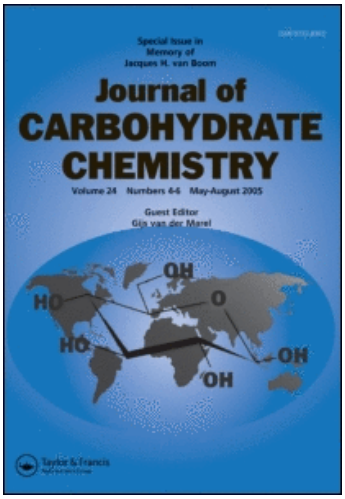


Journal of Carbohydrate Chemistry
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713617200

Synthesis of 4-O-(α-L-Rhamnopyranosyl-D-Glucopyranuronic Acid

Péter Fügedi[a]
[a] Institute of Biochemistry, L. Kossuth University, Debrecen, Hungary

To cite this Article Fügedi, Péter(1987) 'Synthesis of 4-O-(α-L-Rhamnopyranosyl-D-Glucopyranuronic Acid', Journal of Carbohydrate Chemistry, 6: 3, 377 — 398
To link to this Article: DOI: 10.1080/07328308708057927
URL: http://dx.doi.org/10.1080/07328308708057927

J. CARBOHYDRATE CHEMISTRY, 6(3), 377-398 (1987)

SYNTHESIS OF 4-O-(α-L-RHAMNOPYRANOSYL)-D-GLUCOPYRANURONIC ACID

Péter Fügedi

Institute of Biochemistry, L. Kossuth University, H-4010 Debrecen, Hungary

Received January 23, 1987 - Final Form May 26, 1987

ABSTRACT

Two approaches were used for the synthesis of 4-O-(α-L-rhamnopyranosyl)-D-glucopyranuronic acid (1). Rhamnosylation of benzyl 6-O-allyl-2,3-di-O-benzyl-β-D-glucopyranoside (7), followed by deallylation, oxidation to uronic acid, and deblocking afforded 1. Alternatively, rhamnosylation of suitably protected D-glucuronic acid derivatives (25 and 26) gave the protected pseudoaldobiouronic acid derivatives (19 and 30), which were deprotected. Rhamnosylations were performed in high stereoselectivity without neighbouring-group assistance using 2,3,4-tri-O-benzyl-1-O-trichloroacetimidoyl-α-L-rhamnopyranose (27) with trifluoromethanesulfonic acid catalysis.

INTRODUCTION

Klebsiella bacteria are classified into about 80 strains due to differences in the structures of their capsular polysaccharides.[1]

Structures of most of these acidic polysaccharides are known,[2,3] and show a wide diversity, though common structural elements may occur in some serotypes, as was demonstrated by serological cross-reactions.[1,4]

The pseudoaldobiouronic acid 4-O-(α-L-rhamnopyranosyl)-D-glucopyranuronic acid (1) was found as a structural element in several serotypes. It may occur either as a side-chain, as in type K47[5,6] and K67,[7] or as a part of the backbone, as in serotypes K81,[8] K70,[9] K17,[10] and K53.[11] The Klebsiella K52 polysaccharide was reported[12] to contain an L-Rhap-(1→4)-D-GlcpA sequence with unspecified configuration of the interglycosidic linkage, but it was deduced[11] from serological cross-reactions[4] that 1 is an antigenic determinant for K47, K52, and K53 serotypes.

The title pseudoaldobiouronic acid also occurs in Shigella boydii type 4[13] and Streptococcus pneumoniae type 17A[14] polysaccharides and is known to be the non-reducing end group in Acacia senegal gum (gum arabic).[15,16]

As pseudoaldobiouronic acids are generally not formed during chemical degradation of polysaccharides, 1 has not been isolated in the course of structural elucidation of the above polysaccharides. Phage induced degradation of Klebsiella polysaccharides also did not produce reducing glycuronic acids[17].

The title compound seems to be most readily accessible by chemical synthesis which is reported here.

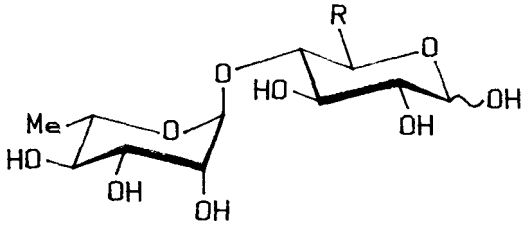
RESULTS AND DISCUSSION

Two synthetic schemes were used for the preparation of the title pseudoaldobiouronic acid:

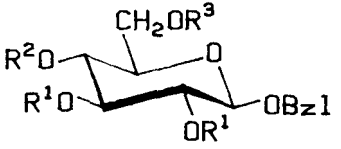
a.) glycosylation at O-4 of a protected D-glucose derivative possessing a temporary protecting group at O-6, followed by the removal of this group and subsequent oxidation to carboxylic acid;

b.) glycosylation of a partially protected D-glucuronic acid derivative.

