

Synthesis of Methyl *O*-α-D-Mannosyl-(1→4)-[(3-*O*-methyl-α-D-mannosyl)-(1→4)-]$_n$3-*O*-methyl-α-D-mannosides (n = 0, 1, and 2) via Dehydrative Glycosylation

Motoko Hirooka,* Megumi Terayama, Emi Mitani, Shinkiti Koto,* Asako Miura, Kayo Chiba, Ayano Takabatake, and Takako Tashiro

School of Pharmaceutical Sciences, Kitasato University, Shirokane, Minato-ku, Tokyo 108-8641

(Received September 26, 2001)

Methyl *O*-α-D-mannopyranosyl-(1→4)-[(3-*O*-methyl-α-D-mannopyranosyl-(1→4)-]$_n$3-*O*-methyl-α-D-mannopyranosides (n = 0, 1, and 2), the lowest homologs related to the 3-*O*-methylmannose polysaccharides (MMP) from *Mycobacterium smegmatis*, were synthesized via dehydrative glycosylation reactions. The reagent systems, composed of *p*-nitrobenzenesulfonyl chloride, silver trifluoromethanesulfonate, and triethylamine, of *p*-nitrobenzenesulfonyl chloride, silver trifluoromethanesulfonate, and 1, 8-diazabicyclo[5.4.0]undec-7-ene, and of trimethylsilyl trifuloromethanesulfonate and pyridine were useful.

The last quarter of the foregoing century was a time when various improvements of the glycosylation method made it possible to synthesize many kinds of oligosaccharides.[1] Efforts to improve the procedure for glycosylation have been carried out from time to time.[2] One such approach was the direct use of a 1-OH sugar derivative (DOH) as a glycosyl donor, as has recently been shown.[3] This kind of method is free from the preparation of any derivative carrying a leaving group at the anomeric center.[3,4] We have proposed several reagent systems for one-stage dehydrative glycosylations.[5] The one-stage method allows one to add the activating reagent(s) directly into a mixture of DOH and an acceptor (AOH) as Eq. 1. Oligosaccharide syntheses via such one-stage dehydrative glycosylation

$$(\mathrm{DOH} + \mathrm{AOH}) + \mathit{Reagent}(s) \rightarrow \mathrm{DOA} \qquad (1)$$

remains to be explored.[3,4b,4d,6] Recently, it has been found that the NST reagent system,[5b] composed of *p*-nitrobenzenesulfonyl chloride (NsCl), silver trifluoromethanesulfonate (AgOTf), and triethylamine (Et_3N), performs α-selective mannosylation.[6d] This dehydrative glycosylation is considered to proceed via 1-*O*-*p*-nitrobenzenesulfonates of DOH.[5e] We now wish to report on the utility of the two dehydrative glycosylation systems[5b,5f] in the synthesis of a mannooligosaccharide series: **1**, **2**, and **3** (Fig. 1, n = 0, 1, and 2). These are the lowest homologs of the α(1→4)-linked linear 3-*O*-methylmannose polysaccharides (MMP)-related oligosaccharides (Fig. 1, $n \geqq 3$) in *Mycobacterium smegmatis*.[7] The lower series of such oligosaccharides of 3-*O*-methyl-D-mannopyranose, terminated at the non-reducing end with D-mannopyranose and the reducing end with simple methyl aglycon, are considered to be biosynthetic precursors for higher MMP.[7] Syntheses of the oligosaccharides of the repeating part, composed of a 3-*O*-methyl-D-mannopyranose unit,[8a] and the synthesis of the octamer in an acceptor form have been accomplished.[8b]

For synthesizing the disaccharide **1**, the known acetal **4**[9] was transformed into an acceptor **5** via tin-mediated 3-*O*-methylation,[10] benzylation, and convenient regioselective reduction of the benzylidene group with triethylsilane in the presence of trifluoroacetic acid.[11] This was glycosylated with donors **6**[12] and **7**[13] in the presence of the NST reagent system[5b] for dehydrative glycosylation to selectively afford the corresponding α-linked disaccharides, **8** (62%, Run 1, Table 1) and **9** (83%, Run 2), respectively. The by-products were the sulfonate **10** (8% and 7%, respectively) and self-condensates, **11**[14] (12%) and **12**[15] (5%). The TP system,[5g] composed of trimethylsilyl trifluoromethanesulfonate (Me_3SiOTf) and pyridine (Py), a homogeneous system free from the use of heavy metal,[4b] was also useful for the α-mannosylation of **5** with **7** (56%, Run 3). The trimethylsilyl derivatives, **13** (13%) and **14** (22%), were isolated. Self-condensation[16] did not proceed concurrently. The catalytic hydrogenolysis of the protecting groups of **8** and **9** furnished **1**.

The synthesis of the trisaccharide **2** was started from the known acetal **15**[6d] (Fig. 2). This was transformed into the alcohol **16** via 3-*O*-methylation, as in the above-described derivatization of **4** into **5**. This alcohol was transformed into a donor **17** having an acetyl group as a temporary masking group[8a] by way of acetylation and deallylation.[17] The above-described **5** was derived into another donor **18** with an allyl group as a temporary protecting group via allylation and hydrolysis. The acceptor **5** was then glycosylated with **17** and **18** in the presence of the NST system (Runs 4 and 5) to furnish intermediary disaccharide derivatives **19** and **20**, respectively. The NSD system,[5f] composed of NsCl, AgOTf, and diazabicyclo[5.4.0]undec-7-ene (DBU), reported by us in a previous paper, slightly improved the yields of the glycosides (Runs 6 and 7). The TP system was useful (Runs 8 and 9). The acceptor **16** was also glycosylated with **17** (Run 10) to furnish a known intermediate **21**.[8a] Compounds **19** and **20** were deprotected into a known

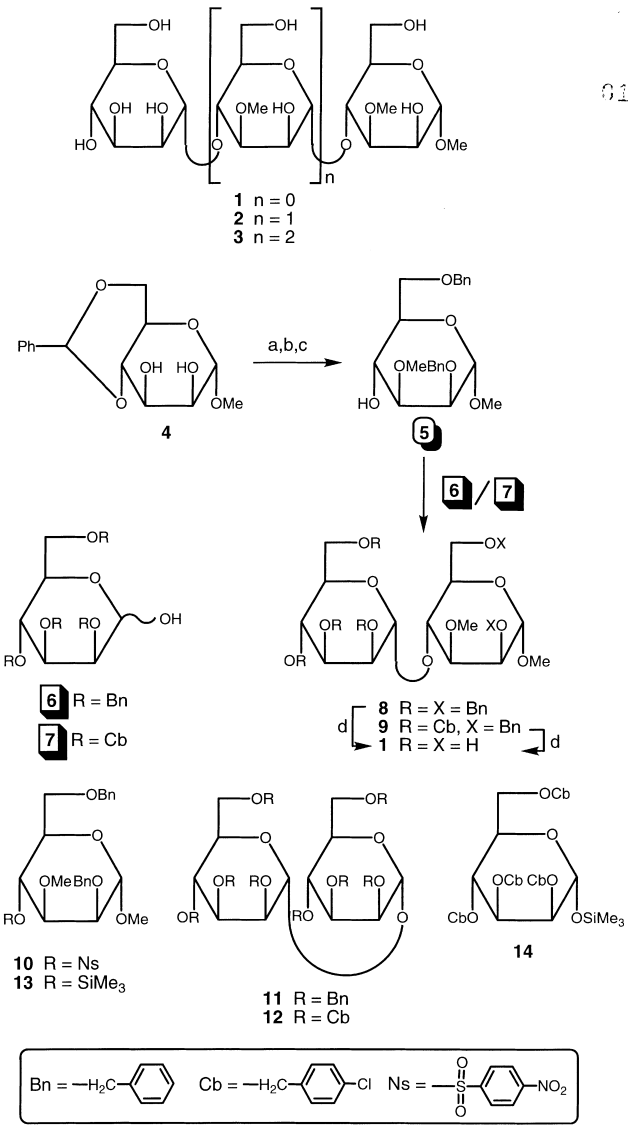

Fig. 1. Synthesis of α-D-Man*p*-(1→4)-3-*O*-Me-α-D-Man*p*-*O*-Me (**1**): a. (i) *n*-Bu_2SnO/MeOH, Δ; (ii) MeI/DMF, Δ; b. BnBr, NaH/DMF, 0 °C → room temperature (rt); c. Et_3SiH, CF_3CO_2H/CH_2Cl_2, 0 °C → rt; d. H_2, Pd–C(10%)/AcOH, rt. A code with square shade is a donor, whereas that with round shade is an acceptor.

disaccharide acceptor **22**.[8a] The donor **6** was condensed with the acceptor **22** in the presence of the NST system to give the protected trisaccharide **23** (72%, Run 11). The NSD system condensed **7** with **22** (66%, Run 12) to give the condensate **24**. This was also obtained via glycosylation of **22** with **7** with the TP system (68%, Run 13). In the case of Run 12, the sulfonate **25** was isolated (21%). Hydrogenolytic deprotection of **23** or **24** afforded the desired **2**.

Finally, the synthesis of tetrasaccharide **3** was carried out (Fig. 3). The acceptor **16** was glycosylated with **6** and **7** in the presence of the NST system to give intermediates **26** and **27** (Runs 14 and 15), respectively. The NSD system gave a better yield (64%, Run 16); the sulfonate **28** was isolated (15%). The TP system was also useful (60%, Run 17). The deallylation of **27** smoothly afforded the disaccharide donor **29**. The final condensation of **29** with **22** was performed in the presence of the NSD system to furnish the desired **30** (67%, Run 18). The TP system was also of use to connect **29** with **22** to give **30** (48%, Run 19). The catalytic deprotection of **30** yielded the targeted tetrasaccharide **3**.

The NMR spectra of the synthesized oligosaccharide series (**1**, **2**, and **3**), observed in deuterium oxide, were consistent with their structures. Table 2 summarizes the sets of assignment of their ^{13}C NMR spectra. The differential NOE spectrum of **2** showed the proximity between $H1^{II}$ and $H4^{I}$ in the $C1^{II}$ to $C4^{I}$ junction and that between $H1^{III}$ and $H4^{II}$ in the $C1^{III}$ to $C4^{II}$ junction. The signals of the methyl groups of the ^1H NMR spectrum were assigned by observing its deifferential NOE and GHMQC spectra.

