Available online at www.sciencedirect.com
SCIENCE DIRECT®
Carbohydrate Research 340 (2005) 1213–1217
Carbohydrate RESEARCH

Note

An expedient synthesis of benzyl 2,3,4-tri-*O*-benzyl-β-D-glucopyranoside and benzyl 2,3,4-tri-*O*-benzyl-β-D-mannopyranoside

Wallach Lu, Latifeh Navidpour and Scott D. Taylor*

Department of Chemistry, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1

Received 17 November 2004; accepted 14 February 2005

Abstract—An efficient three-step synthesis of benzyl 2,3,4-tri-*O*-benzyl-β-D-glucopyranoside, a widely used building block in carbohydrate chemistry, is described. The key step is the selective debenzylation–acetylation of perbenzylated β-glucose using $ZnCl_2$–Ac_2O–HOAc. This approach was also used to affect an efficient three-step synthesis of benzyl 2,3,4-tri-*O*-benzyl-β-D-mannopyranoside.

Keywords: Carbohydrate building blocks; Glucose; Mannose; Perbenzylated glucose; Selective debenzylation–acetylation

Key to the understanding of the functions of complex oligosaccharides, as well as for the development of novel oligosaccharide-based therapeutics, is the design of efficient methods for their synthesis. However, before such species can be constructed, specifically protected monosaccharide building blocks must first be prepared. One such building block, benzyl 2,3,4-tri-*O*-benzyl-β-D-glucopyranoside (**3**), has been used extensively in the preparation of a wide variety of mono- and oligosaccharides.[1] As part of our research program on the preparation of sulfated carbohydrates and their nonhydrolyzable analogues, we found it necessary to prepare multigram quantities of **3**. A review of the literature revealed that a number of syntheses of **3** have been reported. The most commonly used procedures involve the preparation of benzyl β-D-glucopyranoside, which is typically prepared by a two[2]- to four[3]-step procedure, depending on the route and whether D-glucose or penta-*O*-acetyl-D-glucose is chosen as the starting material. Compound **3** is prepared from benzyl β-D-glucopyranoside by either selective protection of the 6-OH group followed by benzylation and 6-OH deprotection[1b,d] or by benzylidene protection of the 4- and 6-OH groups, followed by benzylation and regiospecific reduction of the benzylidene moiety.[4] Although the yields of the individual steps are usually good, and the overall yield of **3** usually ranges from 40% to 50%, these syntheses require five to seven steps, are time consuming, and can also be costly when performed on a multigram scale when employing certain 6-OH protecting groups such as the TBDPS group.[1d] Due to our need for multigram quantities of **3** and because of its widespread use in carbohydrate chemistry, we embarked on a search for a more efficient synthesis of this compound, as well as benzyl 2,3,4-tri-*O*-benzyl-β-D-mannopyranoside (**6**), a compound also required for our studies and whose synthesis has never been reported.

Our approach to the synthesis of **3** and **6** involves the selective debenzylation–acetolysis of the benzyl protecting group at C-6 of perbenzylated glucose or mannose. The resulting 6-*O*-acetyl derivatives are then subjected to deacetylation under Zemplén conditions to give the desired products.[†] The first step is the

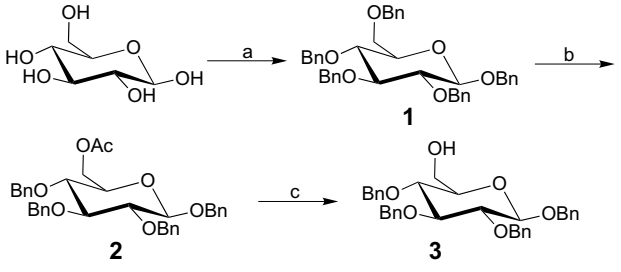
* Corresponding author. Tel.: +1 519 888 4567; fax: +1 519 746 0435; e-mail: s5taylor@sciborg.uwaterloo.ca

[†] While our studies were in progress we became aware of a similar approach reported by Lorentzen et al.[1m] for the synthesis of **3**. In this case, synthesis of **3** was achieved by per-*O*-benzylation of glucose using NaH–BnBr, followed by selective debenzylation–acetolysis using Ac_2O–H_2SO_4, then deacetylation under Zemplén conditions. However, no experimental details, characterization data or yields were given. To our knowledge, no other group has reported using Lorentzen's synthesis of **3**.