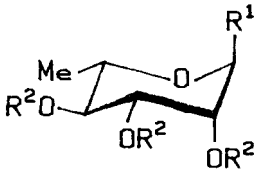
As no direct method from D-glucuronic acid for the preparation of a partially protected derivative having the required blocking group



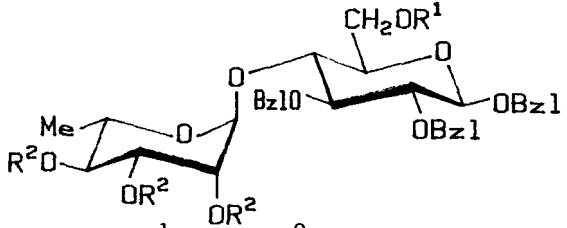
1 R = CO_2H
20 R = CO_2Me
21 R = CO_2H



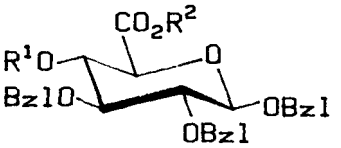
2 R^1 = Bzl; R^2 = R^3 = H
3 R^1 = R^2 = R^3 = H
4 R^1 = H; R^2, R^3 = Me_2C
5 R^1 = Bzl; R^2, R^3 = Me_2C
6 R^1 = Ac; R^2, R^3 = Me_2C
7 R^1 = Bzl; R^2 = H; R^3 = All
15 R^1 = R^2 = Bzl; R^3 = H
22 R^1 = R^3 = Bzl; R^2 = H
32 R^1 = R^2 = R^3 = Ac



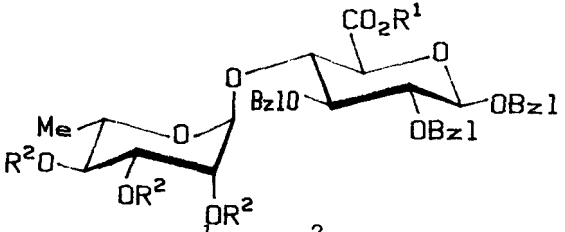
8 R^1 = Br; R^2 = Ac
11 R^1 = OMe; R^2 = H
12 R^1 = OMe; R^2 = Ac
27 R^1 = $OC(=NH)CCl_3$; R^2 = Bzl
28 R^1 = OH; R^2 = Bzl
29 R^1 = OMe; R^2 = Bzl



9 R^1 = All; R^2 = H
10 R^1 = All; R^2 = Ac
13 R^1 = All; R^2 = Bzl
14 R^1 = H; R^2 = Bzl
23 R^1 = Bzl; R^2 = H



16 R^1 = Bzl; R^2 = H
17 R^1 = Bzl; R^2 = Me
24 R^1 = R^2 = H
25 R^1 = H; R^2 = Me
26 R^1 = H; R^2 = Bzl



18 R^1 = H; R^2 = Bzl
19 R^1 = Me; R^2 = Bzl
30 R^1 = R^2 = Bzl
31 R^1 = Me; R^2 = H

pattern is available, both routes started from benzyl 2,3-di-O-benzyl-β-D-glucopyranoside[18] (2). This compound was prepared from benzyl β-D-glucopyranoside (3) without purification of the intermediates. Isopropylidenation of 3 in 2,2-dimethoxypropane[19] gave the 4,6-O-isopropylidene derivative (4), which was benzylated with benzyl bromide and potassium hydroxide in dimethyl sulfoxide[20] to give the 2,3-di-O-benzyl-4,6-O-isopropylidene derivative (5), hydrolysis of 5 with 60% aqueous acetic acid afforded 2 in 80% yield, based on 3. The isopropylidene derivative (4) was also characterized as its crystalline diacetate (6).

In the ^{13}C NMR spectra (Table 1.) of the isopropylidene derivatives (4-6) the signals of the acetal and methyl carbons appeared in the region characteristic for isopropylidene acetals having a 1,3-dioxane ring.[21] The assignments in the ^{13}C NMR spectra were greatly facilitated by using the attached proton test technique,[22] in which carbons bearing odd and even numbers of protons give signals of opposite intensity, thereby readily differentiating between signals for methylene carbons of benzyl groups and signals of ring carbons. In the case of 6 the 2D ^{1}H-^{13}C correlated spectrum was also recorded, and gave unequivocal assignment, except from C-2 and C-3. In agreement with the ^{13}C NMR spectra of 4,6-O-benzylidene acetals[23] a large upfield shift for C-5 in the isopropylidene acetals was observed. However, C-4 and C-6 showed only very slight downfield shifts. This is in keeping with the data we found for 4,6-O-(2'-methyl)-benzylidene acetals,[24] and can be explained by the gauche effect[25] of the axial substituent at C-2 of the 1,3-dioxane ring.