In conclusion, the titled α-linked oligomannosides were synthesized using the dehydrative glycosylation method. As a temporary protecting group for the non-reducing end, the allyl group was useful as an acetyl group.[8a]

Experimental[3,6g]

The solvent systems for column chromatography on silica gel (Kanto Chemical, No. 37047; gradient elusion) and thin-layer chromatography (TLC) (Merck, DC-Plastikfolien Kieselgel 60 F 254, Art. 5735) were AcOEt–MeOH (EM), hexane–AcOEt (HE), and PhMe–2-butanone (TK). Hydrogenolytic deprotection was carried out using a Parr-3911 hydrogenation apparatus under 340 kPa of H_2 at room temperature. Evaporation was carried out under reduced pressure. The melting points were determined on a Yanaco Micro Melting Point Apparatus (Yanagimoto). The optical rotations were measured on a JASCO DIP-180 Digital Polarimeter at room temp. The ^1H and ^{13}C NMR spectra were recorded with a Varian VXR300 spectrometer or a Varian XL-400 spectrometer, along with measurements of the H,H-COSY, C,H-COSY, and DEPT spectra. For assigning of the anomeric configuration of the mannosides, their $J_{C1,H1}$ values[15] were determined by gated decoupling with the NOE experiment. The assignments of the spectra of **2**, **3**, **23**, **24**, and **30** were made by auxiliary measurements of HOHAHA, HMQC, HMBC, GHMQC, and differential NOE spectra. The elemental analyses were carried out with a Yanaco CHN Corder MT-5. The LRMS and the HRMS were recorded with a JEOL JMS-AX505H spectrometer and a JEOL JMS-AX505HA spectrometer as well as a JEOL JMS-700 spectrometer (operated generously at JEOL System Technology Co., Ltd), respectively. The abbreviations used here for the assigned substituents are All (allyl), Bd (benzylidene), Bn (benzyl), Ns (*p*-nitrophenylsulfonyl), and Tf (trifluoromethanesulfonyl).

Commercial *p*-nitrobenzenesulfonyl chloride (NsCl) was passed through a silica-gel column eluted with benzene, evaporated to dryness, and stored in a dry box in a refrigerator.[5b] Silver trifluoromethansulfonate (AgOTf, Aldrich), triethylamine (Et_3N, Tokyo Kasei), diazabicyclo[5.4.0]undec-7-ene (DBU, Tokyo Kasei), trimethylsilyl trifluoromethanesulfonate (Me_3SiOTf, Tokyo Kasei), and anhydrous pyridine (Py, Tokyo Kasei) were used without purification.

Methyl 2,6-Di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (5). A mixture of **4**[8] (19.2 g, 68 mmol), *n*-Bu_2SnO (Tokyo Kasei, 17 g, 68 mmol), and MeOH (140 mL) was refluxed for 7 h. The mixture was evaporated to dryness. The residue was stirred in dry *N*, *N*-dimethylformamide (DMF, Tokyo Kasei, 150 mL) containing MeI (Tokyo Kasei, 8.5 mL, 136 mmol) and molecular sieves

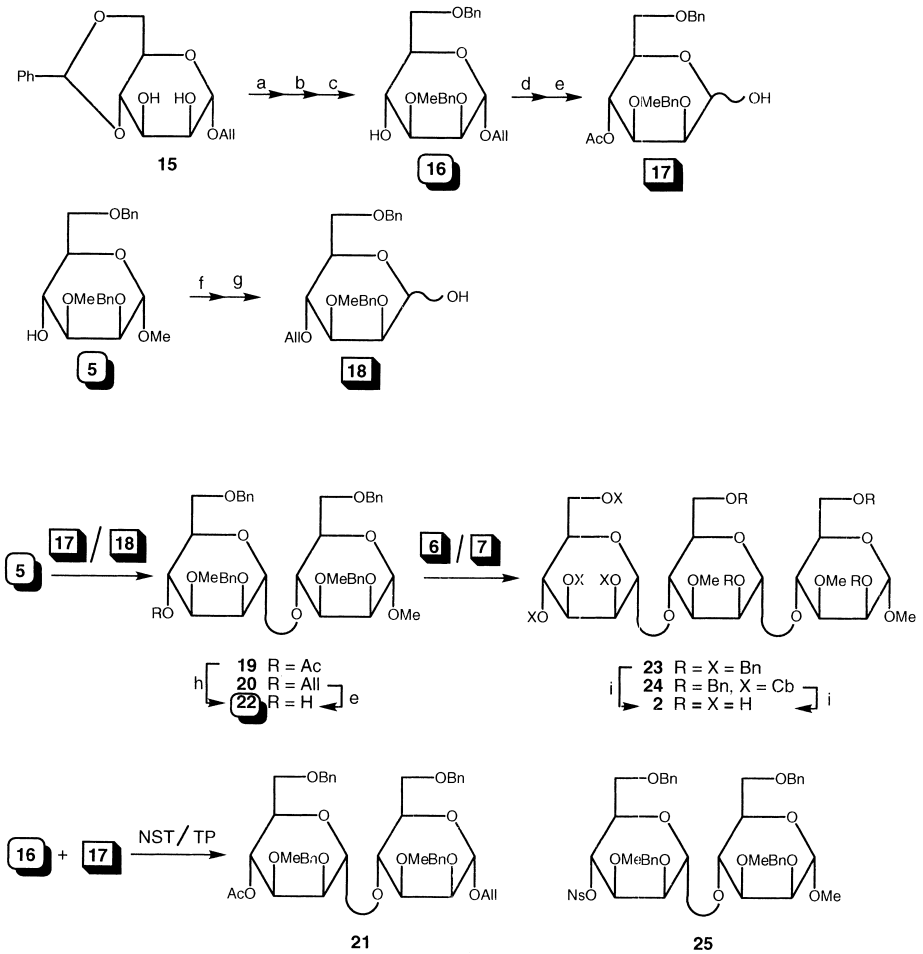

Fig. 2. Synthesis of α-D-Man*p*-(1→4)-3-*O*-Me-α-D-Man*p*-(1→4)-3-*O*-Me-α-D-Man*p*-*O*-Me (**2**): a. (i) *n*-Bu_2SnO/MeOH, Δ; (ii) MeI/DMF, Δ; b. BnBr, NaH/DMF, 0 °C → rt; c. Et_3SiH, CF_3CO_2H/CH_2Cl_2, 0 °C → rt; d. Ac_2O, Py/rt; e. $PdCl_2$, NaOAc/aq AcOH, Δ; f. AllBr, NaH/Δ; g. aq H_2SO_4/aq AcOH, Δ; h. NaOMe/MeOH, rt; i. H_2, Pd–C(10%)/AcOH, rt. A code with square shade is a donor, whereas that with round shade is an acceptor.

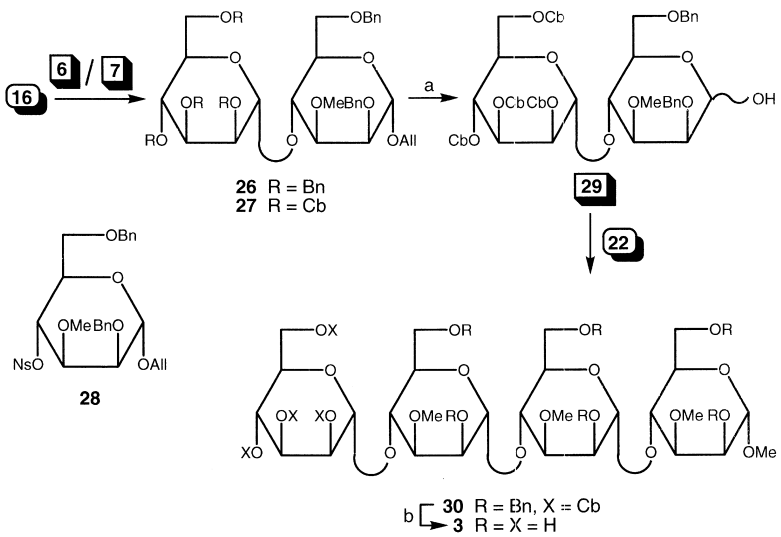

Fig. 3. Synthesis of α-D-Man*p*-(1→4)-[3-*O*-Me-α-D-Man*p*-(1→4)-]$_2$3-*O*-Me-α-D-Man*p*-*O*-Me (**3**): a. $PdCl_2$, NaOAc/aq AcOH, Δ; b. H_2, Pd–C(10%)/AcOH, rt. A code with square shade is a donor, whereas that with round shade is an acceptor.

Table 1. Results of Glycosylation (DOH + AOH → DOA)[a)]

Run	Donor (DOH)	Acceptor (AOH)	Reagents	Glycosides (DOA)/%	
1	**6**	**5**	NST	**8**,	62[b)]
2	**7**	**5**	NST	**9**,	83[c)]
3	**7**	**5**	TP	**9**,	56[d)]
4	**17**	**5**	NST	**19**,	37
5	**18**	**5**	NST	**20**,	43
6	**17**	**5**	NSD	**19**,	58
7	**18**	**5**	NSD	**20**,	53
8	**17**	**5**	TP	**19**,	53
9	**18**	**5**	TP	**20**,	46
10	**17**	**16**	NST	**21**,	64
11	**6**	**22**	NST	**23**,	72
12	**7**	**22**	NSD	**24**,	66[e)]
13	**7**	**22**	TP	**24**,	68
14	**6**	**16**	NST	**26**,	36
15	**7**	**16**	NST	**27**,	41
16	**7**	**16**	NSD	**27**,	64[f)]
17	**7**	**16**	TP	**27**,	60
18	**29**	**22**	NSD	**30**,	67
19	**29**	**22**	TP	**30**,	48

a) NST: acceptor (0.042 – 0.174 mmol), donor (1.3 equiv), NsCl (2.5 equiv), AgOTf (2.5 equiv), Et_3N (2.5 equiv), and CH_2Cl_2 (8 mL/mmol of acceptor); NSD: acceptor (0.032 – 0.180 mmol), donor (1.3 equiv), NsCl (2.5 equiv), AgOTf (2.5 equiv), DBU (2.5 equiv), and CH_2Cl_2 (8 mL/mmol of acceptor); TP: acceptor (0.023 – 0.065 mmol), donor (1.3 equiv), Me_3SiOTf (4.8 equiv), Py (2.8 equiv), and CH_2Cl_2 (5 mL/mmol of acceptor). b) **10** (8%) and **11** (12%) were isolated. c) **10** (7%) and **12** (5%) were isolated. d) **13** (18%) and **14** (22%) were isolated. e) **12** (23%) and **25** (21%) were isolated. f) **12** (9%) and **28** (15%) were isolated.

