January 1993 Notes *Chem. Pharm. Bull.* **41**(1) 201—204 (1993)

Novel α-Mannoside Synthesis Promoted by the Combination of Trimethylsilyl Chloride and Zinc Triflate

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Received April 27, 1992

α-Mannosides were obtained in good yields and with good selectivity directly from benzyl-protected mannopyranosyl *p*-nitrobenzoate or acetate using a trimethylsilyl chloride–zinc triflate catalyst system.

Keywords glycosidation; α-mannoside; mannosyl ester; trimethylsilyl chloride; zinc triflate; solvent effect

The glycosidation reaction is one of the most important in carbohydrate chemistry.[1] During the course of our studies on synthesis of human serum albumin modified with D-mannose through octamethylene spacer group *via* ether and amide bonds, it was necessary to develop a new method for the preparation of benzyl-protected α-mannopyranoside (**4aα**)[2] in good yield and with good selectivity. Usually, α-mannosyl bonds are synthesized with 2-acyl-protected mannosyl donors utilizing the neighboring-group effect,[3] but recently, synthesis of α-mannosides from mannosyl fluoride[4] or chloride,[5] without the neighboring-group effect, has been reported. These mannosyl halides are prepared from mannosyl esters. In this paper, we wish to describe a selective synthesis, promoted with trimethylsilyl chloride (TMSCl) and zinc triflate (Zn(OTf)$_2$), of α-mannosides from mannosyl esters without the neighboring-group effect (Chart 1).

Results and Discussion

In a previous paper, we reported a novel method for the direct activation of stable glycosyl esters with TMSCl and Zn(OTf)$_2$.[6] We applied the method to the reaction of benzyl-protected mannopyranosyl *p*-nitrobenzoate (**1**)[7,8] to extend the utility of our new glycosidation method. Reaction of **1** with 8-methoxycarbonyloctanol (**3a**) (2 eq)[9] in dichloromethane in the presence of TMSCl (1.5 eq) and Zn(OTf)$_2$ (1.5 eq) gave the known substances, **4aα**[2] and its β-isomer (**4aβ**),[2] at an 86 : 14 ratio in 89% combined yield (Table I, run 1).

We examined the solvent effect by reaction of **1** and **3a** in the presence of TMSCl and Zn(OTf)$_2$ as promoters. The results (runs 1—4) made it clear that acetonitrile (run 2) was the best solvent in terms of yields and α-selectivity.

To optimize the reaction conditions, some other silyl halides, such as trimethylsilyl bromide (TMSBr, run 5), *tert*-butyldimethylsilyl chloride (TBDMSCl, run 6), and triphenylsilyl chloride (run 7), were examined using the above-mentioned reaction of **1** and **3a** in the presence of Zn(OTf)$_2$ in acetonitrile. High yields and α-selectivity were attained when TMSCl was employed as the promoter. Next, we tried using other metal triflates, such as copper triflate (Cu(OTf)$_2$, run 8) and tin triflate (Sn(OTf)$_2$, run 9) in combination with TMSCl in acetonitrile, resulting in 72% and 70% yields, and 80 : 20 and 98 : 2 α : β selectivity. These