As O-4 of glucose in glycosylation reactions generally shows low reactivity,[26] and the use of alkyl instead of acyl protecting groups increases reactivity,[26,27] temporary protection of 2 at O-6 was as its allyl ether yielding the 6-O-allyl derivative (7).[28] Glycosylation of 7 with 2,3,4-tri-O-acetyl-α-L-rhamnopyranosyl bromide (8) in the presence of mercuric bromide and molecular sieves in boiling dichloromethane gave, after deacetylation, the crystalline disaccharide (9) in 75% yield. Reacetylation of 9 gave the triacetate (10). The configuration of the interglycosidic linkage was proved from the one-bond ^{13}C-^{1}H coupling constant,[29] the 173 Hz value found for 10 clearly supporting an α-L-rhamnosidic linkage. Assignment of the ^{13}C NMR spectrum (Table 2.)

Table 1. ^{13}C NMR Data of D-glucose and D-glucuronic acid derivatives[a]

Carbon	Compound 2	4	5	6	7	15	16	17	22	24	25	26	32
C-1	102.8	102.3	103.1	100.0	102.6	103.0	103.0	102.7	102.7	102.6	102.7	102.7	99.1
C-2	81.9	73.2[b]	81.5	72.3[b]	81.8	82.6	82.0	81.8	81.9	81.0	81.2	81.2	71.2
C-3	84.0	73.5[b]	82.2	72.4[b]	84.2	84.8	83.6	83.8	84.3	83.1	83.2	83.2	72.7
C-4	70.4	74.6	74.4	71.2	71.6	77.4	80.5	79.3	71.6	71.6	71.8	71.7	68.4
C-5	75.0	67.3	67.0	67.3	74.3	75.4	76.7	74.5	74.5	73.6	74.3	74.4	71.6
C-6	62.5	62.0	62.3	61.9	70.3	62.2	176.5	169.0	70.4	171.6	f	169.0	61.8
$PhCH_2$	71.5 74.7 75.2	71.3	71.5 74.8 75.3	70.9	71.1 74.6 75.1	71.7 75.0 75.1 75.7	71.9 74.6 74.6 75.2	71.3 74.8 74.9 75.6	71.1 74.7 75.1 73.7	71.7 74.9 75.4	71.3 74.8 75.3	71.3 74.8 75.3 67.3	70.5
O Me C O Me	-	19.0 99.8 28.9	19.2 99.3 29.2	18.8 99.7 28.8	-	-	-	-	-	-	-	-	-
Others	-	-	-	20.5[c] 20.7[c]	72.5[d] 134.5[d] 117.0[d]	-	-	52.3[e]	-	-	52.6[e]	-	20.2[c] 20.4[c]

[a] in $CDCl_3$; [b] assignments might be interchanged; [c] acetyl Me; [d] $OCH_2CH{=}CH_2$; [e] OMe; [f] not determined.

Table 2. ^{13}C NMR data of L-rhamnose and disaccharide derivatives[a]

Carbon	10	11[f]	12[f]	14	19	23	27	28	29	30	31[i]
C-1	102.8 (157)[b]			102.9	102.4	102.5				102.4 (162)[b]	103.6
C-2	82.6			82.7	81.7	82.4				81.7	83.0
C-3	82.8			82.8	82.0	82.7				82.0	83.2
C-4	75.1[c]			75.3[c]	76.2	75.0[c]				76.1	77.9
C-5	74.9[c]			75.6[c]	74.9	75.3[c]				75.2	75.5
C-6	71.1			61.8	g	68.9				g	170.5
$PhCH_2$	71.2 74.7 75.7			71.4 74.8 75.1	71.2 74.6 75.1	71.0 74.6 75.0 73.6				71.0 74.5 75.0	72.3 75.4 76.1
Others	72.3[d] 134.7[d] 116.9[d]				52.4[h]						53.7[h]
C-1'	97.4 (173)[b]	101.7	99.0	98.5	98.0	100.0	96.4 (177)[b]	93.3 (171)[b]	99.1 (169)[b]	98.0 (173)[b]	101.8
C-2'	69.3	71.4	70.3	74.9	74.8	71.7	74.1	74.1	75.0	74.8	72.5
C-3'	68.6	71.0	70.1	79.6	79.4	71.0	79.1	79.3	80.2	79.4	71.8
C-4'	70.3	72.9	70.7	80.8	80.3	72.9	79.9	80.2	80.5	80.3	73.8
C-5'	66.9	69.1	68.6	68.9	68.8	68.6	71.2	68.5	67.9	68.8	70.5
C-6'	17.1	17.9	17.3	17.9	17.7	17.2	18.1	17.8	17.9	17.8	18.9
$PhCH_2$				72.1 72.7 75.1	71.9 72.5 75.1		72.4 72.9 75.4	72.1 72.6 75.4	72.1 72.8 75.1	71.6 72.3 74.6	
Others	20.6[e] 20.7[e]								54.5[h]		

[a] in $CDCl_3$; [b] $^1J_{C,H}$ coupling constants given in brackets; [c] assignments might be interchanged; [d] OCH_2-CH=CH_2; [e] acetyl CH_3; [f] taken from ref. 30; [g] not determined; [h] OCH_3; [i] in $CDCl_3$-DMSO-d_6 (3:1).

of 10 was based on comparison with that of the aglycon, and with the reported data[30] for methyl α-L-rhamnopyranoside (11) and methyl 2,3,4-tri-O-acetyl-α-L-rhamnopyranoside (12). The disaccharide derivative (9) was benzylated, and the resulting 13 was deallylated with palladium on charcoal catalyst[31,32] to afford the crystalline 14, having a free 6-OH group.