4A powder (13 g) at 75 °C for 24 h. The mixture was evaporated to dryness and chromatographed with a TK system (10:1) to give a syrup (13.6 g). This was dissolved in DMF (85 mL) containing $PhCH_2Br$ (Wako, 7.0 mL, 59 mmol). After the addition of NaH (ca. 60% in oil, Wako, 2.4 g, 60 mmol) at 0 °C (bath temperature), the mixture was stirred at this temperature for 30 min and then at room temperature for 2 h. After MeOH (6 mL) was added dropwise under cooling, the mixture was evaporated to dryness. The residue was chromatographed with the HE system (3:1) to afford a homogeneous syrup (11.8 g) of the benzyl ether. This syrup (10.5 g) was treated with CF_3CO_2H (Wako, 10 mL, 135 mmol) in CH_2Cl_2 (Wako, 120 mL) containing Et_3SiH (Tokyo Kasei, 21 mL, 131 mmol) at 0 °C for 30 min. After evaporation, the obtained syrup was chromatographed with the TK system (10:1) to furnish **5** (7.535 g, 32%); $[\alpha]_D^{20}$ −10° (*c* 0.6, $CHCl_3$)(lit.,[8a] $[\alpha]_D$ −5.3° (*c* 2.6, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.42 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3), 3.47 (dd, $J_{1,2}$ = 1.5 Hz, $J_{2,3}$ = 3.0 Hz, H-2), 3.94 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4), 4.77 (d, $J_{1,2}$ = 1.5 Hz, H-1), 2.73 (s, OH-4), 3.32 (s, Me-3), 3.34 (s, Me-1); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 67.6 (C-4), 70.4 (C-6), 71.3 (C-5), 72.7 (C-2), 81.1 (C-3), 99.0 (C-1), 54.0 (Me-1), 57.0 (Me-3).

Allyl 2,6-Di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (16). Similarly to the case of the derivatization of **4** into **5**, sequential reactions were carried out. The reaction of **15**[6d] (1.20 g, 3.9 mmol), *n*-Bu_2SnO (1.59 g, 6.4 mmol), and MeOH (20 mL), followed by evaporation and a reaction with MeI (0.73 mL, 11.7 mmol) in DMF (14 mL) containing molecular sieves 4A (1.2 g), afforded the 3-*O*-methyl ether (1.088 g). This (1.008 g) was benzylated with $PhCH_2Br$ (0.58 mL, 4.9 mmol) and NaH (ca. 60%, 188.2 mg, 4.7 mmol) in DMF (6.7 mL), followed by a treatment with CF_3CO_2H (1.2 mL, 16.2 mmol) in CH_2Cl_2 (13.5 mL) containing Et_3SiH (2.5 mL, 15.7 mmol), to furnish **16** (810 mg, 54%); $[\alpha]_D^{26}$ +6° (*c* 0.4, $CHCl_3$)(lit.,[8a] $[\alpha]_D$ +7° (*c* 1.3, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.50 (dd, $J_{2,3}$ = 3.5 Hz, $J_{3,4}$ = 9.5 Hz, H-3), 3.80 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4), 3.83 (dd, $J_{1,2}$ = 1.5 Hz, $J_{2,3}$ = 3.5 Hz, H-2), 4.96 (d, $J_{1,2}$ = 1.5 Hz, H-1), 2.66 (s, OH-4), 3.36 (s, Me-3), 3.37 (s, Me-1), 5.89 (m, All); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 67.8 (C-4), 70.4 (C-6), 71.5 (C-5), 72.8 (C-2), 81.1 (C-3), 97.1 (C-1), 57.1 (Me-3).

4-*O*-Acetyl-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranose (17). A mixture of **16** (884.0 mg, 2.1 mmol), pyridine (5.0 mL), and Ac_2O (5.0 mL, 53 mmol) was kept standing overnight. Evaporation and chromatography with the HE system (4:1) afforded a homogeneous syrup (860.0 mg). This was dissolved in aq AcOH (90%, 4.0 mL). After the addition of NaOAc (270.0 mg, 3.3 mmol) and $PdCl_2$ (270.0 mg, 1.5 mmol), the mixture was stirred overnight at room temperature for. Evaporation and chromatography with the HE system (2:1) gave **17** (498.4 mg, 56%), $[\alpha]_D^{23}$ +1° (*c* 1.1, $CHCl_3$)(lit.,[8a] $[\alpha]_D$ +3.2° (*c* 1.2, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) (85% α) δ 3.47 (dd, $J_{5,6a}$ = 2.5 Hz, $J_{6a,6b}$ = 10.5 Hz, H-6aα), 3.62 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 10.0 Hz, H-3α), 3.80 (dd, $J_{1,2}$ = 2.5 Hz, $J_{2,3}$ = 3.0 Hz, H-2α), 4.08 (ddd, $J_{4,5}$ = 10.0 Hz, $J_{5,6a}$ = 2.5 Hz, $J_{5,6b}$ = 7.5 Hz, H-5α), 5.20 (t, $J_{3,4}$ = $J_{4,5}$ = 10.0 Hz, H-4α), 5.24 (t, $J_{1,2}$ = $J_{1,OH}$ = 2.5 Hz, H-1α), 3.60 (d, $J_{1,OH}$ = 2.5 Hz, OH-1α), 2.00 (s, Ac), 3.34 (s, Me); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 68.7 (C-4β), 69.1 (C-4α), 69.8 (C-6β), 70.05 (C-6α), 70.11 (C-5α), 73.7 (C-2α, C-5β), 74.5 (C-2β), 78.7 (C-3α), 82.5 (C-3β), 92.8 (C-1α), 93.6 (C-1β), 57.8 (Me-α), 58.4 (Me-β), 20.9, 170.1 (Ac).

4-*O*-Allyl-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranose

Table 2. ^{13}C NMR Chemical Shifts of Methyl *O*-α-D-Mannosyl-(1→4)-[3-*O*-methyl-*O*-α-D-mannosyl-(1→4)-]$_n$3-*O*-methyl-α-D-mannosides (n = 0, 1, and 2)[a]

C	**1** (n = 0)	**2** (n = 1)	**3** (n = 2)
1^{I}	103.3 ($J_{C,H}$ = 171.8 Hz)	103.3 ($J_{C,H}$ = 170.1 Hz)	103.3 ($J_{C,H}$ = 172.1 Hz)
2^{I}	68.3	68.3	68.3
3^{I}	83.6	83.6	83.6
4^{I}	75.3	75.4	75.3
5^{I}	73.6	73.6	73.6
6^{I}	63.63	63.64	63.63
Me-1^{I}	57.4	57.5	57.5
Me-3^{I}	58.8	58.8	58.8
1^{II}	104.1 ($J_{C,H}$ = 171.9 Hz)	103.9 ($J_{C,H}$ = 170.6 Hz)	103.85[d] ($J_{C,H}$ = 170.0 Hz)
2^{II}	73.0	68.8	68.8
3^{II}	73.0	83.4	83.4[e]
4^{II}	69.2	75.0	75.1
5^{II}	76.4	74.9	74.8
6^{II}	63.55	63.55	63.56
(Me-3^{II})[b]		58.8	58.8
1^{III}		104.1 ($J_{C,H}$ = 171.9 Hz)	103.88[d] ($J_{C,H}$ = 171.3 Hz)
2^{III}		72.98	68.8
3^{III}		73.01	83.3[e]
4^{III}		69.2	75.0
5^{III}		76.4	74.9
6^{III}		63.55	63.56
(Me-3^{III})[c]			58.8
1^{IV}			104.1 ($J_{C,H}$ = 170.6 Hz)
2^{IV}			72.99
3^{IV}			73.01
4^{IV}			69.2
5^{IV}			76.4
6^{IV}			63.56

a) Determined at 400.0 MHz for ^1H NMR spectra and at 100.6 MHz for ^{13}C NMR spectra in D_2O (see Experimental). b) In the case of **1**, methyl group was absent. c) In the case of **2**, methyl group was absent. d) Exchageable. e) Exchangeable.

(18). A mixture of **5** (7.535 mg, 19.4 mmol), allyl bromide (60 mL, 694 mmol), and NaH (ca. 60%, 2.3 g, 57.5 mmol) was stirred at 80 °C for 2 h. After evaporation, the residue was chromatographed using the TK system (20:1) to give a homogeneous syrup (7.939 g). To this, AcOH (150 mL) and aq H_2SO_4 (30%, 20 mL) were added and the mixture was stirred at 100 °C for 60 min. The cooled mixture was diluted with PhMe (200 mL) and H_2O (100 mL) under stirring. The organic layer was washed with aq $NaHCO_3$ (5%, 50 mL, four times). Evaporation and chromatography with the TK system (6:1) afforded **18** (5.144 g, 64%), $[\alpha]_D^{26}$ +14° (*c* 1.2, $CHCl_3$); ^1H NMR ($CDCl_3$, 300 MHz) (80% α) δ 3.36 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3β), 3.64 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4α), 3.78 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.5 Hz, H-2α), 3.82 (dd, $J_{1,2}$ = 1.5 Hz, $J_{2,3}$ = 3.0 Hz, H-2β), 5.23 (dd, $J_{1,2}$ = 2.0 Hz, $J_{1,OH}$ = 3.5 Hz, H-1α), 3.34 (dd, $J_{1,OH}$ = 3.5 Hz, OH-1α), 3.40 (s, Me-3α), 3.49 (s, Me-3β), 5.84 (allyl); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 69.2 (C-6β), 69.9 (C-6α), 71.5 (C-α), 74.3 (C-2α), 74.4 (C-5β), 75.2 (C-4α, C-2β, C-5β), 81.3 (C-3α), 81.3 (C-3α), 85.4 (C-3β), 92.6 (C-1α), 93.7 (C-1β); 57.7 (Me-3α), 58.4 (Me-3β), 116.4, 135.1 (All-β), 116.6, 134.9 (All-α); HRMS (FAB) Found: *m/z* 437.1940. Calcd for $C_{24}H_{30}NaO_6$ $[M + Na]^+$: 437.19400.

Glycosylation Using the NST System or the NSD System. To a stirred mixture of an acceptor (0.030 – 0.120 mmol), a donor (1.3 equiv), NsCl (2.5 equiv), AgOTf (2.5 equiv), and CH_2Cl_2 (8 mL/mmol of acceptor) at −60 °C (bath temperature), Et_3N (2.5 equiv) or DBU (2.5 equiv) was added. The reaction temperature was allowed to rise up to 0 °C during ca. 5 h. The mixture was stirred for 16 h at this temperature under anhydrous conditions. To the mixture, PhMe (3 mL/mL of CH_2Cl_2) and powderized $NaHCO_3$ (10 equiv) were added; the mixture was stirred for 15 min and transferred onto a silica-gel column, which was then eluted with the TK system (gradient) to give a crude condensate. This was further purified with the TK system, or occasionally with the HE system. The results were summarized in Table 1.