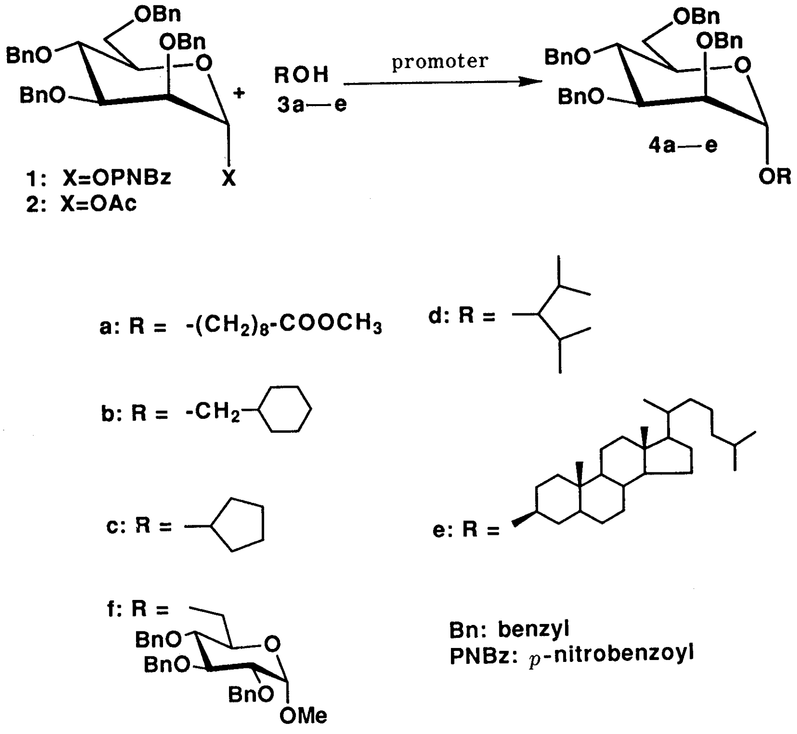

Chart 1

TABLE I. α-Selective Mannoside Synthesis

Run	Donor	Acceptor[a]	Promoter[b]	Solvent[c]	Time[d] (h)	Yield[e] (%)	α : β[f]
1	**1**	**3a**	TMSCl–Zn(OTf)$_2$	CH$_2$Cl$_2$	5.5	89	86 : 14
2	**1**	**3a**	TMSCl–Zn(OTf)$_2$	MeCN	4	96	99 : 1
3	**1**	**3a**	TMSCl–Zn(OTf)$_2$	PhCH$_3$	7.5	73	94 : 6
4	**1**	**3a**	TMSCl–Zn(OTf)$_2$	DME	23	73	64 : 36
5	**1**	**3a**	TMSBr–Zn(OTf)$_2$	MeCN	1.5	85	99 : 1
6	**1**	**3a**	TBDMSCl–Zn(OTf)$_2$	MeCN	3	88	94 : 6
7	**1**	**3a**	Ph$_3$SiCl–Zn(OTf)$_2$	MeCN	5.5	89	99 : 1
8	**1**	**3a**	TMSCl–Cu(OTf)$_2$	MeCN	5	72	80 : 20
9	**1**	**3a**	TMSCl–Sn(OTf)$_2$	MeCN	3	70	98 : 2
10	**2**	**3a**	TMSCl–Zn(OTf)$_2$	MeCN	4	88	99 : 1
11	**1**	**3b**	TMSCl–Zn(OTf)$_2$	MeCN	5	95	98 : 2
12	**2**	**3b**	TMSCl–Zn(OTf)$_2$	MeCN	4	92	97 : 3
13	**1**	**3c**	TMSCl–Zn(OTf)$_2$	MeCN	4	89	99 : 1
14	**2**	**3c**	TMSCl–Zn(OTf)$_2$	MeCN	5	83	99 : 1
15	**1**	**3d**	TMSCl–Zn(OTf)$_2$	MeCN	6	57	96 : 4
16	**1**	**3d**	TMSCl–Zn(OTf)$_2$[g]	MeCN	6	82	95 : 5
17	**1**	**3e**	TMSBr–Zn(OTf)$_2$	CH$_2$Cl$_2$[h]	15	91	93 : 7
18	**1**	**3f**	TMSCl–Zn(OTf)$_2$	MeCN	1	80	97 : 3

a) Two amounts of acceptor were used in each case. *b*) Each promoter was used in an amount of 1.5 eq. *c*) DME; 1,2-dimethoxyethane. *d*) All reactions were carried out with ice cooling. *e*) Isolated total yield. *f*) The α : β ratios were determined by ^{1}H-NMR analysis. *g*) Addition of powdered molecular sieves AW-300 (twice the weight of **1**). *h*) Five equivalents of diglyme was used as an additive.

results showed that the metal cation influenced selectivity. Good yields and α-selectivity were achieved, when Zn(OTf)$_2$ was employed as the promoter. The best result was attained when the reaction was carried out in acetonitrile using TMSCl and Zn(OTf)$_2$ as promoters. After stirring with **3a** (2 eq), TMSCl (1.5 eq) and Zn(OTf)$_2$ (1.5 eq) in acetonitrile with ice cooling for 4 h, **4aβ** was isomerized to an epimeric mixture (**4aα** : **4aβ** = 92 : 8). This demonstrated that thermodynamic control contributed to the α-selectivity.