Chromic acid oxidation of the methyleneoxy group of 14 to carboxylic acid was considered problematical as both the anomeric[32] and benzylic[33] carbons are known to be susceptible to oxidation by the Jones reagent. However, benzyl 2,3,4-tri-O-benzyl-β-D-glucopyranoside[35,36] (15) was oxidized in good yield with this reagent to the corresponding uronic acid[35] (16), characterized as its methyl esther (17). Oxidation of 14 with potassium dichromate and sulfuric acid in aqueous acetone gave a 70% yield of the pseudoaldobiouronic acid derivative (18), which afforded the methyl ester (19) on treatment with diazomethane. Catalytic hydrogenolysis of 18 and 19 with palladium on charcoal catalyst gave the title compound (1) and its methyl ester (20), respectively.

By a similar sequence of reactions 4-O-(α-L-rhamnopyranosyl)-D-glucose (21) was also prepared. This compound was isolated as a degradation product of gum arabic,[15] and was synthesized formerly,[37,38] though in low yields. Mercuric bromide promoted glycosylation of benzyl 2,3,6-tri-O-benzyl-β-D-glucopyranoside[28,36,39] (22) with 8 gave, after deacetylation, the disaccharide 23 in 79% yield. Catalytic debenzylation of 23 then gave 21 in 97% yield.

Preparation of 1 and the methyl uronate (20) was also performed by route b. For this purpose 2 was subjected to Heyns-oxidation[40] to give the uronic acid[41] (24), which was converted into the methyl uronate[41] (25) by treatment with diazomethane. Preparation of the benzyl uronate (26) was most conveniently achieved by phase-transfer catalyzed alkylation of 24. Phase-transfer catalyzed reactions[42,43] are frequently used for partial protection of carbohydrate derivatives, but, as far as we are aware, have not been used for selective esterification of carboxylic derivatives of sugars. Steric accessibility and acidity of sugar hydroxyls were suggested[42,43] as the factors directing the regioselectivity of this type of reactions, and on this basis selective benzylation of the carboxylic group of 24 could be expected. Indeed, phase-transfer catalyzed benzylation of 24 in boiling 1,2-dichloroethane-aqueous sodi-

um hydroxide gave a single product (26) isolated in 74% yield after crystallization.

As the presence of the carboxyl group at C-5 is expected to decrease further the reactivity of O-4 towards glycosylation, an efficient procedure for rhamnosylation of the glucuronic acid derivatives (25, 26) was necessary. We have reported[44] that the trichloroacetimidate procedure,[45,46] in the case of benzylated α-L-rhamno- and α-D-mannopyranosyl trichloroacetimidates, resulted in retention of the anomeric configuration,[44] thereby providing a method for α-L-rhamnosylation and α-D-mannosylation without the need for a participating blocking group at C-2. Use of the benzylated imidate (27) has the advantage that deprotection after glycosylation can be done in one step, and basic conditions that might result in undesired reactions (see below) can be avoided.

2,3,4-Tri-O-benzyl-L-rhamnopyranose[47] (28) was prepared from L-rhamnose via the described route,[47] but using different procedures for benzylation[20] and for hydrolysis[48] of the methyl glycoside, thus increasing the yield from 24%[47] to 61%. For ^{13}C NMR studies methyl 2,3,4-tri-O-benzyl-α-L-rhamnopyranoside[47] (29) was also prepared. Treatment of 28 with sodium hydride and trichloroacetonitrile[45] in dichloromethane gave 2,3,4-tri-O-benzyl-1-O-trichloroacetimidoyl-α-L-rhamnopyranose[44] (27) in 85% yield. Glycosylation of 26 with 27 was catalyzed by trifluoromethanesulfonic acid, which is a much more efficient catalyst[49] than the p-toluenesulfonic acid used before[44]: the glycosylation took place in 1 min at -20 °C. The reaction showed a high degree of stereoselectivity, the pseudoaldobiouronic acid derivative (30) was isolated in 79% yield and only traces of a compound having similar mobility (probably the β-L-rhamnopyranosyl derivative) were detected on TLC. The configuration of the rhamnose moiety in 30 was supported by the 168 Hz coupling constant for C-1',H-1'.

The imidate method was much more convenient for the glycosylation of 26 than a Koenigs-Knorr type reaction. Rhamnosylation of 26 with 8 took 1 day at 40 °C, and required 4 equivalents of 8 to go to completion, however, because of by-product formation a pure disaccharide (31) could be isolated only after deacetylation and repeated chromatographic purification. During Zemplén deacetylation of the reaction product

transesterification took place and the methyl uronate (31) was the product isolated from the Koenigs-Knorr type reaction.

Rhamnosylations of the 6-O-allyl derivative (7) and the methyl uronate (25) by the imidate (27) also proceeded smoothly, giving the disaccharides 13 and 19, in 86% and 92% yields, respectively. This route is more favourable for the synthesis of 13 and 19 than the one described above. Catalytic debenzylation of 30 gave 1, identical with that obtained above.