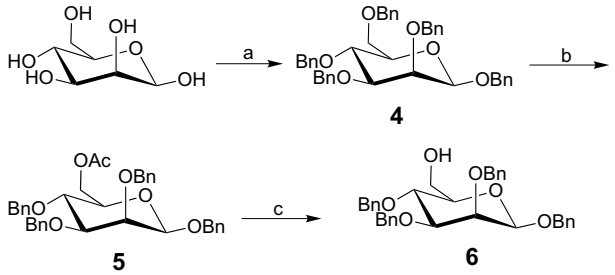
0008-6215/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.carres.2005.02.013

perbenzylation glucose and mannose. Per-*O*-benzylated β-D-glucose has been prepared by a number of groups; however, these are all multistep syntheses.[5] To our knowledge, only a single report, that by Decoster et al.,[6] has appeared describing an experimental procedure for a one-step per-*O*-benzylation of carbohydrates. This involves subjecting the carbohydrate to an excess of powdered KOH in DMSO, followed by the slow addition of benzyl bromide. Using this procedure, we were able to obtain per-*O*-benzylated D-glucose in a 65–67% yield (after chromatography) as a mixture of α and β isomers with the β isomer being by far the predominant species (as determined by ^{13}C NMR spectroscopy). Recrystallization gave exclusively benzyl 2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranoside (**1**, Scheme 1) in a slightly lower yield (55–60%) than that obtained by Decoster (65%). In an attempt to improve upon the per-*O*-benzylation, we also examined the reaction using NaH as base. Subjecting D-glucose to an excess of NaH in DMF, followed by the addition of excess BnBr or BnCl, gave per-*O*-benzylated D-glucose in yields of only 25–30%. However, by adding NaH and BnBr in portions over several hours, compound **1** could be obtained in 70–75% yield as a mixture of α (minor) and β (major) isomers after chromatography. Recrystallization of the chromatographed material in methanol gave compound **1** exclusively in 60–66% yield, a slight improvement over the KOH method. The addition of varying amounts of tetrabutylammonium iodide to the reaction mixture did result in a slight increase in the overall yield of the per-*O*-benzylated species; however, the ratio of β:α isomer decreased. Using the KOH procedure, per-*O*-benzylated-D-mannose was obtained from mannose in an 84–86% yield as a mixture of α (minor) and β (major) isomers after chromatography. Recrystallization gave exclusively benzyl 2,3,4,6-tetra-*O*-benzyl-β-D-mannopyranoside (**4**, Scheme 2) in yields ranging from 60% to 63%. Surprisingly, per-*O*-benzylation of mannose using the NaH procedure proceeded in low yield (28%).