In a similar manner, the reaction of benzyl-protected mannopyranosyl acetate (**2**)[10] with **3a** gave **4aα** in good yield and with good selectivity (run 10). We then investigated the reaction of mannosyl esters (**1** and **2**) with other alcohols (**3b**—**f**). All the reactions resulted in the formation of the corresponding α-glycosides (**4bα**—**4fα**) with good selectivity (runs 11—18). When the alcohol (**3d**) was sterically hindered, the yield was low, because of the formation of a hydrolysis product (2,3,4,6-tetrabenzylmannopyranose), which was detected by thin-layer chromatography in the reaction mixture (run 15). In this case, addition of powdered molecular sieves AW-300 improved the yield (run 16). Since β-cholestanol (**3e**) showed poor solubility in acetonitrile, the reaction of **1** and **3e** (run 17) was carried out in dichloromethane containing diglyme, a condition[6] that we had used for the synthesis of steroidal glycosides. The reaction of **1** with glycosyl alcohol (**3f**) gave the disaccharide **4fα** and its β-isomer (**4fβ**) at a 97 : 3 ratio in an 80% combined yield (run 18); and when **1** and **3f** were reacted using trimethylsilyl triflate[8] instead of TMSCl and Zn(OTf)$_2$ as the promoter, with ice cooling for 1 h, the yield was decreased (70%) but the α-selectivity was the same (97 : 3).

The stereochemical assignment of the glycosidic bond in **4a**—**f** was verified by comparison of the specific rotations of the minor and major isomers based on Hudson's rule of isorotation.[11] The major isomers of reaction products were dextrorotatory, in contrast with the minor isomers, indicating the stereochemistry of the glycosidic bond that had formed to be α in the major isomers and β in the minor isomers.

In summary, we have demonstrated that combination of TMSCl and Zn(OTf)$_2$ can serve as a potential activator in α-mannosidation using mannosyl esters as mannosyl donors.

Experimental

Melting points were determined on a Yanagimoto melting point apparatus and are uncorrected. Proton nuclear magnetic resonance (^{1}H-NMR) spectra were obtained on a Varian VXR-500 spectrometer (500 MHz) in deuteriochloroform using tetramethylsilane as an internal standard. Optical rotations were measured in chloroform with a Perkin-Elmer 241 polarimeter. IR spectra were obtained on a Hitachi 270-30 IR spectrophotometer. Mass spectra (MS) and high-resolution mass spectra (HRMS) were obtained on a JEOL JMS-HX110 mass spectrometer. Column chromatography was performed with Merck Silica gel 60 (230—430 mesh). Glycosyl alcohol **3f** was purchased from Junsei Chemical Co., Ltd.

Typical Procedure for the α-Selective Glycosidation (Table I, Run 1). TMSCl (0.038 ml, 0.3 mmol) was added to a mixture of the mannosyl ester **1** (138 mg, 0.2 mmol), the alcohol **3a** (75 mg, 0.4 mmol) and Zn(OTf)$_2$ (109 mg, 0.3 mmol) in dichloromethane (2 ml) was added TMSCl (0.038 ml, 0.3 mmol) under ice-cooling, and the mixture was stirred for 5.5 h. The reaction mixture was diluted with ethyl acetate and washed with water, saturated NaHCO$_3$ solution and water, then dried over MgSO$_4$ and concentrated under reduced pressure. The residue was chromatographed on silica gel (70 g) with toluene–ethyl acetate (19 : 1) to give a 86 : 14 epimeric mixture (126 mg, 89%) of **4aα** and **4aβ** as a colorless oil. Analytical samples of **4aα** and **4aβ** were prepared by repeated silica gel column chromatography.

4aα[2]: A colorless oil. $[\alpha]_D$ +21.1° (c=1.48). ^{1}H-NMR δ: 1.27 (8H, s), 1.51—1.52 (2H, m, $C\underline{H}_2$–CH_2–$COOCH_3$), 1.59—1.62 (2H, m, $C\underline{H}_2$–CH_2–O), 2.29 (2H, t, J=7.6 Hz, $C\underline{H}_2$–$COOCH_3$), 3.34 (1H, dt, J=9.8, 6.6 Hz, CH_2–O), 3.37 (1H, dt, J=9.5, 6.8 Hz, CH_2–O), 3.66 (3H, s, OCH_3), 3.67—3.80 (4H, m, H-2, 5, 6, 6′), 3.90 (1H, dd, $J_{3,2}$=2.9, $J_{3,4}$=9.3 Hz, H-3), 3.98 (1H, dd $J_{4,3}$=9.3, $J_{4,5}$=9.0 Hz, H-4), 4.50 (1H, d, J=10.7 Hz, $ArCH_2$), 4.55 (1H, d, J=12.2 Hz, $ArCH_2$), 4.63 (2H, s, $ArCH_2$), 4.66 (1H, d, J=12.2 Hz, $ArCH_2$), 4.72 (1H, d, J=12.7 Hz, $ArCH_2$), 4.76 (1H, d, J=12.7 Hz, $ArCH_2$), 4.85 (1H, d, $J_{1,2}$=1.7 Hz, H-1), 4.87 (1H, d, J=10.7 Hz, $ArCH_2$), 7.15—7.17 (2H, m, ArH), 7.23—7.38 (18H, m, ArH). IR (KBr): 2936, 2864, 1736, 1496, 1454, 1364 cm^{-1}. MS m/z: 710 (M^+), 619 ($M^+ - C_7H_7$). HRMS Calcd for $C_{44}H_{54}O_8 - C_7H_7$ 619.3271. Found 619.3257.