^{13}C NMR assignments of the disaccharide derivatives were based on comparison with the partially protected monosaccharides taking into account the expected glycosylation shifts. Assignments of disaccharides having benzylated rhamnopyranosyl units were accomplished by comparison with the spectra of 27 and 29. Oxidation and esterification of the partially protected D-glucose derivatives to the D-glucuronate derivatives caused the expected large (>100 ppm) downfield shift for C-6, a small (about 1 ppm) downfield shift for C-4, and an upfield shift for C-5. Glycosylation shifts for both the partially protected D-glucose and D-glucuronic acid derivatives showed the same tendency, though the values for the α-shifts were about 1 ppm greater in the uronic acid derivatives. However, in the case of the unprotected disaccharides (Table 3.), glycosylation shifts calculated with the help of the reported[50] data for D-glucose and D-glucuronic acid had approximately the same value.

EXPERIMENTAL

Melting points (uncorrected) were determined with a Kofler apparatus. Optical rotations were measured with a Perkin-Elmer 241 polarimeter. NMR spectra were recorded with a Bruker WP 200 SY spectrometer. Chemical shifts are given relative to internal Me_4Si for solutions in $CDCl_3$, and ^{13}C NMR chemical shifts for solutions in D_2O are relative to internal dioxane (67.4 ppm).

Table 3. ^{13}C NMR Data of free disaccharides[a]

Compound		C-1	C-2	C-3	C-4	C-5	C-6	C-1'	C-2'	C-3'	C-4'	C-5'	C-6'	OMe
D-glucose[b]	α	92.9	72.5	73.8	70.6	72.3	61.6							
	β	96.7	75.1	76.7	70.6	76.8	61.7							
D-glucopyran-uronic acid[b]	α	93.2	72.0	73.4	72.4	71.4	172.9							
	β	96.9	74.7	76.3	72.2	75.4	173.8							
1	α	92.9	72.0	72.0	79.5	70.4	c	101.7	70.9	70.9	72.6	69.9	17.2	
	β	96.8	74.8	74.8	79.8	74.3	c							
20	α	93.0	71.9[d]	72.0[d]	79.5	70.3	c	101.7	71.1	71.1	72.7	70.0	17.3	54.1
	β	96.9	74.8	74.8	79.7	74.3	c							
21	α	92.6	72.5[d]	72.8[d]	78.5	72.3	61.2	101.6	71.2[e]	71.1[e]	72.8	69.8	17.2	
	β	96.6	75.3	75.8	78.3	75.8	61.2							

[a] in D_2O relative to dioxane (67.4 ppm); [b] taken from ref. 50; [c] not determined; [d,e] assignments might be interchanged.

Light petroleum refers to the fraction boiling between 40-60 °C. Solutions in organic solvents were dried with sodium sulfate, and evaporations were performed *in vacuo* at <40 °C (bath). TLC was performed on Kieselgel 60 F_{254} (Merck), and Kieselgel G (Reanal, Budapest) was used for short-column chromatography. Detection in TLC was effected under UV light and/or by charring with sulfuric acid.

Benzyl 2,3-di-O-Benzyl-β-D-glucopyranoside (2). p-Toluenesulfonic acid (0.05 g) was added to a stirred suspension of 3 (10 g) in 2,2-dimethoxypropane (50 mL). After 90 min additional 2,2-dimethoxypropane (20 mL) and p-toluenesulfonic acid (0.05 g) were added, which resulted in the formation of a clear solution within 30 min. Aqueous $NaHCO_3$ was added, the mixture was diluted with dichloromethane, washed with water, dried, and concentrated, to give 11.4 g of crude syrupy 4, which was used directly in the next step. A pure sample of 4 (obtained by column chromatography with dichloromethane-acetone, 4:1) was a syrup having $[\alpha]_D$ -77.8° (c 1.2, chloroform): R_F 0.44 (dichloromethane-acetone, 4:1); ^1H NMR ($CDCl_3$) δ 7.4-7.2 (m, 5H, Ph), 4.67 (q, 2H, $PhCH_2$, J= 11.8 Hz), 4.35 (d, 1H, H-1, $J_{1,2}$= 7.5 Hz), 3.95-3.05 (m, 7H, H-2,3,4,5,6,6' + 2OH), 1.45 and 1.42 (2s, 2 X 3H, CMe_2).

4 was also characterized as its crystalline diacetate (6), mp 145-146 °C (from ethyl acetate-light petroleum): $[\alpha]_D$ -92.1°C (c 0.80, chloroform); R_F 0.45 (dichloromethane-ethyl acetate, 95:5); ^1H NMR ($CDCl_3$) δ 7.4-7.2 (m, 5H, Ph), 5.15-4.95 (m, 2H, H-2,3), 4.74 (q, 2H, $PhCH_2$, J= 12.3 Hz), 4.58 (d, 1H, H-1, $J_{1,2}$= 7.8 Hz), 3.98 (dd, 1H, $H\text{-}6_{eq}$, $J_{6eq,6ax}$= 11 Hz, $J_{5,6eq}$= 5.5 Hz), 3.81 (dd, 1H, $H\text{-}6_{ax}$, $J_{5,6ax}$= 10 Hz), 3.75 (t, 1H, H-4, $J_{3,4}$= $J_{4,5}$= 10 Hz), 3.32 (st, 1H, H-5), 2.04 and 1.99 (2s, 2 X 3H, 2 OOCMe), 1.47 and 1.37 (2s, 2 X 3H, CMe_2).