Glycosylation Using the TP System. To a stirred mixture of an acceptor (0.030 – 0.065 mmol), a donor (1.3 equiv), Py (2.8 equiv), and CH_2Cl_2 (5 mL/mmol of acceptor), Me_3SiOTf (4.8 equiv) was added at −50 °C (bath temperature). The reaction temperature was increased to 0 °C during ca. 4 h. The mixture was then stirred at this temperature for 4.5 h. After the addition of Et_3N (4.8 equiv) and PhMe (3 mL/mL of CH_2Cl_2), the mixture was transferred onto a silica-gel column, which was then eluted with the TK system (gradient) to give crude glycoside. This was further purified with the TK system, or occasionally with the HE system. The results are summarized in Table 1.

Methyl *O*-(2,3,4,6-Tetra-*O*-benzyl-α-D-mannopyranosyl)-(1→4)-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (8). (Run 1). After elusion of **10** and **11** , there appeared **8**, $[\alpha]_D^{22}$ +16° (*c* 0.8, $CHCl_3$); ^1H NMR ($CDCl_3$, 300 MHz) δ 3.39 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3^I), 3.55 (dd, $J_{5,6}$ = 10.5 Hz, $J_{6a,6b}$ =

1.5 Hz, H-6a^{II}), 3.76 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{I}), 3.80 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{II}), 3.84 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{II}), 3.93 (t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4^{I}), 4.02 (t, $J_{3,4}$ =$J_{4,5}$ = 9.0 Hz, H-4^{II}), 4.78 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.30 (d, $J_{1,2}$ = 2.0 Hz, H1^{II}), 3.14 (Me-3^{I}), 3.36 (Me-1^{I}); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 69.4 (C-6^{II}), 70.2 (C-6^{I}), 71.3 (C-5^{I}), 72.97 (C-5^{II}), 73.02 (C-2^{I}), 74.7 (C-4^{I}), 75.0 (C-4^{II}), 75.4 (C-2^{II}), 80.0 (C-3^{II}), 81.9 (C-3^{I}), 98.8 (C-1^{I}, $J_{C1,H1}$ = 169.0 Hz), 99.9 (C-1^{II}, $J_{C1,H1}$ = 171.0 Hz); 54.9 (Me-1^{I}), 56.7 (Me-3^{I}). Found: C, 73.77; H, 6.99%. Calcd for $C_{56}H_{62}O_{11}$: C, 73.82; H, 6.86%.

Methyl *O*-(2,3,4,6-Tetra-*O*-(*p*-chlorobenzyl)-α-D-mannopyranosyl)-(1→4)-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (9). (Run 2). After elusion of **10** and **12** , there appeared **9**, $[\alpha]_D^{23}$ +14° (*c* 1.6, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.43 (dd, $J_{5,6}$ = 10.5 Hz, $J_{6a,6b}$ = 1.5 Hz, H-6a^{II}), 3.43 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3^{I}), 3.62 (dd, $J_{5,6}$ = 10.5 Hz, $J_{6a,6b}$ = 4.0 Hz, H-6b^{II}), 3.74 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{II}), 3.79 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{I}), 3.96 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{I}), 3.97 (t, $J_{3,4}$ =$J_{4,5}$ = 9.5 Hz, H-4^{II}), 4.80 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.30 (d, $J_{1,2}$ = 2.0 Hz, H-1^{II}), 3.18 (Me-3^{I}), 3.37 (Me-1^{I}); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 69.1 (C-6^{II}), 70.1 (C-6^{I}), 71.2 (C-5^{I}), 72.7 (C-5^{II}), 72.8 (C-2^{I}), 74.5 (C-4^{I}), 74.7 (C-4^{II}), 75.5 (C-2^{II}), 79.9 (C-3^{II}), 81.8 (C-3^{I}), 98.6 (C-1^{I}, $J_{C1,H1}$ = 168.3 Hz), 99.6 (C-1^{II}, $J_{C1,H1}$ = 170.9 Hz); 55.0 (Me-1^{I}), 56.5 (Me-3^{I}). Found: C, 63.88; H, 5.65%. Calcd for $C_{56}H_{58}Cl_4O_{11}$: C, 64.13; H, 5.57%.

Methyl 2,6-Di-*O*-benzyl-3-*O*-methyl-4-*O*-(*p*-nitrophenylsulfonyl)-α-D-mannopyranoside (10). $[\alpha]_D^{25}$ −15° (*c* 0.6, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.45 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3), 3.75 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2), 4.76 (d, $J_{1,2}$ = 2.0 Hz, H-1), 5.04 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4), 2.78 (Me-3), 3.34 (Me-1); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 69.0 (C-6), 70.1 (C-5), 73.4 (C-2), 78.6 (C-4), 78.7 (C-3), 98.8 (C-1), 55.1 (Me-1), 56.3 (Me-3); 143.2, 150.0 (Ns); HRMS (FAB) Found: *m/z* 596.1566. Calcd for $C_{28}H_{31}NaO_{10}S$ [M + Na]$^+$: 596.15662.

***O*-(2,3,4,6-Tetra-*O*-benzyl-α-D-mannopyranosyl)-(1→1)-2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranoside (11).** $[\alpha]_D^{24}$ +32° (*c* 0.4, $CHCl_3$) (lit.,[16] $[\alpha]_D^{20}$ +40° (*c* 0.85, $CHCl_3$)); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.55 (ddd, $J_{4,5}$ = 9.5 Hz, $J_{5,6a}$ = 2.0 Hz, $J_{5,6b}$ = 5.0 Hz, H5), 3.61 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2), 3.63 (dd, $J_{5,6a}$ = 2.0 Hz, $J_{5a,5b}$ = 11.0 Hz, H-6a), 3.72 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3), 3.76 (dd, $J_{5,6b}$ = 5.0 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6b), 3.98 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4), 5.20 (d, $J_{1,2}$ = 2.0 Hz, H-1); ^{13}C NMR($CDCl_3$, 75 MHz) δ 69.1 (C-6), 72.8 (C-5), 74.2 (C-2), 74.3 (C-4), 79.5 (C-3), 93.4 (C1, $J_{C1,H1}$ = 168.0 Hz); HRMS (FAB) Found: *m/z* 1085.4816. Calcd for $C_{68}H_{70}NaO_{11}$ [M + Na]$^+$: 1085.4815.

***O*-(2,3,4,6-Tetra-*O*-(*p*-chlorobenzyl)-α-D-mannopyranosyl-(1→1)-2,3,4,6-tetra-*O*-(*p*-chlorobenzyl)-α-D-mannopyranoside (12).** $[\alpha]_D^{23}$ +25° (*c* 1.4, $CHCl_3$)(lit.,[17] $[\alpha]_D^{20}$ +21° (*c* 1, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.49 (ddd, $J_{4,5}$ = 9.5 Hz, $J_{5,6a}$ = 2.0 Hz, $J_{5,6b}$ = 5.0 Hz, H5), 3.53 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2), 3.57 (dd, $J_{5,6a}$ = 2.0 Hz, $J_{5a,5b}$ = 10.5 Hz, H-6a), 3.65 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3), 3.68 (dd, $J_{5,6b}$ = 5.0 Hz, $J_{6a,6b}$ = 10.5 Hz, H-6b), 3.91 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4), 5.11 (d, $J_{1,2}$ = 2.0 Hz, H-1); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 69.1 (C-6), 72.8 (C-5), 74.5 (C-2), 74.6 (C-4), 79.5 (C-3), 93.5 (C1, $J_{C1,H1}$ = 170.5 Hz). Found: C, 61.17; H, 4.81%. Calcd for $C_{68}H_{62}Cl_8O_{11}$: C, 61.00; H, 4.67%.

In the case of Run 3 using TP system, the order of elution of the products was **14**, **13**, and then **9**.

Methyl 2,6-Di-*O*-benzyl-3-*O*-methyl-4-*O*-trimethylsilyl-α-D-mannopyranoside (13). (Run 3). $[\alpha]_D$ +16° (*c* 0.6, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.35 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3), 3.80 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2), 3.93 (dd, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4), 4.77 (d, $J_{1,2}$ = 2.0 Hz, H-1); 3.32 (Me-3), 3.35 (Me-1), 0.07 (MeSi); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 68.1 (C-4), 69.7 (C-6), 72.9 (C-5), 73.4 (C-2), 81.9 (C-3), 99.2 (C-1); 54.6 (Me-1), 57.1 (Me-3), 0.4 (MeSi); HRMS (FAB) Found: *m/z* 483.2179. Calcd for $C_{25}H_{36}NaO_6Si$ [M + Na]$^+$: 483.21786.

Trimethylsilyl 2,3,4,6-Tetra-*O*-(*p*-chlorobenzyl)-α-D-mannopyranoside (14). (Run 3). $[\alpha]_D$ +18° (*c* 0.6, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.60 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2), 3.62 (dd, $J_{5,6a}$ = 2.0 Hz, $J_{6a,6b}$ = 10.0 Hz, H-6a), 3.76 (dd, $J_{5,6b}$ = 4.0 Hz, $J_{5a,5b}$ = 10.0 Hz, H-6b), 3.82 (ddd, $J_{4,5}$ = 9.0 Hz, $J_{5,6a}$ = 2.0 Hz, $J_{5,6b}$ = 4.0 Hz, H-5), 3.92 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3), 3.99 (t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4), 5.18 (d, $J_{1,2}$ = 2.0 Hz, H-1), 0.11 (MeSi); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 69.2 (C-6), 71.7 (C-5), 75.0 (C-4), 76.7 (C-2), 79.8 (C-3), 92.8 (C1, $J_{C1,H1}$ = 166.5 Hz), −2.0 (MeSi); HRMS (FAB) Found: *m/z* 771.1246. Calcd for $C_{37}H_{40}Cl_4NaO_6Si$ [M + Na]$^+$: 771.12457.