4aβ[2]: A colorless solid. mp 54—55 °C. $[\alpha]_D$ −46.5° (c=0.10). ^{1}H-NMR δ: 1.25—1.39 (8H, m), 1.47—1.53 (2H, m, $C\underline{H}_2$–CH_2–$COOCH_3$), 1.59—1.65 (2H, m, $C\underline{H}_2$–CH_2–O), 2.30 (2H, t, J=7.4 Hz, $C\underline{H}_2$–$COOCH_3$), 3.40 (1H, dt, J=9.3, 6.8 Hz, CH_2–O), 3.45 (1H, ddd, $J_{5,4}$=9.5, $J_{5,6}$=6.1,

$J_{5,6'}=2.0$ Hz, H-5), 3.50 (1H, dd, $J_{3,2}=2.9$, $J_{3,4}=9.5$ Hz, H-3), 3.66 (3H, s, OCH_3), 3.74 (1H, dd, $J_{6,5}=6.1$, $J_{6,6'}=10.8$ Hz, H-6), 3.81 (1H, dd, $J_{6',5}=2.0$, $J_{6',6}=10.8$ Hz, H-6′), 3.86 (1H, dd, $J_{4,3}=9.5$, $J_{4,5}=9.5$ Hz, H-4), 3.90 (1H, d, $J_{2,3}=2.9$ Hz, H-2), 3.97 (1H, dt, $J=9.3$, 6.4 Hz, CH_2–O), 4.37 (1H, s, H-1), 4.44 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.51 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.53 (2H, d, $J=10.7$ Hz, $ArCH_2$), 4.59 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.63 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.87 (1H, d, $J=12.5$ Hz, $ArCH_2$), 4.90 (1H, d, $J=10.7$ Hz, $ArCH_2$), 5.00 (1H, d, $J=12.5$ Hz, $ArCH_2$), 7.17—7.19 (2H, m, ArH), 7.22—7.35 (16H, m, ArH), 7.46—7.47 (2H, m, ArH). IR (KBr): 2932, 2860, 1732, 1497, 1454, 1362 cm^{-1}. MS *m/z*: 710 (M^+), 619 ($M^+-C_7H_7$). HRMS Calcd for $C_{44}H_{54}O_8-C_7H_7$ 619.3271. Found 619.3241.

Physical and spectral data for glycosides (**4b—f**) are as follows.[12)]

4bα: A colorless oil. $[\alpha]_D$ +28.7° ($c=1.09$). ^{1}H-NMR δ: 0.84—0.91 (2H, m, cyclohexyl-H), 1.12—1.26 (3H, m, cyclohexyl-H), 1.47—1.70 (6H, m, cyclohexyl-H), 3.15 (1H, dd, $J=6.1$, 9.3 Hz, O–CH_2), 3.45 (1H, dd, $J=6.8$, 9.3 Hz, O–CH_2), 3.71—3.79 (4H, m, H-2, 5, 6, 6′), 3.89 (1H, dd, $J_{2,3}=3.2$, $J_{3,4}=9.3$ Hz, H-3), 3.97 (1H, dd, $J_{4,3}=9.3$, $J_{4,5}=9.0$ Hz, H-4), 4.51 (1H, d, $J=10.7$ Hz, $ArCH_2$), 4.55 (1H, d, $J=12.2$ Hz, $ArCH_2$), 4.62 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.65 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.66 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.70 (1H, d, $J=12.5$ Hz, $ArCH_2$), 4.75 (1H, d, $J=12.5$ Hz, $ArCH_2$), 4.81 (1H, d, $J_{1,2}=1.7$ Hz, H-1), 4.87 (1H, d, $J=10.5$ Hz, $ArCH_2$), 7.16—7.18 (2H, m, ArH), 7.23—7.38 (18H, m, ArH). IR (KBr): 2928, 2860, 1498, 1454, 1364 cm^{-1}. MS *m/z*: 636 (M^+), 545 ($M^+-C_7H_7$). HRMS Calcd for $C_{41}H_{48}O_6-C_7H_7$ 545.2903. Found 545.2883.

