 202, 43 (base); HREI-MS m/z 286.1297 (286.1289 calcd for $C_{13}H_{20}NO_6$).

Allyl 2-acetamido-3,6-anhydro-2-deoxy-5-*O*-isovaleryl-D-mannofuranoside (15). By the use of **14** (65.4 mg, 0.229 mmol) as a substrate, **15** (mixture of α and β-anomers, 1:1, 64.1 mg, 86%) was afforded in the same manner as the synthesis of **8a**. **15**: a colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 6.15 (0.5H, br.s), 6.13 (0.5H, br.s), 5.84−5.95 (1H, m), 5.28 (0.5H, dq, J = 17.2, 1.6 Hz), 5.27 (0.5H, dq, J = 17.2, 1.6 Hz), 5.16−5.21 (1.5H, m), 5.07 (0.5H, d, J = 1.8 Hz), 5.07 (0.5H, d, J = 5.2 Hz), 5.01 (0.5H, ddd, J = 9.5, 8.0, 5.4 Hz), 4.86 (0.5H, t, J = 5.1 Hz), 4.84 (0.5H, t, J = 5.0 Hz), 4.73 (0.5H, dd, J = 6.6, 5.0 Hz), 4.61 (0.5H, dd, J = 5.6, 5.0 Hz), 4.49 (0.5H, dt, J = 8.8, 5.6 Hz), 4.33 (0.5H, td, J = 6.6, 1.8 Hz), 4.28 (0.5H, ddt, J = 12.9, 5.3, 1.5 Hz), 4.15 (0.5H, ddt, J = 12.9, 5.3, 1.5 Hz), 4.10 (0.5H, dd, J = 9.4, 5.8 Hz), 4.08 (0.5H, t, J = 8.0 Hz), 4.01 (0.5H, dq, J = 12.9, 1.3 Hz), 4.00 (0.5H, dq, J = 12.9, 1.3 Hz), 3.94 (0.5H, dd, J = 9.5, 8.0 Hz), 3.90 (0.5H, dd, J = 9.4, 6.0 Hz), 2.20−2.30 (2H, m), 2.09−2.17 (1H, m), 2.05 (1.5H, s), 2.03 (1.5H, s), 0.99 (1.5H, d, J = 6.6 Hz), 0.98 (4.5H, d, J = 6.6 Hz); ^{13}C NMR ($CDCl_3$, 125 MHz, all signals correspond to 0.5C) δ 172.3, 172.0, 169.9, 169.9, 133.8, 133.6, 117.3, 117.3, 108.8, 100.3, 80.7, 80.1, 80.0, 79.7, 73.3, 72.3, 70.9, 68.7, 68.5, 68.2, 57.0, 54.7, 43.0, 43.0, 25.7, 25.7, 23.1, 23.1, 22.4, 22.3, 22.3, 22.2; EI-MS m/z 328 $[M + H]^+$, 286, 268, 253, 85 (base), 57, 43; HREI-MS m/z 328.1789 (328.1759 calcd for $C_{16}H_{26}NO_6$).

2-Acetamido-3,6-anhydro-2-deoxy-5-*O*-isovaleryl-D-mannofuranose (furanodictine B) (2). By the use of**15** (43.9 mg, 0.136 mmol) as a substrate, **2** (19.7 mg, 50%) was afforded in the same manner as the synthesis of **1**. Synthetic **2**: $[\alpha]^{25}_D$ +98.4 (*c* 0.808, $CHCl_3$); other spectral data were identical with those of the natural product.

Acknowledgment. This work was supported in part by a Grant-in-Aid for Scientific Research (No. 12470474) from the Ministry of Education, Science, Sports, and Culture of Japan.

Supporting Information Available: ^{1}H and ^{13}C NMR spectra for natural and synthetic compounds **1** and **2** and their biological data. This material is available free of charge via the Internet at http://pubs.acs.org.

JO015657X