Anal. Calcd for $C_{20}H_{26}O_8$: C, 60.90; H, 6.64. Found: C, 60.97; H, 6.60.

Crude 4 was dissolved in dimethyl sulfoxide (50 mL), and powdered potassium hydroxide (16.7 g) was added. To the vigorously stirred mixture benzyl bromide (17.6 mL) was added dropwise in about 15 min and stirring was continued for 30 min. Excess benzyl bromide was decomposed with methanol (10 mL) and after 30 min dichloromethane and water were added. The organic layer was washed with water, dried, and concentrated, first on a rotary evaporator, then with a mechanical pump to give 17.0 g of crude 5 as a yellowish syrup.

An analytical sample of 5, obtained by column chromatography (light petroleum-ethyl acetate, 4:1), was a syrup having $[\alpha]_D$ -28.7° (c 1.3, chloroform): R_F 0.71 (light petroleum-ethyl acetate, 4:1); ^{1}H NMR ($CDCl_3$) δ 7.4-7.2 (m, 15H, 3Ph), 5.0-4.5 (m, 7H, $3PhCH_2$ + H-1), 4.0-3.15 (m, 6H, H-2,3,4,5,6,6'), 1.48 and 1.42 (2s, 2 X 3H, CMe_2).

Anal. Calcd for $C_{30}H_{34}O_6$: C, 73.45; H, 6.99. Found: C, 73.55; H, 7.05.

Crude 5 (17.0 g) was stirred in 60% aqueous acetic acid at 70 °C for 30 min. The solution was concentrated, co-evaporated several times with toluene, and the residue was dissolved in dichloromethane. This solution was washed with water, dried, and concentrated. Recrystallization of the crude product from ethyl acetate-light petroleum gave 2 (12.6 g, 75.6%): mp 113-114 °C; $[\alpha]_D$ -6.4° (c 0.73, acetone), -45.5° (c 0.88, chloroform); R_F 0.27 (dichloromethane-acetone, 9:1); lit.[18] mp 112-113 °C, $[\alpha]_D$ -6.5° (c 2, acetone); ^{1}H NMR ($CDCl_3$) δ 7.4-7.2 (m, 15H, 3Ph), 5.0-4.64 (3q, 3 X 2H, $3PhCH_2$), 4.58 (d, 1H, H-1, $J_{1,2}$= 7.8 Hz), 3.88 (dd, 1H, H-6a, $J_{6a,6b}$= 12 Hz, $J_{5,6a}$= 3.8 Hz), 3.75 (dd, 1H, H-6b, $J_{5,6b}$= 5.0 Hz), 3.61-3.39 (m, 3H, H-2,3,4), 3.32 (o, 1H, H-5, $J_{4,5}$= 9.5 Hz), 2.30 and 2.02 (2 broad s, 2 X 1H, 2OH). Recrystallization of the mother liquor gave an additional 0.81 g of 2 (total yield: 13.41 g, 80 %).

Benzyl 6-O-Allyl-2,3-di-O-benzyl-4-O-(α-L-rhamnopyranosyl)-β-D-glucopyranoside (9). A mixture of 7[28] (1.47 g), powdered mercuric bromide (1.35 g), and 4 Å molecular sieves powder (7 g) in dry dichloromethane (25 mL) was refluxed with stirring under dry nitrogen. A solution of 8 (1.32 g) in dry dichloromethane (5 mL) was injected through a rubber septum, and stirring of the reaction mixture under reflux was continued for 3 h. The mixture was diluted with dichloromethane, filtered through Celite, and the solid was washed with dichloromethane. The filtrate was washed with 10% aqueous potassium iodide, with saturated sodium hydrogen carbonate, and with water, then dried, and concentrated. The syrupy residue was deacetylated in dry methanol (50 mL) with sodium methoxide. After neutralization with Amberlite IR-120 (H^+) resin, filtration and solvent evaporation, the residue was purified by column chromatography with toluene-methanol (88:12) to give first 0.09 g (6%) of unchanged 7. Eluted second was 9 (1.43 g, 75%): mp 153-154 °C (from ethyl acetate-light petroleum); $[\alpha]_D$ -34.1° (c 0.47,

chloroform); R_F 0.47 (toluene-methanol, 4:1); ^{1}H NMR ($CDCl_3$) δ 7.5-7.2 (m, 15H, 3Ph), 6.2-5.8 (m, 1H, OCH_2-CH=CH_2), 0.95 (d, 3H, H-6').

Anal. Calcd for $C_{36}H_{44}O_{10}$: C, 67.91; H, 6.97. Found: C, 67.80; H, 6.92.