4bβ: A colorless solid. mp 63—64 °C. *Anal.* Calcd for $C_{41}H_{48}O_6\cdot 1/4 H_2O$: C, 76.79; H, 7.62. Found: C, 76.64; H, 7.90, $[\alpha]_D$ −46.6° ($c=1.26$). ^{1}H-NMR δ: 0.96—1.01 (2H, m, cyclohexyl-H), 1.16—1.29 (3H, m, cyclohexyl-H), 1.63—1.81 (6H, m, cyclohexyl-H), 3.21 (1H, dd, $J=6.6$, 9.3 Hz, O–CH_2), 3.45 (1H, ddd, $J_{5,4}=9.8$, $J_{5,6}=6.1$, $J_{5,6'}=2.0$ Hz, H-5), 3.50 (1H, dd, $J_{3,4}=9.6$, $J_{3,2}=2.9$ Hz, H-3), 3.74 (1H, dd, $J_{6,5}=6.1$, $J_{6,6'}=11.0$ Hz, H-6), 3.80—3.83 (2H, m, O–CH_2, H-6′), 3.85 (1H, dd, $J_{4,3}=9.6$, $J_{4,5}=9.8$ Hz, H-4), 3.91 (1H, d, $J_{2,3}=2.9$ Hz, H-2), 4.34 (1H, s, H-1), 4.44 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.51 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.53 (1H, d, $J=10.7$ Hz, $ArCH_2$), 4.60 (1H, d, $J=12.2$ Hz, $ArCH_2$), 4.63 (1H, d, $J=12.2$ Hz, $ArCH_2$), 4.87 (1H, d, $J=12.7$ Hz, $ArCH_2$), 4.90 (1H, d, $J=10.7$ Hz, $ArCH_2$), 5.03 (1H, d, $J=12.7$ Hz, $ArCH_2$), 7.16—7.21 (2H, m, ArH), 7.23—7.36 (16H, m, ArH), 7.46—7.48 (2H, m, ArH). IR (KBr): 2924, 2856, 1496, 1454, 1366 cm^{-1}. MS *m/z*: 636 (M^+), 545 ($M^+-C_7H_7$). HRMS Calcd for $C_{41}H_{48}O_6-C_7H_7$ 545.2903. Found 545.2911.

4cα: Colorless oil. $[\alpha]_D$ +36.1° ($c=1.01$), ^{1}H-NMR δ: 1.45—1.73 (8H, m), 3.69 (1H, dd, $J_{2,1}=2.0$, $J_{2,3}=3.2$ Hz, H-2), 3.72 (1H, dd, $J_{6,5}=3.9$, $J_{6,6'}=8.8$ Hz, H-6), 3.78—3.82 (2H, m, H-5, H-6′), 3.90 (1H, dd, $J_{3,2}=3.2$, $J_{3,4}=9.3$ Hz, H-3), 3.98 (1H, dd, $J_{4,3}=9.3$, $J_{4,5}=9.0$ Hz, H-4), 4.16—4.18 (1H, m, O–CH), 4.35 (1H, d, $J=10.7$ Hz, $ArCH_2$), 4.54 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.63 (2H, s, $ArCH_2$), 4.67 (1H, d, $J=12.5$ Hz, $ArCH_2$), 4.70 (1H, d, $J=12.7$ Hz, $ArCH_2$), 4.82 (1H, d, $J=12.5$ Hz, $ArCH_2$), 4.87 (1H, d, $J=10.7$ Hz, $ArCH_2$), 4.90 (1H, d, $J_{1,2}=2.0$ Hz, H-1), 7.16—7.19 (2H, m, ArH), 7.24—7.38 (18H, m, ArH). IR (KBr): 2940, 2876, 1498, 1456, 1364 cm^{-1}. MS *m/z*: 608 (M^+), 517 ($M^+-C_7H_7$). HRMS Calcd for $C_{39}H_{44}O_6-C_7H_7$ 517.2590. Found 517.2615.