Methyl *O*-(4-*O*-Acetyl-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranosyl)-(1→4)-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (19). $[\alpha]_D^{24}$ +23° (*c* 0.9, $CHCl_3$)(lit.,[8a] $[\alpha]_D$ +20.2° (*c* 1.3, $CHCl_3$)); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.52 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 10.0 Hz, H-3^{II}), 3.78 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{I}), 3.94 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{I}), 4.79 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.30 (dd, $J_{1,2}$ = 2.0 Hz, H-1^{II}), 5.30 (t, $J_{3,4}$ = $J_{4,5}$ = 10.0 Hz, H-4^{II}); 3.19 (Me-3^{I}), 3.33 (Me-3^{II}), 3.77 (Me-1^{I}), 2.08 (s. Ac); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 69.1 (C-4^{II}), 70.1 (C-6^{II}), 70.4 (C-6^{I}), 71.3 (C-5^{II}), 71.4 (C-5^{I}), 72.8 (C-2^{I}), 74.0 (C-2^{II}), 74.1 (C-4^{I}), 78.8 (C-3^{II}), 81.3 (C-3^{I}), 98.7 (C-1^{I}, $J_{C1,H1}$ = 169.2 Hz), 99.5 (C-1^{II}, $J_{C1,H1}$ = 172.0 Hz); 54.9 (Me-1^{I}), 56.6 (Me-3^{I}), 57.6 (Me-3^{II}); 21.0, 169.9 (Ac). Found: C, 68.48; H, 6.86%. Calcd for $C_{45}H_{54}O_{12}$: C, 68.68; H, 6.92%.

Methyl *O*-(4-*O*-Allyl-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranosyl)-(1→4)-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (20). $[\alpha]_D^{21}$ +19° (*c* 0.6, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.44 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{I}), 3.45 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3^{II}), 3.70 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{II}), 3.77 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 9.5 Hz, H-2^{I}), 3.82 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{II}), 3.94 (t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4^{II}), 4.79 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.31 (dd, $J_{1,2}$ = 2.0 Hz, H-1^{II}); 3.20 (Me-3^{I}), 3.36 (Me-1^{I}), 3.41 (Me-3^{II}), 5.85 (m, All); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 69.3 (C6^{II}), 70.2 (C-6^{I}), 71.3 (C-5^{I}), 72.9 (C-5^{II}), 73.0 (C-2^{I}), 74.5 (C-2^{II}), 74.6 (C-4^{I}), 74.8 (C-4^{II}), 81.4 (C-3^{II}), 81.8 (C-3^{I}), 98.7 (C-1^{I}, $J_{C1,H1}$ = 167.8 Hz), 99.7 (C-1^{II}, $J_{C1,H1}$ = 169.0 Hz); 54.9 (Me-1^{I}), 56.7 (Me-3^{I}), 57.6 (Me-3^{II}); 116.2, 135.3 (All). Found: C, 70.25; H, 7.32%. Calcd for $C_{46}H_{56}O_{11}$: C, 70.39; H, 7.19%.

Allyl *O*-(4-*O*-Acetyl-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranosyl)-(1→4)-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (21). $[\alpha]_D^{22}$ +24° (*c* 1.3, $CHCl_3$) (lit.,[8a] $[\alpha]_D$ +28.7° (*c* 2.8, $CHCl_3$)); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.43 (dd, $J_{5,6a}$ = 3.0 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6a^{II}), 3.80 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{I}), 3.96 (t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4^{I}), 4.94 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.30 (t, $J_{3,4}$ = $J_{4,5}$ = 10.0 Hz, H-4^{II}), 5.32 (dd, $J_{1,2}$ = 2.0 Hz, H-1^{II}); 3.20 (s, Me-3^{I}), 3.33 (s, Me-3^{II}), 5.90 (m, All), 1.98 (s. Ac); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 69.1 (C-4^{II}), 70.1 (C-6^{II}), 70.4 (C-6^{I}), 71.2 (C-5^{II}), 71.5 (C-5^{I}), 72.8 (C-2^{I}), 73.9 (C-2^{II}), 74.7 (C-4^{I}), 78.8 (C-3^{II}), 81.8 (C-3^{I}), 98.7 (C-1^{I}, $J_{C1,H1}$ = 169.0 Hz), 99.9 (C-1^{II}, $J_{C1,H1}$ = 172.1 Hz); 56.6 (Me-3^{I}), 57.6 (Me-3^{II}); 68.1, 117.5, 133.8 (All), 21.0, 169.9 (Ac). Found: C,

69.29; H, 6.93%. Calcd for $C_{47}H_{56}O_{12}$: C, 69.44; H, 6.94%.

Methyl *O*-(2,6-Di-*O*-Benzyl-3-*O*-methyl-α-D-mannopyranosyl)-(1→4)-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (22). A mixture of **20** (76.1 mg, 0.097 mmol) and dil NaOMe (0.2%, 8.2 mL) was kept standing overnight. Evaporation and chromatography using the TK system (10:1) furnished **22** (58.6 mg, 81%), $[\alpha]_D^{23}$ +7° (*c* 1.2, $CHCl_3$) (lit.,[8a] $[\alpha]_D$ +7.4° (*c* 1.4, $CHCl_3$)); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.40 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$= 9.5 Hz, H-3^{II}), 3.49 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{I}), 3.79 (dd, $J_{1,2}$ = 2.0 Hz, $J_{3,4}$ = 9.0 Hz, H-2^{I}), 3.81 (dd, $J_{5,6b}$ = 1.5 Hz, $J_{6a,6b}$ = 10.5 Hz, H-6b^{I}), 3.85 (dd, $J_{2,3}$ = 2.0 Hz, $J_{3,4}$ = 3.0 Hz, H-2^{II}), 3.99 (t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4^{I}), 4.00 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{II}), 4.80 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.35 (d, $J_{1,2}$ = 2.0 Hz, H-1^{II}); 3.24 (s, Me-3^{I}), 3.35 (s, Me-3^{II}), 3.37 (s, Me-1^{I}), 2.27 (s, OH-4^{II}); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 67.9 (C-4^{I}), 70.2 (C-6^{I}), 70.6 (C-6^{II}), 71.3 (C-5^{I}), 72.4 (C-5^{II}), 72.9 (C-2^{I}), 73.3 (C-2^{II}), 74.4 (C-4^{I}), 80.7 (C-3^{II}), 81.9 (C-3^{I}), 98.7 (C-1^{I}), 99.8 (C-1^{II}); 54.9 (Me-1^{I}), 56.6 (Me-3^{I}). 57.0 (Me-3^{II}).

This was obtained via deallylation of **20**: a mixture of **20** (48.1 mg, 0.061 mmol), NaOAc (55.6 mg, 0.68 equiv), $PdCl_2$ (30.2 mg, 0.17 equiv), and aq AcOH (95%, 2.26 mL) was stirred at 60 °C for 60 min. Evaporation and chromatography as above gave **22** (22.2 mg, 49%).

Methyl *O*-(2,3,4,6-Tetra-*O*-benzyl-α-D-mannopyranosyl)-(1→4)-*O*-(2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranosyl)-(1→4)-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (23). $[\alpha]_D^{21}$ +23° (*c* 1.6, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.37 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3^{II}), 3.44 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3^{I}), 3.56 (dd, $J_{5,6a}$ = 1.5 Hz, $J_{6a,6b}$ = 10.5 Hz, H-6a^{III}), 3.62 (dd, $J_{5,6a}$ = 6.0 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6a^{II}), 3.69 (dd, $J_{5,6b}$ = 4.0 Hz, $J_{6a,6b}$ = 10.5 Hz, H-6b^{III}), 3.69 (dd, $J_{5,6a}$ = 2.0 Hz, $J_{6a,6b}$ = 10.0 Hz, H-6a^{I}), 3.69 (dd, $J_{5,6b}$ = 2.0 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6b^{II}), 3.71 (ddd, $J_{4,5}$ = 9.5 Hz, $J_{5,6a}$ = 2.0 Hz, $J_{5,6b}$ = 6.0 Hz, H-5^{II}), 3.72 (dd, $J_{5,6a}$ = 2.0 Hz, $J_{6a,6a}$ = 12.0 Hz, H-6a^{I}), 3.73 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{III}), 3.77 (ddd, $J_{5,6a}$ = 1.5 Hz, $J_{5,6b}$ = 4.0 Hz, $J_{6a,6b}$ = 9.5 Hz, H-5^{III}), 3.80 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{II}), 3.83 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{III}), 3.86 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3^{III}), 3.91 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{I}), 3.96 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{II}), 4.04 (dd, $J_{3,4}$ = 9.5 Hz, $J_{4,5}$ = 10.5 Hz, H-4^{III}), 4.77 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.28 (d, $J_{1,2}$ = 2.0 Hz, H-1^{II}), 5.32 (d, $J_{1,2}$ = 2.0 Hz, H-1^{III}); 3.16 (s, Me-3^{I}), 3.20 (s, Me-3^{II}), 3.36 (s, Me-1^{I}); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 69.2 (C-6^{III}), 70.2 (C-6^{II}), 70.4 (C-6^{I}), 71.5 (C-5^{I}), 72.3 (C-5^{II}), 72.7 (C-2^{I}), 72.9 (C-2^{II}), 73.1 (C-5^{III}), 74.3 (C-4^{II}), 74.9 (C-4^{III}), 75.0 (C-4^{I}), 75.2 (C-2^{III}), 80.1 (C-3^{III}), 81.5 (C-3^{II}), 81.8 (C-3^{I}), 98.7 (C-1^{I}, $J_{C1,H1}$ = 170.4 Hz), 99.7 (C-1^{II}, $J_{C1,H1}$ = 171.5 Hz), 99.8 (C-1^{III}, $J_{C1,H1}$ = 171.5 Hz); 54.9 (Me-1^{I}), 56.4 (Me-3^{I}), 56.7 (Me-3^{II}); HRMS (FAB) Found: *m/z* 1289.5846. Calcd for $C_{77}H_{86}NaO_{16}$ $[M + Na]^+$: 1289.5814.