Benzyl 4-O-(2,3,4-tri-O-Acetyl-α-L-rhamnopyranosyl)-6-O-allyl-2,3-di-O-benzyl-β-D-glucopyranoside (10). Treatment of a solution of 9 in dry pyridine with acetic anhydride gave 10 as a syrup: $[\alpha]_D$ -40.2° (c 0.71, chloroform); R_F 0.62 (dichloromethane-ethyl acetate, 9:1); ^{1}H NMR ($CDCl_3$) δ 7.5-7.2 (m, 15H, 3Ph), 6.2-5.8 (m, 1H, OCH_2-CH=CH_2), 2.09, 1.96 and 1.94 (3s, 3 X 3H, 3 OOCMe), 0.76 (d, 3H, H-6').

Benzyl 6-O-Allyl-2,3-di-O-benzyl-4-O-(2,3,4-tri-O-benzyl-α-L-rhamnopyranosyl)-β-D-glucopyranoside (13). a.) To a solution of 9 (1.27 g) in dry N,N-dimethylformamide (15 mL) sodium hydride (0.63 g) was added with stirring. After 30 min the mixture was cooled to 0 °C and benzyl bromide (1.5 mL) was added dropwise. After 3 h methanol was added, the mixture was concentrated, the residue was taken up in dichloromethane, the solution was washed with water, dried, and concentrated. Column chromatography with light petroleum-ethyl acetate (85:15) afforded syrupy 11 (1.72 g, 95%): $[\alpha]_D$ -26.4° (c 1.04, chloroform); R_F 0.36 (light petroleum-ethyl acetate, 4:1); ^{1}H NMR ($CDCl_3$) δ 7.4-7.1 (m, 30H, 6Ph), 6.0-5.7 (m, 1H, OCH_2-CH=CH_2), 1.06 (d, 3H, H-6').

b.) A mixture of 7 (0.98 g), 27 (1.73 g), and molecular sieves (4 Å, 3 g) in dry dichloromethane (20 mL) was stirred at -20 °C under dry nitrogen for 30 min. A solution of trifluoromethanesulfonic acid (35 μL) in dichloromethane (2 mL) was injected through a septum. TLC immediately after injection indicated the absence of 7, and the mixture was neutralized with triethylamine. The mixture was filtered through a bed of Celite and after washing the solid with dichloromethane the filtrate was concentrated. Column chromatography of the residue (dichloromethane-ethyl acetate, 49:1) gave 13 (1.56 g, 86%).

Benzyl 2,3-di-O-Benzyl-4-O-(2,3,4-tri-O-benzyl-α-L-rhamnopyranosyl)-β-D-glucopyranoside (14). To a warm solution of 13 (1.61 g) in a mixture of methanol (40 mL) and acetic acid (20 mL) water (10 mL) was added dropwise. After addition of palladium on charcoal (10%, 0.5 g) the mixture was refluxed for 2 h. The solid was filtered through Celite, washed with methanol, the filtrate was concentrated, and co-evaporated with toluene. Recrystallization of the crystalline residue from ethyl acet-

ate-light petroleum gave 14 (1.18 g, 77%): mp 109-110 °C; $[\alpha]_D$ -44.3° (c 0.7, chloroform); R_F 0.15 (light petroleum-ethyl acetate, 4:1); ^{1}H NMR ($CDCl_3$) δ 7.6-7.2 (m, 30H, 6Ph), 2.36 (t, 1H, OH), 1.05 (d, 3H, H-6').

Anal. Calcd for $C_{54}H_{58}O_{10}$: C, 74.80; H, 6.74. Found: C, 74.89; H, 6.79.

Benzyl 2,3,4-tri-O-Benzyl-β-D-glucopyranosiduronic acid (16) and Methyl (Benzyl 2,3,4-tri-O-Benzyl-β-D-glucopyranosid)uronate (17). A solution of 15 (1.08 g) in acetone (20 mL) was treated with a solution of potassium dichromate (0.88 g) in 3.5 M sulfuric acid (4 mL) at 55 °C for 1 h, and the mixture was worked up as described for 18. Column chromatography (toluene-methanol, 4:1) afforded 0.92 g (84 %) of 16. Recrystallization from ethyl acetate-light petroleum gave 16 having mp 120-126 °C: $[\alpha]_D$ -30° (c 0.75, chloroform); R_F 0.35 (toluene-methanol, 4:1); lit.[35] mp 115-125 °C, $[\alpha]_D$ -34.1° (c 1, chloroform). 16 was converted into the methyl uronate (17) by treatment with ethereal diazomethane. After concentration, recrystallization of the residue from methanol gave 17: mp 111 °C; $[\alpha]_D$ -23.3° (c 0.7, chloroform); R_F 0.71 (toluene-methanol, 9:1); lit.[35] mp 109.5-110.5 °C, $[\alpha]_D$ -26.0° (c 1, chloroform); ^{1}H NMR ($CDCl_3$) δ 7.4-7.2 (m, 20H, 4Ph), 3.70 (s, 3H, OMe).