A number of reports have appeared on the selective 6-O-debenzylation–acetolysis of protected carbohydrates. However, yields and selectivities are often poor, and this reaction is usually performed with methyl pyranosides. Selective acetolysis of the benzyl protecting group at C-6 in **1** was first attempted using H_2SO_4–Ac_2O[1m,7] in various ratios and at different temperatures, but only poor yields of benzyl 6-*O*-acetyl-2,3,4-tri-*O*-benzyl-β-D-glucopyranoside (**2**) were obtained mainly due to loss of the anomeric benzyl group. We attempted next the procedure of Angibeaud and Utille[8] who used TMSOTf–Ac_2O at −40 or −65 °C for the selective and high yielding debenzylation–acetylation of methyl 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside.[8] This procedure was used by Jain and Matta[9] to effect a 6-*O*-debenzylation–acetylation of benzyl 2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranoside,[9] and this is the only report that we are aware of describing a procedure for the 6-*O*-debenzylation–acetylation of a benzyl pyranoside. However, with **1**, this procedure was unsuccessful due to the formation of a thick slurry (which could not even be stirred) when a solution of **1** in Ac_2O was cooled to below −40 °C. Higher temperatures resulted in poor selectivity. Finally, we examined $ZnCl_2$–Ac_2O–HOAc, which was used by Yang et al. for the 6-*O*-debenzylation of a wide variety of methyl pyranosides.[10] Following their procedure, a solution of freshly fused $ZnCl_2$ (9 equiv) in 1:2 HOAc–Ac_2O was added to a solution of **1** in 1:2 HOAc–Ac_2O and stirred for 2 h at rt. This gave **2** in a 51% yield. Analysis of the products revealed that considerable loss of the benzyl group at the anomeric position had occurred. However, by changing the ratio of HOAc–Ac_2O to 1:5 and using just 5 equiv of freshly fused $ZnCl_2$ and reacting for 90 min, **2** was consistently obtained in 78–80% yield. Deacetylation of **2** under Zemplén conditions gave compound **3** in 94–97% yield (Scheme 1). Alternatively, crude **2** could be directly deacetylated to give **3** in a 78–80% yield from **1**. In the case of the mannose derivative **4**, the $ZnCl_2$–HOAc–Ac_2O procedure worked poorly giving low yields and a variety of unidentified byproducts. However, using TMSOTf–Ac_2O at −78 °C, the debenzylation–acetylation proceeded well. The crude benzyl 6-*O*-acetyl-2,3,4-tri-*O*-benzyl-β-D-mannopyranoside (**5**)



Scheme 1. Reagents and conditions: (a) NaH (excess), BnBr (excess), DMF, rt, 24 h; (b) HOAc–Ac_2O (5:1), $ZnCl_2$ (5 equiv), 90 min; (c) NaOMe–MeOH.



Scheme 2. Reagents and conditions: (a) KOH (excess), BnBr (excess), DMSO, rt, 24 h; (b) Ac_2O–TMSOTf, −78 °C, 1 h; (c) NaOMe–MeOH.

was directly deacetylated to give benzyl 2,3,4-tri-*O*-benzyl-β-D-mannopyranoside (**6**) in a 75–77% yield (two steps, Scheme 2). The overall yield of **3**, 47–53% (if not isolating **2**), is slightly better than that of the other procedures discussed earlier. Most significantly, this approach gives the desired product in just three steps starting from glucose and is amenable to scaleup to multigram quantities. The overall yield of the mannose derivative **6** was 45–49%. We are not aware of any reports describing the synthesis of compound **6**. However, its α-anomer has been prepared by several groups by a variety of routes each requiring at least four steps.[9,11] Attempts to construct benzyl 2,3,4-tri-*O*-benzyl-β-D-galactopyranoside using this approach were unsuccessful. Per-*O*-benzylation of galactose using either the NaH or KOH method gave the per-*O*-benzylated furanose isomer as a mixture of α (major) and β isomers in 75–80% yield.[6]

In summary, an expedient three-step synthesis of benzyl 2,3,4-tri-*O*-benzyl-β-D-glucopyranoside (**3**) was developed. We expect that this procedure will find widespread use in the preparation of this compound, a widely used building block in carbohydrate chemistry. This procedure was also used for the first synthesis of benzyl 2,3,4-tri-*O*-benzyl-β-D-mannopyranoside (**6**).

1. Experimental

1.1. General methods

All starting materials and reagents were obtained from Aldrich Chemical Company. CH_2Cl_2 was distilled from calcium hydride under nitrogen. DMF was distilled under reduced pressure from CaH_2 onto freshly activated 4 Å sieves under Ar. MeOH was dried from Mg/I_2, followed by distillation onto freshly activated 4 Å sieves and storage under Ar. TMSOTf was distilled under reduced pressure under Ar into a Schlenk flask and stored under Ar. Silica gel chromatography was performed using Silica Gel 60 Å (230–400 mesh) obtained from Silicycle (Laval, Quebec, Canada). ^1H and ^{13}C NMR spectra were recorded on a Bruker Avance 300 spectrometer. All NMR spectra were run in $CDCl_3$ unless stated otherwise. Chemical shifts (δ) for ^1H NMR are reported in ppm relative to the internal standard tetramethylsilane (Me_4Si). ^{13}C NMR spectra are reported in ppm relative to the $CDCl_3$ ($\delta = 77.0$) central peak. ^{13}C NMR was used throughout this study to determine the presence of α and β isomers. Low-resolution (LRMS) and high-resolution (HRMS) electron impact (EI) mass spectra were obtained on a Micromass 70-S-250 sector mass spectrometer. Melting points were determined on a Fisher–Johns melting point apparatus and are uncorrected. Optical rotations were obtained using a Perkin–Elmer 241 polarimeter.