Methyl *O*-(2,3,4,6-Tetra-*O*-(*p*-chlorobenzyl)-α-D-mannopyranosyl)-(1→4)-*O*-(2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranosyl)-(1→4)-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (24). (Run 12). After the elution of **25** and **12**, there appeared **24**; $[\alpha]_D^{22}$ +17° (*c* 0.8, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.39 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3^{II}), 3.46 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3^{I}), 3.46 (dd, $J_{5,6a}$ = 1.5 Hz, $J_{6a,6b}$ = 10.5 Hz, H-6a^{III}), 3.63 (dd, $J_{5,6b}$ = 4.0 Hz, $J_{6a,6b}$ = 10.5 Hz, H-6b^{III}), 3.63 (dd, $J_{5,6a}$ = 6.0 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6a^{II}), 3.69 (dd, $J_{5,6b}$ = 2.0 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6b^{II}), 3.71 (ddd, $J_{4,5}$ = 9.5 Hz, $J_{5,6a}$ = 1.5 Hz, $J_{5,6b}$ = 4.0 Hz, H-5^{III}), 3.71 (ddd, $J_{4,5}$ = 9.5 Hz, $J_{5,6b}$ = 2.0 Hz, $J_{6a,6b}$ = 6.0 Hz, H-5^{II}), 3.71 (ddd, $J_{4,5}$ = 9.5 Hz, $J_{5,6a}$ = 2.0 Hz, $J_{5,6b}$ = 7.0 Hz, H-5^{I}), 3.72 (dd, $J_{5,6a}$ = 2.0 Hz, $J_{6a,6b}$ = 12.0 Hz, H-6a^{I}), 3.73 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{III}), 3.79 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{I}), 3.80 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3^{III}), 3.82 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{II}), 3.88 (ddd, $J_{5,6b}$ = 7.0 Hz, $J_{6a,6b}$ = 12.0 Hz, H-6b^{III}), 3.92 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{I}), 3.98 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{III}), 3.99 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{II}), 4.79 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.30 (d, $J_{1,2}$ = 2.0 Hz, H-1^{II}), 5.30 (d, $J_{1,2}$ = 2.0 Hz, H-1^{III}); 3.16 (s, Me-3^{I}), 3.21 (s, Me-3^{II}), 3.37 (s, Me-1^{I}); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 69.0 (C-6^{III}), 70.2 (C-6^{II}), 70.5 (C-6^{I}), 71.4 (C-5^{I}), 72.3 (C-5^{II}), 72.7 (C-2^{I}), 72.8 (C-2^{II}), 73.1 (C-5^{III}), 74.1 (C-4^{II}), 74.3 (C-4^{III}), 75.0 (C-4^{I}), 75.5 (C-2^{III}), 79.5 (C-3^{III}), 81.5 (C-3^{II}), 81.8 (C-3^{I}), 98.7 (C-1^{I}, $J_{C1,H1}$ = 168.7 Hz), 99.4 (C-1^{II}, $J_{C1,H1}$ = 170.0 Hz), 99.6 (C-1^{III}, $J_{C1,H1}$ = 170.0 Hz); 54.9 (Me-1^{I}), 56.3 (Me-3^{I}). 56.6 (Me-3^{II}); HRMS (FAB) Found: *m/z* 1425.4253. Calcd for $C_{77}H_{82}Cl_4NaO_{16}$ $[M + Na]^+$: 1425.4255.

Methyl *O*-(2,6-Di-*O*-benzyl-3-*O*-methyl-4-*O*-(*p*-nitrophenylsulfonyl)-α-D-mannopyranosyl)-(1→4)-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (25). $[\alpha]_D^{23}$ +9° (*c* 0.7, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.39 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 10.0 Hz, H-3^{II}), 3.43 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3^{I}), 3.56 (dd, $J_{5,6a}$ = 4.5 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6a^{II}), 3.82 (ddd, $J_{4,5}$ = 10.0 Hz, $J_{5,6a}$ = 4.5 Hz, $J_{5,6b}$ = 2.5 Hz, H-5^{II}), 3.94 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{I}), 4.78 (d, $J_{1,2}$ = 1.5 Hz, H-1^{II}), 5.05 (t, $J_{3,4}$ = $J_{4,5}$ = 10.0 Hz, H-4^{II}), 5.32 (d, $J_{1,2}$ = 1.5 Hz, H-1^{II}); 2.78 (s, Me-3^{II}), 3.16 (s, Me-3^{I}), 3.35 (s, Me-1^{I}); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 68.8 (C-6^{II}), 70.1 (C-6^{I}), 71.1 (C-5^{II}), 71.2 (C-5^{I}), 72.6 (C-2^{I}), 73.6 (C-2^{II}), 74.7 (C-4^{I}), 78.4 (C-3^{II}), 78.6 (C-4^{II}), 81.7 (C-3^{I}), 98.7 (C-1^{I}, $J_{C1,H1}$ = 166.6 Hz), 99.4 (C-1^{II}, $J_{C1,H1}$ = 171.7 Hz); 54.9 (Me-1^{I}), 56.1 (Me-3^{II}); 56.5 (Me-3^{I}); 143.4, 150.4 (Ns); HRMS (FAB) Found: *m/z* 952.3190. Calcd for $C_{49}H_{55}NaO_{15}$ $[M + Na]^+$: 952.31897.

Allyl *O*-(2,3,4,6-Tetra-*O*-benzyl-α-D-mannopyranosyl)-(1→4)-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (26). $[a]_D^{23}$ +16° (*c* 1.5, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.43 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{I}), 3.56 (dd, $J_{5,6a}$ = 1.5 Hz, $J_{6a,6b}$ = 10.5 Hz, H-6a^{II}), 3.78 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{I}), 3.80 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{II}), 3.94 (t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4^{I}), 4.02 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{II}), 4.93 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.30 (d, $J_{1,2}$ = 2.0 Hz, H-1^{II}); 3.14 (Me-3^{I}), 5.89 (m, All); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 69.3 (C-6^{II}), 70.2 (C-6^{I}), 71.4 (C-5^{I}), 73.0 (2C, C-2^{I} and C-5^{II}), 74.7 (C-4^{I}), 74.9 (C-4^{II}), 75.3 (C-2^{II}), 79.9 (C-3^{II}), 81.8 (C-3^{I}), 96.8 (C-1^{I}, $J_{C1,H1}$ = 168.0 Hz), 99.9 (C-1^{II}, $J_{C1,H1}$ = 171.0 Hz); 56.7 (Me-1^{I}); 68.0, 117.5, 133.8 (All). Found: C, 74.35; H, 6.97%. Calcd for $C_{58}H_{64}O_{11}$: C, 74.34; H, 6.88%.

Allyl *O*-(2,3,4,6-Tetra-*O*-(*p*-chlorobenzyl)-α-D-mannopyranosyl)-(1→4)-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (27). (Run16). After elution of **28** and **12**, there appeared **27**, $[\alpha]_D^{22}$ +18° (*c* 1.2, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.62 (dd, $J_{5,6b}$ = 4.0 Hz, $J_{6a,6b}$ = 10.5 Hz, H-6b^{II}), 3.74 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 2.3 Hz, H-2^{II}), 3.82 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{I}), 3.97 (t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4^{II}), 3.98 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{I}), 4.96 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.30 (d, $J_{1,2}$ = 2.0 Hz, H-1^{II}); 3.19 (Me-3^{I}), 5.90 (m, All); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 69.1 (C-6^{II}), 70.1 (C-6^{I}), 71.3 (C-5^{I}), 72.8 (2C, C-2^{I} and C-5^{II}), 74.1 (C-4^{II}), 74.7 (C-4^{I}), 75.5 (C-2^{II}), 79.8 (C-3^{II}), 81.8 (C-3^{I}), 96.7 (C-1^{I}, $J_{C1,H1}$ = 168.7 Hz), 99.6 (C-1^{II}, $J_{C1,H1}$ = 170.9 Hz); 56.7 (Me-1^{I}); 68.1, 117.5, 133.8 (All). Found: C, 64.91; H, 5.62%. Calcd for $C_{58}H_{60}Cl_4O_{11}$: C, 64.81; H, 5.63%.

Allyl 2,6-Di-*O*-benzyl-3-*O*-methyl-4-*O*-(*p*-nitrophenylsulfonyl)-α-D-mannopyranoside (28). $[\alpha]_D^{25}$ −21° (*c* 0.5, $CHCl_3$);

^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.49 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3), 3.76 (dd, $J_{1,2}$ = 1.5 Hz, $J_{2,3}$ = 3.0 Hz, H-2), 4.63 (d, $J_{1,2}$ = 1.5 Hz, H-1), 5.06 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4), 2.80 (Me-3), 5.84 (m, All); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 68.9 (C-6), 70.2 (C-5), 73.4 (C-2), 78.7 (2C, C-3 and C-4), 96.8 (C-1), 56.3 (Me-3), 68.3, 117.9, 133.3 (All); 143.2, 150.0 (Ns). HRMS (FAB) Found: *m/z* 622.1723. Calcd for $C_{30}H_{33}NaO_{10}$ [M + Na]$^+$: 622.17227.

***O*-(2,3,4,6-Tetra-*O*-(*p*-chlorobenzyl)-α-D-mannopyranosyl)-(1→4)-2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranose (29).** A mixture of **27** (41.2 mg, 0.038 mmol), NaOAc (25.7 mg, 0.31 mmol), $PdCl_2$ (14.3 mg, 0.081 mmol), and aq AcOH (95%, 1.5 mL) was stirred at 60 °C for 60 min. Additional portions of NaOAc (25.7 mg, 0.31 mmol) and $PdCl_2$ (14.3 mg, 0.081 mmol) were added to the mixture, which was further stirred at 60 °C for another 60 min. Evaporation and chromatography with the TK system (10:1) afforded **29** (32.0 mg, 81%), $[\alpha]_D^{23}$ +6° (*c* 1.2, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz) (80% α) δ 3.13 (dd, $J_{2,3}$ = 2.5 Hz, $J_{3,4}$ = 9.0 Hz, H-3β^{I}), 3.42 (dd, $J_{5,6a}$ = 1.5 Hz, H-6aα^{II}), 3.48 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H 3α^{I}), 3.58 (dd, $J_{5,6b}$ = 4.0 Hz, $J_{6a,6b}$ = 10.5 Hz, H-6bα^{II}), 3.72 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2α^{I}), 3.78 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2α^{I}), 3.98 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4α^{II}), 5.25 (d, $J_{1,2}$ = 2.0 Hz, H-1α^{II}), 5.27 (d, $J_{1,2}$ = 2.0 Hz, H-1α^{I}); 1.63 (s, OH-1α^{I}), 3.17 (Me-3α^{I}), 3.25 (Me-3β^{I}); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 69.0 (C-6α^{II}), 70.5 (C-6α^{I}), 71.1 (C-5α^{I}), 72.9 (C-5α^{II}), 73.0 (C-2α^{I}), 74.8 (C-4α^{I}), 75.0 (C-4α^{II}), 75.6 (C-2α^{II}), 79.8 (C-3β^{I}), 79.9 (C-2α^{II}), 81.3 (C-3α^{I}), 85.5 (C-3β^{I}), 92.4 (C-1α^{I}), 93.7 (C-1β^{I}), 99.6 (C-1β^{II}), 99.8 (C-1α^{II}); 56.6 (Me-3α^{I}), 57.2 (Me-3β^{I}); HRMS (FAB) Found: *m/z* 1055.2489. Calcd for $C_{55}H_{56}Cl_4NaO_{11}$ [M + Na]$^+$: 1055.2474.