4cβ: Colorless solid. mp 94—95 °C. *Anal.* Calcd for $C_{39}H_{44}O_6\cdot 1/4H_2O$: C, 76.38; H, 7.31. Found: C, 76.36; H, 7.47. $[\alpha]_D$ −51.1° ($c=1.23$). ^{1}H-NMR δ: 1.46—1.91 (8H, m), 3.45 (1H, ddd, $J_{5,4}=9.6$, $J_{5,6}=6.1$, $J_{5,6'}=1.7$ Hz, H-5), 3.50 (1H, dd, $J_{3,2}=2.9$, $J_{3,4}=9.5$ Hz, H-3), 3.74 (1H, dd, $J_{6,5}=6.1$, $J_{6,6'}=10.8$ Hz, H-6), 3.80—3.85 (3H, m, H-2, H-4, H-6′), 4.32—4.34 (1H, m, O–CH), 4.42 (1H, s, H-1), 4.43 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.51 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.54 (1H, d, $J=10.8$ Hz, $ArCH_2$), 4.60 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.63 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.88 (1H, d, $J=12.7$ Hz, $ArCH_2$), 4.90 (1H, d, $J=10.8$ Hz, $ArCH_2$), 4.98 (1H, d, $J=12.7$ Hz, $ArCH_2$), 7.18—7.35 (18H, m, ArH), 7.46—7.47 (2H, m, ArH). IR (KBr): 2960, 2916, 2860, 1498, 1456, 1362 cm^{-1}. MS *m/z*: 608 (M^+), 517 ($M^+-C_7H_7$). HRMS Calcd for $C_{39}H_{44}O_6-C_7H_7$ 517.2590. Found 517.2615.

4dα: Colorless oil. $[\alpha]_D$ +39.6° ($c=0.51$). ^{1}H-NMR δ: 0.72 (3H, d, $J=6.8$ Hz, CH_3), 0.75 (3H, d, $J=6.8$ Hz, CH_3), 0.86 (3H, d, $J=6.6$ Hz, CH_3), 0.90 (3H, d, $J=6.8$ Hz, CH_3), 1.68—1.81 (2H, m, $C\underline{H}(CH_3)_2$), 3.01 (1H, t, $J=4.9$ Hz, O–CH), 3.69 (1H, dd, $J_{6,5}=1.5$, $J_{6,6'}=10.5$ Hz, H-6), 3.76 (1H, dd, $J_{2,1}=1.5$, $J_{2,3}=2.9$ Hz, H-2), 3.81 (1H, dd, $J_{6'6}=10.5$, $J_{6',5}=4.8$ Hz, H-6′), 3.88 (1H, dd, $J_{3,2}=2.9$, $J_{3,4}=9.3$ Hz, H-3), 3.92 (1H, ddd, $J_{5,4}=9.8$, $J_{5,6}=1.5$, $J_{5,6'}=4.8$ Hz, H-5), 4.05 (1H, dd, $J_{4,3}=9.3$, $J_{4,5}=9.8$ Hz, H-4), 4.50 (1H, d, $J=12.2$ Hz, $ArCH_2$), 4.52 (1H, d, $J=10.7$ Hz, $ArCH_2$), 4.62 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.67 (1H, d, $J=12.5$ Hz, $ArCH_2$), 4.68 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.69 (1H, d, $J=12.2$ Hz, $ArCH_2$), 4.73 (1H, d, $J=12.5$ Hz, $ArCH_2$), 4.83 (1H, d, $J_{1,2}=1.5$ Hz, H-1), 4.88 (1H, d, $J=10.7$ Hz, $ArCH_2$), 7.15—7.46 (20H, m, ArH). IR (KBr): 2964, 2936, 2880, 1498, 1456, 1366 cm^{-1}. MS *m/z*: 638 (M^+), 547 ($M^+-C_7H_7$). HRMS Calcd for $C_{41}H_{50}O_6-C_7H_7$ 547.3059. Found 547.3087.

4dβ: Colorless oil. $[\alpha]_D$ −52.7° ($c=1.39$). ^{1}H-NMR δ: 0.89 (3H, d, $J=6.6$ Hz, CH_3), 0.90 (3H, d, $J=6.8$ Hz, CH_3), 0.99 (3H, d, $J=6.8$ Hz, CH_3), 1.00 (3H, d, $J=6.8$ Hz, CH_3), 1.85—1.89 (2H, m, $C\underline{H}(CH_3)_2$), 3.13 (1H, t, $J=5.4$ Hz, O–CH), 3.39 (1H, dt, $J_{5,4}=3.9$, $J_{5,6}=9.5$ Hz, H-5), 3.48 (1H, dd, $J_{3,4}=9.5$, $J_{3,2}=2.9$ Hz, H-3), 3.78 (2H, d, $J_{6,5}=9.5$ Hz, H-6), 3.88 (1H, dd, $J_{4,3}=9.5$, $J_{4,5}=3.9$ Hz, H-4), 3.93 (1H, d, $J_{2,3}=2.9$ Hz, H-2), 4.38 (1H, s, H-1), 4.48 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.53 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.57 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.58 (1H, d, $J=10.7$ Hz, $ArCH_2$), 4.69 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.85 (1H, d, $J=12.5$ Hz, $ArCH_2$), 4.91 (1H, d, $J=10.7$ Hz, $ArCH_2$), 5.02 (1H, d, $J=12.5$ Hz, $ArCH_2$), 7.22—7.34 (18H, m, ArH), 7.46—7.47 (2H, m, ArH). IR (KBr): 2968, 2880, 1498, 1456, 1366 cm^{-1}. MS *m/z*: 638 (M^+), 547 ($M^+-C_7H_7$). HRMS Calcd for $C_{41}H_{50}O_6-C_7H_7$ 547.3059. Found 547.3060.