1.1.1. Preparation of benzyl 2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranoside (1)

1.1.1.1. NaH method. To a suspension of D-glucose (9 g, 50 mmol) in anhyd DMF (250 mL) was added NaH (6.0 g of 60% dispersion in mineral oil, 150 mmol) at room temperature. The suspension was stirred for 30 min then cooled in an ice bath. Benzyl bromide (21.5 mL, 175 mmol) was added dropwise over a 5-min period, and after 10 min the ice bath was removed. After stirring at room temperature for 2.5 h, this procedure was repeated (addition of the same quantities of NaH and benzyl bromide). After another 2.5 h, NaH (4 g, 100 mmol) and benzyl bromide (12 mL, 95 mmol) were added consecutively. The reaction mixture was stirred overnight, and then 10 mL of MeOH was added slowly to react with the excess of the NaH. DMF was removed under reduced pressure at 55 °C. The residue was dissolved in CH_2Cl_2 (250 mL) and washed with water and brine, dried ($MgSO_4$), filtered, and evaporated to give a yellow oil, which solidified to a yellow solid after being subjected to high vacuum overnight. Flash chromatography (1:9 EtOAc–hexane) yielded a white solid. Recrystallization from MeOH gave **1** (20.7 g, 66%) as a white solid: mp 83–84 °C, lit.[5b] 83–83.5 °C; $[\alpha]_D^{22}$ −8.8 (*c* 1.0, $CHCl_3$); lit.[6] $[\alpha]_D^{20}$ −9.1; ^1H NMR: δ 3.48–3.78 (m, 6H), 4.51–5.00 (m, 11H), 7.15–7.37 (m, 25H); ^{13}C NMR spectrum is in agreement with those published.[5c]

1.1.1.2. KOH method. D-Glucose (1.0 g, 5.6 mmol) was added to a solution of powdered KOH (3.5 g, 63.5 mmol) in 4 mL of Me_2SO. The suspension was cooled in an ice bath, and BnBr (4.8 mL, 40.3 mmol) was immediately added dropwise over a period of 25 min with strong stirring (good stirring is essential for achieving the reported yields and a mechanical stirrer is necessary when using over 2 g of carbohydrate). The reaction was allowed to come slowly to room temperature by allowing the ice to melt. After stirring for 24 h, the reaction was diluted with 60 mL of cold water and then extracted with Et_2O (3×50 mL). The combined organics were washed with water (50 mL) and satd brine (50 mL), dried ($MgSO_4$) and concentrated to give a cream-colored solid. Chromatography, followed by recrystallization as described above, gave **1** as a white solid in 58% yield with identical physical and spectral properties as that prepared using the NaH method.

1.1.2. Preparation of benzyl 6-*O*-acetyl-2,3,4-tri-*O*-benzyl-β-D-glucopyranoside (2).

To freshly fused (under high vacuum) zinc chloride (5.46 g, 40 mmol) was added 1:5 HOAc–Ac_2O (30 mL). The mixture was cooled down to 0 °C, and then a solution of **1** (4.88 g, 7.7 mmol) in 1:5 HOAc–Ac_2O (30 mL) was added dropwise. The reaction mixture was stirred at room temperature for 1.5 h, and then 180 mL of ice water was added. The resulting light-brown precipitate was filtered and