Methyl *O*-(2,3,4,6-Tetra-*O*-(*p*-chlorobenzyl)-α-D-mannopyranosyl-(1→4)-[*O*-(2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranosyl-(1→4)-]$_2$2,6-di-*O*-benzyl-3-*O*-methyl-α-D-mannopyranoside (30). $[\alpha]_D^{23}$ +14° (*c* 1.4, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.44 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{I}), 3.42 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{II}), 3.46 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{III}), 3.46 (dd, $J_{5,6a}$ = 2.0 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6a^{IV}), 3.63 (dd, $J_{5,6b}$ = 4.0 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6b^{IV}), 3.64 (dd, $J_{5,6a}$ = 6.0 Hz, $J_{6a,6b}$ = 10.0 Hz, H-6a^{II}), 3.68 (dd, $J_{5,6a}$ = 2.0 Hz, $J_{6a,6b}$ = 10.0 Hz, H-6a^{III}), 3.70 (ddd, $J_{4,5}$ = 9.0 Hz, $J_{5,6a}$ = 2.0 Hz, $J_{5,6b}$ = 5.5 Hz, H-5^{I}), 3.72 (dd, $J_{5,6a}$ = 2.0 Hz, $J_{6a,6b}$ = 10.0 Hz, H-6a^{I}), 3.74 (ddd, $J_{4,5}$ = 9.0 Hz, $J_{5,6a}$ = 2.0 Hz, $J_{5,6b}$ = 6.0 Hz, H-5^{III}), 3.74 (ddd, $J_{4,5}$ = 9.5 Hz, $J_{5,6a}$ = 2.0 Hz, $J_{5,6b}$ = 4.0 Hz, H-5^{IV}), 3.76 (dd, $J_{5,6b}$ = 6.0 Hz, $J_{6a,6b}$ = 10.0 Hz, H-6b^{III}), 3.78 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{I}), 3.78 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{IV}), 3.80 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3^{IV}), 3.83 (d, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{II}), 3.84 (d, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{III}), 3.90 (t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4^{I}), 3.92 (dd, $J_{5,6b}$ = 5.5 Hz, $J_{6a,6b}$ = 10.0 Hz, H-6b^{I}), 3.96 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{II}), 3.99 (t, $J_{3,4}$ = $J_{4,5}$ = 9.5 Hz, H-4^{IV}), 4.03 (t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4^{II}), 4.79 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.29 (d, $J_{1,2}$ = 2.0 Hz, H-1^{II}), 5.32 (d, $J_{1,2}$ = 2.0 Hz, H-1^{III}), 5.34 (d, $J_{1,2}$ = 2.0 Hz, H-1^{IV}), 3.20 (s, 3H, Me-3^{I}), 3.21 (s, 6H, Me-3^{II} and Me-3^{III}), 3.36 (s, 3H, Me-1^{I}); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 69.0 (C-6^{IV}), 70.1 (C-6^{III}), 70.5 (2C, C-6^{I} and C-6^{II}), 71.6 (C-5^{I}), 72.5 (C-5^{II}), 72.6 (C-5^{III}), 72.8 (C-5^{IV}), 73.0 (C-2^{II}), 73.1 (C-2^{III}), 74.07 (C-4^{III}), 74.10 (C-4^{IV}), 74.7 (C-4^{II}), 74.8 (C-4^{I}), 75.3 (C-2^{I}), 75.4 (C-2^{IV}), 80.0 (C-3^{IV}), 81.4 (2C, C-3^{I} and C-3^{II}), 81.7 (C-3^{III}), 98.6 (C-1^{I}, $J_{C1,H1}$ = 168.0 Hz), 99.4 (C-1^{IV}, $J_{C1,H1}$ = 171.0 Hz), 99.5 (C-1^{III}, $J_{C1,H1}$ = 170.5 Hz), 99.7 (C-1^{II}, $J_{C1,H1}$ = 170.0 Hz); 54.9 (Me-1^{I}), 56.3 (Me-3^{I}). 56.4 (Me-3^{II}). 56.6 (Me-3^{III}); HRMS (FAB) Found: *m/z* 1781.5878. Calcd for $C_{98}H_{106}Cl_4NaO_{21}$ [M + Na]$^+$: 1781.5876.

Methyl *O*-α-D-Mannopyranosyl-(1→4)-3-*O*-methyl-α-D-mannopyranoside (1). A mixture of **8** (22.4 mg, 0.021 mmol), Pd on C (Kawaken Fine Chemical Co., 10%, 25 mg), and AcOH (6 mL) was shaken at room temperature overnight under H_2. Filtration, evaporation, and chromatography with the EM system (2:1) afforded **1** (7.1 mg, 78%), glass, $[\alpha]_D^{22}$ +82° (*c* 0.3, H_2O); ^{1}H NMR (D_2O, 400 MHz) δ 3.56 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{I}), 3.62 (ddd, $J_{4,5}$ = 9.0 Hz, $J_{5,6a}$ = 5.5 Hz, $J_{5,6b}$ = 1.5 Hz, H-5^{II}), 3.63 (t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4^{II}), 3.67 (ddd, $J_{4,5}$ = 9.0 Hz, $J_{5,6a}$ = 6.0 Hz, $J_{5,6b}$ = 2.0 Hz, H-5^{I}), 3.72 (dd, $J_{5,6a}$ = 5.5 Hz, $J_{6a,6b}$ = 12.0 Hz, H-6a^{II}), 3.75 (dd, $J_{5,6a}$ = 6.0 Hz, $J_{6a,6b}$ = 12.0 Hz, H-6a^{I}), 3.75 (dd, $J_{2,3}$ = 3.0 Hz, $J_{4,5}$ = 9.0 Hz, H-3^{II}), 3.78 (t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4^{I}), 3.84 (dd, $J_{5,6b}$ = 1.5 Hz, $J_{5a,5b}$ = 12.0 Hz, H-6b^{II}), 3.85 (dd, $J_{5,6b}$ = 2.0 Hz, $J_{6a,6b}$ = 12.0 Hz, H-6b^{I}), 3.96 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{II}), 4.12 (dd, $J_{1,2}$ = 1.5 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{I}), 4.77 (d, $J_{1,2}$ = 1.5 Hz, H-1^{I}), 5.13 (d, $J_{1,2}$ = 2.0 Hz, H-1^{II}); 3.35 (Me-1^{I}), 3.40 (Me-3^{I}). Found: C, 43.59; H, 7.05%. Calcd for $C_{14}H_{26}O_{11}\cdot H_2O$: C, 43.30; H, 7.27%.

A similar hydrogenolysis of **9** (31.5 mg, 0.024 mmol) over Pd on C (35 mg) in AcOH (6 mL), followed by chromatography, afforded **1** (7.0 mg, 63%).

Methyl *O*-α-D-Mannopyranosyl-(1→4)-*O*-(3-*O*-methyl-α-D-mannopyranosyl)-(1→4)-3-*O*-methyl-α-D-mannopyranoside (2). Hydrogenolysis of **23** (23.2 mg, 0.018 mmol) over Pd on C (10%, 25 mg) in AcOH (6 mL) and chromatography with EM system (2:1) furnished **2** (5.4 mg, 54%), glass, $[\alpha]_D^{23}$ +97° (*c* 0.4, H_2O); ^{1}H NMR (D_2O, 400 MHz) δ 3.59 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{I}), 3.61 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{II}), 3.64 (ddd, $J_{4,5}$ = 9.5 Hz, $J_{5,6a}$ = 5.5 Hz, $J_{5,6b}$ = 2.0 Hz, H-5^{III}), 3.65 (~t, $J_{3,4}$ = 9.0 Hz, $J_{4,5}$ = 9.5 Hz, H-4^{III}), 3.67 (ddd, $J_{4,5}$ = 9.5 Hz, $J_{5,6a}$ = 5.5 Hz, $J_{5,6b}$ = 2.0 Hz, H-5^{I}), 3.73 (ddd, $J_{4,5}$ = 9.5 Hz, $J_{5,6a}$ = 5.5 Hz, $J_{5,6b}$ = 2.0 Hz, H-5^{II}), 3.76 (dd, $J_{5,6a}$ = 5.5 Hz, $J_{6a,6b}$ = 12.0 Hz, H-6a^{I}, H-6a^{II}, H-6a^{III}), 3.77 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{III}), 3.81 (~t, $J_{3,4}$ = 9.0 Hz, $J_{4,5}$ = 9.5 Hz, H-4^{I}), 3.82 (~t, $J_{3,4}$ = 9.0 Hz, $J_{4,5}$ = 9.5 Hz, H-4^{II}), 3.85 (dd, $J_{5,6a}$ = 2.0 Hz, $J_{6a,6b}$ = 12.0 Hz, H-6b^{I}, H-6b^{II}, H-6b^{III}), 3.98 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{III}), 4.14 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{I}), 4.16 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{II}), 4.78 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.15 (d, $J_{1,2}$ = 2.0 Hz, H-1^{III}), 5.18 (d, $J_{1,2}$ = 2.0 Hz, H-1^{II}); 3.39 (Me-1^{I}), 3.42 (Me-3^{I}), 3.43 (Me-3^{II}). Found: C, 44.58; H, 7.10%. Calcd for $C_{21}H_{38}O_{16}\cdot H_2O$: C, 44.68; H, 7.14%.

A similar hydrogenolytic deprotection of **24** (25.5 mg, 0.018 mmol) over Pd on C (10%, 30 mg) in AcOH (6 mL) gave **2** (4.9 mg, 49%).