4eα: Colorless solid. mp 109—100 °C. *Anal.* Calcd for $C_{61}H_{82}O_6$: C, 80.39; H, 9.07. Found: C, 80.28; H, 9.22. $[\alpha]_D$ +45.4° ($c=0.61$). ^{1}H-NMR δ: 0.63 (3H, s, CH_3), 0.76 (3H, s, CH_3), 0.86 (3H, d, $J=6.6$ Hz, CH_3), 0.86, (3H, d, $J=6.6$ Hz, CH_3), 0.89 (3H, d, $J=6.6$ Hz, CH_3), 3.73 (1H, dd, $J_{6,5}=1.7$, $J_{6,6'}=10.7$ Hz, H-6), 3.75 (1H, dd, $J_{2,1}=1.5$, $J_{2,3}=2.9$ Hz, H-2), 3.79 (1H, dd, $J_{6',5}=5.1$, $J_{6',6}=10.7$ Hz, H-6′), 3.86 (1H, ddd, $J_{5,4}=9.5$, $J_{5,6}=1.7$, $J_{5,6'}=5.1$ Hz, H-5), 3.92 (1H, dd, $J_{3,2}=2.9$, $J_{3,4}=9.3$ Hz, H-3), 3.97 (1H, dd, $J_{4,3}=9.3$, $J_{4,5}=9.5$ Hz, H-4), 4.50 (1H, d, $J=10.7$ Hz, $ArCH_2$), 4.54 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.63 (2H, s, $ArCH_2$), 4.66 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.71 (1H, d, $J=12.7$ Hz, $ArCH_2$), 4.76 (1H, d, $J=12.7$ Hz, $ArCH_2$), 4.88 (1H, d, $J=10.7$ Hz, $ArCH_2$), 5.02 (1H, d, $J_{1,2}=1.5$ Hz, H-1), 7.16—7.20 (2H, m, ArH), 7.24—7.49 (18H, m, ArH). IR (KBr): 2936, 2872, 1498, 1456, 1368 cm^{-1}. MS *m/z*: 910 (M^+), 819 ($M^+-C_7H_7$). HRMS Calcd for $C_{61}H_{82}O_6-C_7H_7$ 819.5563. Found 819.5559.

4eβ: Colorless solid. mp 95—96 °C. *Anal.* Calcd for $C_{61}H_{82}O_6$: C, 80.39; H, 9.07. Found: C, 80.45; H, 9.35. $[\alpha]_D$ −25.1° ($c=1.38$). ^{1}H-NMR δ: 0.65 (3H, s, CH_3), 0.82 (3H, s, CH_3), 0.86 (3H, d, $J=6.6$ Hz, CH_3), 0.87 (3H, d, $J=6.6$ Hz, CH_3), 0.90 (3H, d, $J=6.6$ Hz, CH_3), 3.44 (1H, ddd, $J_{5,4}=9.5$, $J_{5,6}=6.4$, $J_{5,6'}=1.7$ Hz, H-5), 3.49 (1H, dd, $J_{3,2}=3.2$, $J_{3,4}=9.3$ Hz, H-3), 3.62—3.69 (1H, m, O–CH), 3.72 (1H, dd, $J_{5,6}=6.4$, $J_{6,6'}=10.7$ Hz, H-6), 3.81—3.85 (3H, m, H-2, 4, 6′), 4.43 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.50 (1H, d, $J=11.7$ Hz, $ArCH_2$), 4.51 (1H, s, H-1), 4.54 (1H, d, $J=10.8$ Hz, $ArCH_2$), 4.59 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.62 (1H, d, $J=12.7$ Hz, $ArCH_2$), 4.88 (1H, d, $J=12.5$ Hz, $ArCH_2$), 4.91 (1H, d, $J=10.8$ Hz, $ArCH_2$), 4.99 (1H, d, $J=12.5$ Hz, $ArCH_2$), 7.19—7.21 (2H, m, ArH), 7.27—7.49 (16H, m, ArH), 7.47—7.49 (2H, m, ArH). IR (KBr): 2936, 2872, 1498, 1456, 1368 cm^{-1}. MS *m/z*: 910 (M^+), 819 ($M^+-C_7H_7$). HRMS Calcd for $C_{61}H_{82}O_6-C_7H_7$ 819.5563. Found 819.5559.