washed with water. Purification by chromatography (1:5:1, $CHCl_3$–hexane–Et_2O) gave **2** (3.53 g, 78%) as a white solid: mp 114–115 °C, lit[12] 116–117 °C; $[\alpha]_D^{22}$ −2.8 (*c* 1.0 $CHCl_3$), lit.[12] $[\alpha]_D^{20}$ −2.9; ^{1}H NMR: δ 2.05 (s, 3H, $COCH_3$) 3.48–3.61 (m, 3H, H-2, H-4, H-5), 3.67 (overlapping dd, $J_{3,4}$ 8.3, $J_{3,2}$ 8.3 Hz, 1H, H-3), 4.24 (dd, $J_{5,6a}$ 4.3, $J_{6a,6b}$ 11.7 Hz, 1H, H-6_a), 4.35 (d, $J_{6a,6b}$ 11.7 Hz, 1H, H-6_b), 4.49–4.84 (m, 6H), 4.92–5.02 (m, 3H), 7.21–7.40 (m, 20H); ^{13}C NMR: δ 20.8 (CH_3), 63.0 (C-6), 71.0 (CH_2), 72.7 (C-4), 74.7 (CH_2), 74.8 (CH_2), 75.6 (CH_2), 77.2 (C-2), 82.0 (C-5), 84.5 (C-3), 102.2 (C-1), 127.6, 127.7, 127.8, 127.9, 128.0, 128.2, 128.3, 128.4, 137.0, 137.6, 138.1, 138.3, 170.6. LREIMS: *m*/*z* (relative intensity) 491.2 (M−CH_2Ph, 8), 383.1 (5), 253.1 (52), 181.1 (20), 91.0 (100); HREIMS: Calcd for $C_{29}H_{31}O_7$, *m*/*z* 491.2059; found, *m*/*z* 491.2059.

1.1.3. Preparation of benzyl 2,3,4-tri-*O*-benzyl-β-D-glucopyranoside (3). A suspension of glucosyl 6-acetate **2** (3.53 g, 6.05 mmol) in 50 mL of 0.025 M NaOMe in MeOH was stirred for 5 h. The reaction mixture was then poured into 200 mL of ice water and stirred for 30 min. The resulting precipitate was filtered and washed with satd $NaHCO_3$ and water, and then it was dried under high vacuum to give spectroscopically pure **3** (3.18 g, 97%) as a white powder. Recrystallization from EtOH gave white needles: mp 102–104 °C, lit.[12] 104–106 °C; $[\alpha]_D^{22}$ −8.8 (*c* 1.0, $CHCl_3$), lit.[12] $[\alpha]_D^{20}$ −9.2; ^{1}H and ^{13}C NMR spectra were in agreement with those published.[1d] Alternatively, compound **3** can be prepared by subjecting crude **2** (after precipitation and drying) to NaOMe–MeOH. Using this approach, pure **3** was obtained in an 78–80% yield (from **1**) after chromatography (silica, 20% EtOAc–hexane to 30% EtOAc–hexane).

1.1.4. Preparation of benzyl 2,3,4,6-tetra-*O*-benzyl-β-D-mannopyranoside (4). Compound **4** was prepared in 60–63% yield using the KOH method described above for glucose, except the product was recrystallized in 5% EtOAc–hexane. White solid: mp 69–71 °C, lit.[6] 70–71 °C; $[\alpha]_D^{22}$ −65.2 (*c* 1.0, $CHCl_3$), lit.[6] $[\alpha]_D^{20}$ −69.6; ^{1}H NMR: δ 3.42–3.49 (m, 2H), 3.73–3.91 (m, 4H), 4.40–4.63 (m, 7H), 4.85–5.01 (m, 4H), 7.14–7.50 (m, 25H); ^{13}C NMR: δ 69.7, 70.7, 71.4, 73.4, 73.8, 74.0, 75.0, 75.9, 82.4, 100.4 (C-1), 127.3, 127.4, 127.5, 127.6, 127.62, 127.7, 127.8, 127.9, 128.0, 128.3, 137.5, 138.1, 138.3, 138.4, 138.7. LREIMS: *m*/*z* (relative intensity) 539.2 (M−CH_2Ph, 5), 431.2 (12), 253.1 (55), 181.1 (23), 91.0 (100); HREIMS: Calcd for $C_{34}H_{35}O_6$, *m*/*z* 539.2433; found, *m*/*z* 539.2434.