Methyl *O*-α-D-Mannopyranosyl-(1→4)-[*O*-(3-*O*-methyl-α-D-mannopyranosyl)-(1→4)-]$_2$3-*O*-methyl-α-D-mannopyranoside (3). The hydrogenolysis of **30** (36.8 mg, 0.021 mmol) was performed over Pd on C (10%, 50 mg) in AcOH (6 mL) at room temperature overnight. Filtration of the catalyst, evaporation, and chromatography with EM system (3:2) afforded **3** (7.2 mg, 48%), glass, $[\alpha]_D^{24}$ +89° (*c* 0.4, H_2O); ^{1}H NMR (D_2O, 400 MHz) δ 3.57 (dd, $J_{2,3}$ = 3.5 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{I}), 3.60 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.0 Hz, H-3^{II}, H-3^{III}), 3.64 (~t, $J_{3,4}$ = 9.5 Hz, $J_{4,5}$ = 10.0 Hz, H-4^{IV}), 3.65 (ddd, $J_{4,5}$ = 10.0 Hz, $J_{5,6a}$ = 5.0 Hz, $J_{5,6b}$ = 2.0 Hz, H-5^{IV}), 3.67 (ddd, $J_{4,5}$ = 10.0 Hz, $J_{5,6a}$ = 5.0 Hz, $J_{5,6b}$ = 2.0 Hz, H-5^{I}), 3.70 (ddd, $J_{4,5}$ = 10.0 Hz, $J_{5,6a}$ = 5.0 Hz, $J_{5,6b}$ = 2.0 Hz, H-5^{II}, H-5^{III}), 3.74 (dd, $J_{5,6a}$ = 5.0 Hz, $J_{6a,6b}$ = 12.0 Hz, H-6a^{I}, H-6a^{II}, H-6a^{III}, H-6a^{IV}), 3.77 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 9.5 Hz, H-3^{IV}), 3.80 (~t, $J_{3,4}$ = 9.0 Hz, $J_{4,5}$ = 10.0 Hz, H-4^{II}, H-4^{III}), 3.82 (~t, $J_{3,4}$ = 9.0 Hz, $J_{4,5}$ = 9.5 Hz,H-4^{I}), 3.84 (dd, $J_{5,6a}$ = 2.0 Hz, $J_{6a,6b}$ = 12.0 Hz, H-6b^{I}, H-6b^{II}, H-6b^{III}, H-6b^{IV}), 3.96 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ =

3.0 Hz, H-2^{IV}), 4.13 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{I}), 4.16 (dd, $J_{1,2}$ = 2.0 Hz, $J_{2,3}$ = 3.0 Hz, H-2^{II}, H-2^{III}), 4.77 (d, $J_{1,2}$ = 2.0 Hz, H-1^{I}), 5.14 (d, $J_{1,2}$ = 2.0 Hz, H-1^{IV}), 5.18 (d, $J_{1,2}$ = 2.0 Hz, H-1^{II}, H-1^{III}); 3.38 (Me-1^{I}), 3.41 (Me-3^{I}), 3.42 (Me-3^{II} or Me-3^{II}), 3.43 (Me-3^{III} or Me-3^{II}); HRMS (FAB) Found: *m/z* 721.2766. Calcd for $C_{28}H_{49}O_{21}$ $[M - 1]^-$: 721.27662.

References

1 a) H. Paulsen, "Modern Methods in Carbohydrate Synthesis," ed by S. H. Khan and R. A. O'Neill, Harwood Academic Publishers (1996), p. 1. b) R. R. Schmidt and K.-H. Jung, "Preparative Carbohydrate Chemistry," ed by S. Hanessian, Marcel Dekker, Inc., New York (1997), p. 283. c) S. L. Flitsch and G. M. Watt, "Glycopeptides and Related Compounds," ed by D. G. Large and C. D. Warren, Marcel Dekker, Inc., New York (1997), p. 207. d) R. R. Schmidt, "Glycosciences," ed by H.-J. Gabius and S. Gabius, Chepman & Hall, Weinhaim (1997), p. 31. e) B. Fraser-Reid, R. Madsen, A. S. Campbell, C. S. Roberts, and J. R. Merritt, "Bioorganic Chemistry: Carbohydrates," ed by S. M. Hecht, Oxford University Press, Oxford (1999), p. 89.

2 a) S. Hanessian, "Preparative Carbohydrate Chemistry," ed by S. Hanessian, Marcel Dekker, Inc., New York (1997), p. 381. b) O. Kanie and T. Ogawa, "Medicinal Chemistry: Today and Tomorrow," ed by M. Yamazaki, Blackwell Science Ltd., Oxford (1997), p. 221. c) G. H. Veeneman, "Carbohydrate Chemistry," by G.-J. Boons, Blackie Academic and Professional, London (1998), p. 98. d) S. Oscarson, *Carbohydrates*, **1999**, 150. e) R. R. Schmidt, J. C. Castro-Palomino, and O. Retz, *Pure Appl. Chem.*, **71**, 729 (1999). f) B. G. Davis, *J. Chem. Soc., Perkin Trans. 1*, **2000**, 2137. g) G. Capozzi, S. Menichetti, and C. Nativi, *Methods Princ. Med. Chem.*, **7** (New Trends in Synthetic Medicinal Chemistry), 221 (2000). h) K. Toshima, *Carbohydr. Res.*, **327**, 15 (2000). i) O. Seitz, *ChemBioChem*, **1**, 214 (2000).

3 M. Hirooka, Y. Mori, A. Sasaki, S. Koto, Y. Shinoda, and A. Morinaga, *Bull. Chem. Soc. Jpn.*, **74**, 1679 (2001).

4 a) Ref. 3 of the foregoing report. b) B. Fischer, A. Nudelman, M. Ruse, J. Herzig, and H. E. Gottlieb, *J. Org. Chem.*, **49**, 4983 (1984). c) H. M. Nguyen, J. L. Poole, and D. Y. Gin, Angew. Chem., **40**, 414 (2001). d) Y.-J. Kim and D. Y. Gin, *Org. Lett.*, **3**, 1801 (2001).

5 a) S. Koto, N. Morishima, and S. Zen, *Bull. Chem. Soc. Jpn.*, **52**, 784 (1979). b) S. Koto, T. Sato, N. Morishima, and S. Zen, *Bull. Chem. Soc. Jpn.*, **53**, 1761 (1980). c) S. Koto, N. Morishima, and S. Zen, *Bull. Chem. Soc. Jpn.*, **55**, 1543 (1982). d) S. Koto, N. Morishima, C. Kusuhara, S. Sekido, T. Yoshida, and S. Zen, *Bull. Chem. Soc. Jpn.*, **55**, 2995 (1982). e) S. Koto, N. Morishima, M. Owa, and S. Zen, *Carbohydr. Res.*, **130**, 73 (1984). f) S. Koto, N. Morishima, K. Takenaka, C. Uchida, and S. Zen, *Bull. Chem. Soc. Jpn.*, **58**, 1464 (1985). g) S. Koto, K. Yago, S. Zen, F. Tomonaga, and S. Shimada, *Bull. Chem. Soc. Jpn.*, **59**, 411 (1986). h) M. Hirooka and S. Koto, *Bull. Chem. Soc. Jpn.*, **71**, 2893 (1998).

6 a) S. Koto, N. Morishima, M. Uchino, M. Fukuda, M. Yamazaki, and S. Zen, *Bull. Chem. Soc. Jpn.*, **61**, 3943 (1988). b) S. Koto, H. Haigoh, S. Shichi, M. Hirooka, T. Nakamura, C. Maru, M. Fujita, A. Goto, T. Sato, M. Okada, S. Zen, K. Yago, and F. Tomonaga, *Bull. Chem. Soc. Jpn.*, **68**, 2331 (1995). c) S. Koto, T. Miura, M. Hirooka, A. Tomaru, M. Iida, M. Kanemitsu, K. Takenaka, S. Miyaji, N. Kuroyanagi, M. Yagishita, S. Zen, K. Yago, and F. Tomonaga, *Bull. Chem. Soc. Jpn.*, **69**, 3247 (1996). d) S. Koto, K. Asami, M. Hirooka, K. Nagura, M. Takizawa, S. Yamamoto, N. Okamoto, M. Sato, H. Tajima, T. Yoshida, N. Nonaka, T. Sato, S. Zen, K. Yago, and F. Tomonaga, *Bull. Chem. Soc. Jpn.*, **72**, 765 (1999). e) S. Koto, M. Hirooka, K. Yago, M. Komiya, T. Shimizu, K. Kato, T. Takehara, A. Ikefuji, A. Iwasa, S. Hagino, M. Sekiya, Y. Nakase, S. Zen, F. Tomonaga, and S. Shimada, *Bull. Chem. Soc. Jpn.*, **73**, 173 (2000). f) S. Koto, A. Kusunoki, and M. Hirooka, *Bull. Chem. Soc. Jpn.*, **73**, 967 (2000). g) S. Koto, M. Hirooka, T. Yoshida, K. Takenaka, C. Asai, T. Nagamitsu, H. Sakuma, M. Sakurai, S. Masuzawa, M. Komiya, T. Sato, S. Zen, K. Yago, and F. Tomonaga, *Bull. Chem. Soc. Jpn.*, **73**, 2521 (2000).

7 H. Yamada, R. E. Cohen, and C. E. Ballou, *J. Biol. Chem.*, **254**, 1972 (1979).

8 a) W. Liao and D. Lu, *Carbohydr. Res.*, **296**, 171 (1996). b) W. Liao and D. Lu, *Carbohydr. Res.*, **300**, 347 (1997).

9 J. J. Patroni, R. V. Stick, B. W. Skelton, and A. H. White, *Aust. J. Chem.*, **41**, 92 (1988).

10 a) M. A. Nashed and L. Anderson, *Tetrahedron Lett.*, **1976**, 3503. b) M. E. Haque, T. Kikuchi, K. Yoshimoto, and Y. Tsuda, *Chem. Pharm. Bull*, **33**, 2242 (1985). c) G. Yang and F. Kong, *Carbohydr. Res.*, **211**, 179 (1991). d) W. Liao, Y. Liu, and D. Lu, *Carbohydr. Res.*, **260**, 151 (1994). e) M. K. Gurjar, S. K. Das, and P. S. Mainkar, *J. Carbohydr. Chem.*, **13**, 899 (1994).

11 M. P. DeNinno, J. B. Etienne, and K. C. Duplantier, *Tetrahedron Lett.*, **36**, 669 (1995).

12 S. Koto, N. Morishima, Y. Miyata, and S. Zen, *Bull. Chem. Soc. Jpn.*, **49**, 2639 (1976).

13 S. Koto, S. Inada, N. Morishima, and S. Zen, *Carbohydr. Res.*, **87**, 294 (1980).

14 A. A. Pavia, J.-M. Rocheville, and S. N. Ung, *Carbohydr. Res.*, **79**, 79 (1980).

15 S.Koto, S. Inada, and S. Zen, *Bull. Chem. Soc. Jpn.*, **54**, 2728 (1976).

16 a) J. Yoshimura, K. Hara, Y. Sato, and H. Hashimoto, *Tetrahedron Lett.*, **1983**, 319. b) M. Nishizawa, D. M. Garcia, Y. Noguchi, K. Komatsu, S. Hatakeyama, and H. Yamada, *Chem. Pharm. Bull.*, **42**, 2400 (1994).

17 T. Ogawa, S. Nakabayashi, and T. Kitajima, *Carbohydr. Res.*, **114**, 225 (1983).

18 a) K. Bock and C. Pedersen, *Adv. Carbohydr. Chem. Biochem.*, **41**, 27 (1983); b) K. Bock, I. Lundt, and C. Pedersen, *Tetrahedron Lett.*, **1973**, 1037; c) K. Bock and C. Pedersen, *J. Chem. Soc., Perkin Trans. 2*, **1974**, 293.