4fα: A colorless oil. $[\alpha]_D$ +35.2° ($c=1.24$). ^{1}H-NMR δ: 3.30 (3H, s, OCH_3), 3.38 (1H, dd, $J_{4,3}=9.3$, $J_{4,5}=9.0$ Hz, H(Glc)-4), 3.46 (1H, dd, $J_{2,1}=3.4$, $J_{2,3}=9.5$ Hz, H(Glc)-2), 3.58—3.71 (5H, m, H(Glc)-5, 6, H(Man)-6), 3.78 (1H, d, $J_{2,1}=1.7$ Hz, H(Man)-2), 3.81—3.85 (2H, m, H(Man)-3, 5), 3.95—4.00 (2H, m, H(Glc)-3, H(Man)-4), 4.44 (1H, d, $J=12.2$ Hz, $ArCH_2$), 4.48 (1H, d, $J=10.7$ Hz, $ArCH_2$), 4.48 (1H, d, $J=11.2$ Hz, $ArCH_2$), 4.56 (1H, d, $J=3.7$ Hz, H(Glc)-1), 4.59 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.61 (2H, s, $ArCH_2$), 4.67 (1H, d, $J=12.2$ Hz, $ArCH_2$), 4.68 (1H, d, $J=12.5$ Hz, $ArCH_2$), 4.72 (1H, d, $J=12.7$ Hz, $ArCH_2$), 4.77 (2H, d, $J=12.0$ Hz, $ArCH_2$), 4.79 (1H, d, $J=10.7$ Hz, $ArCH_2$), 4.85 (1H, d, $J=10.3$ Hz, $ArCH_2$), 4.87 (1H, d, $J=10.5$ Hz, $ArCH_2$), 4.96 (1H, d, $J=1.7$ Hz, H(Man)-1), 4.97 (1H, d, $J=10.7$ Hz, $ArCH_2$), 7.13—7.37 (35H, m, ArH). IR (KBr): 1498, 1456, 1362 cm^{-1}. MS *m/z* 906 (M^+), 895 ($M^+-C_7H_7$).

4fβ: A colorless solid. mp 123—125 °C. *Anal.* Calcd for $C_{62}H_{66}O_{11}\cdot 1/2 H_2O$: C, 74.75; H, 6.78. Found: C, 74.81; H, 6.85. $[\alpha]_D$ −5.6° ($c=1.01$). ^{1}H-NMR δ: 3.32 (3H, s, OCH_3), 3.36—3.47 (4H, m), 3.51 (1H, dd, $J=3.7$, 9.8 Hz), 3.69—3.84 (5H, m), 4.01 (1H, dd, $J=9.3$, 9.3 Hz), 4.16 (1H, dd, $J=10.5$, 1.7 Hz), 4.47 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.49—4.54 (4H, m, $ArCH_2$), 4.56 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.57 (1H, d, $J=4.4$ Hz, H(Glc)-1), 4.58 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.66 (1H, d, $J=12.0$ Hz, $ArCH_2$), 4.77 (1H, s, H(Man)-1), 4.72 (1H, d, $J=12.7$ Hz, $ArCH_2$), 4.77 (2H, d, $J=12.0$ Hz, $ArCH_2$), 4.78 (1H, d, $J=12.5$ Hz, $ArCH_2$), 4.82 (1H, d, $J=11.0$ Hz, $ArCH_2$), 4.88 (1H, d, $J=10.7$ Hz, $ArCH_2$), 4.93 (1H, d, $J=12.5$ Hz, $ArCH_2$), 5.01 (1H, d, $J=11.0$ Hz, $ArCH_2$), 7.17—7.42 (35H, m, ArH). IR (KBr): 1497, 1454, 1362 cm^{-1}. MS *m/z*: 906 (M^+), 895 ($M^+-C_7H_7$).

Acknowledgment We are grateful to Miss H. Tsukamoto for her technical assistance.

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