1.2. Benzyl 2,3,4-tri-*O*-benzyl-β-D-mannopyranoside (6)

A 100 mL round bottom flask was flame dried and then flushed with Ar. To this was added carbohydrate **4** (500 mg, 0.80 mmol), followed by Ac_2O (5 mL, freshly distilled), and the solution was cooled to −78 °C (CO_2/acetone bath). To this was added a freshly prepared solution of 1:1 TMSOTf–CH_2Cl_2 (0.320 mL) dropwise over a period of 3 min, and the solution was stirred at −78 °C for 60 min under Ar. The cold bath was removed, and a 1:1 mixture of satd $NaHCO_3$–CH_2Cl_2 (50 mL) was immediately added with vigorous stirring, and the mixture was stirred for 30 min. The organic layer was separated, and the aq layer was extracted with CH_2Cl_2 (2 × 30 mL). The organic layers were combined, washed with water, dried (Na_2SO_4) and then concentrated first on a rotary evaporator under aspirator pressure and then using a high-vacuum rotary evaporator to remove the remaining Ac_2O. The resulting clear, colorless oil (crude **5**) became a white solid after being subjected to high vacuum overnight. To a suspension of this crude material in dry MeOH (5 mL) was added 0.5 mL of a 0.3 M solution of NaOMe in MeOH. The reaction was stirred for 6 h and became clear. The reaction was diluted with ether (70 mL) and washed with water and satd brine, dried (Na_2SO_4), and concentrated. The residue was purified by flash chromatography (silica, 20% EtOAc–hexane to 30% EtOAc–hexane) to give **6** (318 mg, 75%) as a colorless oil that became a white solid after being subjected to high vacuum overnight. Mp 64–66 °C; $[\alpha]_D^{22}$ −64.7 (*c* 1.0, $CHCl_3$), ^{1}H NMR: δ 3.32 (ddd, $J_{5,6a}$ 2.6, $J_{5,6b}$ 5.4, $J_{5,4}$ 8.1 Hz, 1H, H-5), 3.51 (dd, $J_{3,2}$ 5.4, $J_{3,4}$ 9.4 Hz, 1H, H-3), 3.78 (dd, $J_{6a,6b}$ 11.8 Hz, 1H, H-6_b), 3.93 (m, 3H, H-6_a, H-4, H-2), 4.42–4.64 (m, 5H), 4.84–4.99 (m, 4H), 7.23–7.46 (m, 20H); ^{13}C NMR: δ 62.2 (C-6), 70.9 (C-4), 71.3 (CH_2), 73.8 (CH_2), 73.9 (C-2), 74.6 (CH_2), 74.9 (CH_2), 75.8 (C-5), 82.1 (C-3), 100.3 (C-1), 127.2, 127.3, 127.4, 127.5, 127.54, 127.8, 127.9, 128.1, 137.2, 127.9, 138.1, 138.4; LREIMS: *m*/*z* (relative intensity) 449.2 (M−CH_2Ph, 3), 341.1 (13), 253.1 (52), 181.1 (15), 91.0 (100); HREIMS: Calcd for $C_{27}H_{29}O_6$, *m*/*z* 449.1964; found, *m*/*z* 449.1964.

Acknowledgments

We thank the Natural Sciences and Engineering Research Council of Canada (NSERC) for financial support. L.N. thanks the Government of Iran for a Scholarship. S.D.T. also thanks the Government of Ontario for a Premiere's Research Excellence (PREA) Award.

Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.carres.2005.02.013.

References

1. For just a few examples on the use of **3** as a carbohydrate building block see: (a) Ishiwata, A.; Ito, Y. *Synlett* **2003**, *9*, 1339–1343; (b) Fernandez, C.; Nieto, O.; Fontenia, J. A.; Rivas, E.; de Ceballos, M. L.; Fernandez-Mayoralas, A. *Org. Biomol. Chem.* **2003**, *1*, 767–771; (c) Koshida, S.; Suda, Y.; Sobel, M.; Kusumoto, S. *Tetrahedron Lett.* **2001**, *42*, 1289–1292; (d) Berkowitz, D. B.; Bose, M.; Pfannenstiel, T. J.; Doukov, T. *J. Org. Chem.* **2000**, *65*, 4498–4508; (e) Koto, S.; Hirooka, M.; Yago, K.; Komiya, M.; Shimizu, T.; Toshio, K.; Kata, K.; Takehara, T.; Ikefuji, A.; Iwasa, A.; Hagino, S.; Sekiya, M.; Michiyo, N.; Nakase, Y.; Zen, S.; Tomonaga, F.; Shimada, S. *Bull. Chem. Soc. Jpn.* **2000**, *73*, 173–183; (f) Lergenmuller, M.; Nukada, T.; Kuramochi, K.; Dan, A.; Ogawa, T.; Ito, Y. *Eur. J. Org. Chem.* **1999**, *6*, 1367–1376; (g) Szabovik, G.; Medgyes, A.; Antal, Z.; Varga, Z.; Knott, W.; Liptak, A. *Pol. J. Chem.* **1999**, *73*, 1003–1009; (h) Hirooka, M.; Koto, S. *Bull. Chem. Soc. Jpn.* **1998**, *71*, 2893–2902; (i) Ito, Y.; Ogawa, T. *J. Am. Chem. Soc.* **1997**, *119*, 5562–5566; (j) Koto, S.; Haigoh, H.; Shichi, S.; Hirooka, M.; Nakamura, T.; Maru, C.; Fujita, M.; Goto, A.; Sato, T. *Bull. Chem. Soc. Jpn.* **1995**, *68*, 2331–2348; (k) Ito, Y.; Ogawa, T. *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 1765–1767; (l) Hashimoto, S.-i.; Umeo, K.; Sano, A.; Watanabe, N.; Nakajima, M.; Ikegami, S. *Tetrahedron Lett.* **1995**, *36*, 2251–2254; (m) Lorentzen, J. P.; Helpap, B.; Lockoff, O. *Angew. Chem., Int. Ed. Engl.* **1991**, *30*, 1681–1682.
2. Gomez, A.; Danelon, G. O.; Valverde, S.; Lopez, J. C. *Carbohydr. Res.* **1999**, *320*, 138–142.
3. Slotta, K. H.; Heller, H. *Chem. Ber.* **1930**, 1028–1040.
4. Fugedi, P.; Liptak, A.; Nanasi, P. *Carbohydr. Res.* **1982**, *104*, 55–67.
5. (a) Zemplén, G. *Ber. Dtsch. Chem. Ges.* **1937**, 1848–1856; (b) Petit, J. M.; Sinaÿ, P. *Carbohydr. Res.* **1978**, *64*, 9–16; (c) Qiu, D.-X.; Wang, Y.-F.; Cai, M.-S. *Synth. Commun.* **1989**, *19*, 3453–3456.
6. Decoster, E.; Lacombe, J.-M.; Strebler, J.-L.; Ferrari, B.; Pavia, A. A. *J. Carbohydr. Chem.* **1983**, *2*, 329–341.
7. Sakai, J.-I.; Takeda, T.; Ogihara, Y. *Carbohydr. Res.* **1981**, *95*, 125–131.
8. Angibeaud, P.; Utille, J.-P. *Synthesis* **1991**, 737–738.
9. Jain, R. K.; Matta, K. L. *Carbohydr. Res.* **1996**, *282*, 101–111.
10. Yang, G.; Ding, X.; Kong, F. *Tetrahedron Lett.* **1997**, *38*, 6725–6728.
11. (a) Dziewiszek, K.; Zamojski, A. *Carbohydr. Res.* **1986**, *150*, 163–171; (b) Alais, J.; Veyrieres, A. *Carbohydr. Res.* **1981**, *92*, 310–313.
12. Zissis, E.; Fletcfher, H. G. *Carbohydr. Res.* **1970**, *12*, 361–368.