Benzyl 2,3-di-O-Benzyl-4-O-(2,3,4-tri-O-benzyl-α-L-rhamnopyranosyl)-β-D-glucopyranosiduronic acid (18). To a solution of 14 (1.0 g) in acetone (20 mL) was added dropwise a solution of potassium dichromate (0.51 g) in 3.5 M sulfuric acid (2.5 mL). The mixture was stirred at 55 °C for 1 h. The liquid was decanted from the green precipitate into 200 mL of water, the solid was washed with acetone, and the washing was also poured into the water. The gum-like material which precipitated in water was extracted with dichloromethane, and the extract was washed with water, dried, and concentrated. Column chromatography of the residue with toluene-methanol (9:1) gave 0.71 g (70%) of 18 as a white foam: $[\alpha]_D$ -24° (c 0.57, chloroform); R_F 0.26 (toluene-methanol, 9:1); ^{1}H NMR ($CDCl_3$) δ 7.4-7.1 (m, 30H, 6Ph), 0.92 (d, 3H, H-6').

Methyl [Benzyl 2,3-di-O-Benzyl-4-O-(2,3,4-tri-O-benzyl-α-L-rhamnopyranosyl)-β-D-glucopyranosid]uronate (19). a.) To a solution of 18 (0.3 g) in a mixture of methanol (5 mL) and dichloromethane (5 mL) was added ethereal diazomethane. When TLC indicated the complete disappearance of the starting material the solution was concentrated and the

residue was purified by column chromatography (dichloromethane-ethyl acetate, 19:1) to afford 18 (0.27 g, 89%): mp 92-93 °C (ethyl acetate-light petroleum); $[\alpha]_D$ -45.9° (c 0.94, chloroform); R_F 0.76 (dichloromethane-ethyl acetate, 19:1); ^1H NMR ($CDCl_3$) δ 7.4-7.1 (m, 30H, 6Ph), 3.66 (s, 3H, OMe), 1.06 (d, 3H, H-6').

Anal. Calcd for $C_{55}H_{58}O_{11}$: C,73.81; H, 6.53. Found: C, 73.69; H, 6.44.

b.) A mixture containing 25 (0.24 g), 27 (0.43 g) and molecular sieves (4 Å, 2.0 g) in dry dichloromethane (10 mL) was treated with a solution of trifluoromethanesulfonic acid (8.8 μL) in dry dichloromethane (2 mL) at -20 °C as described for 13. Processing as described above, followed by column chromatography with light petroleum-ethyl acetate (9:1) gave 19 (0.41 g, 92%), identical with the compound obtained by route a.

4-O-(α-L-Rhamnopyranosyl)-D-glucopyranuronic acid (1). a.) A mixture of 18 (0.28 g) and palladium on charcoal (10%, 0.3 g) in acetic acid was stirred overnight under hydrogen at atmospheric pressure. The mixture was filtered, the solid was washed with water, and the filtrate was concentrated and then dried in vacuo to give 1 (0.108 g) as a white foam in quantitative yield: $[\alpha]_D$ -18.1°, $[\alpha]_{436}$ -35.1° (c 0.99, water); R_F 0.33 (dichloromethane-methanol-water, 5:4:1); ^1H NMR (D_2O) δ 5.28 (d, 0.5H, H-1 (α-anomer), $J_{1,2}$= 3.5 Hz), 4.74 (s, 1H, H-1'), 4.69 (d, 1H, H-1 (β-anomer), $J_{1,2}$= 8 Hz), 4.40 (d, 0.5H, H-5, $J_{4,5}$= 10 Hz), 1.24 (d, 3H, H-6', $J_{5',6'}$=6.3 Hz).

b.) A mixture of 30 (0.45 g) and palladium on charcoal (10%, 0.3 g) in acetic acid (10 mL) was hydrogenolyzed as described above to give 1 in quantitative yield.

Methyl [4-O-(α-L-Rhamnopyranosyl)-D-glucopyran]uronate (20). Compound 19 (0.32 g) in acetic acid (10 mL) was hydrogenolyzed with palladium on charcoal catalyst (10%, 0.2 g) as described above to give 20 as a white foam (0.12 g, 91%): $[\alpha]_D$ -7.4° (c 1.48, water); R_F 0.40, R_{Rha} 0.82 (dichloromethane-methanol, 3:1); ^1H NMR (D_2O) δ 5.28 (d, 0.5H, H-1 (α-anomer), $J_{1,2}$= 3.5 Hz), 4.71 (s, 1H, H-1') 4,70 (d, 0.5H, H-1 (β-anomer), $J_{1,2}$= 8 Hz), 4.49 (d, 0.5H, H-5, $J_{4,5}$= 9.5 Hz), 4.17 (d, 0.5H, H-5, $J_{4,5}$= 9.5 Hz), 3.84 and 3.83 (2s, 3H, OMe), 1.24 (d, 3H, H-6', $J_{5',6'}$= 6.3 Hz).

Benzyl 2,3,6-tri-O-Benzyl-4-O-(α-L-rhamnopyranosyl)-β-D-glucopyranoside (23). A mixture of 22 (1.62 g), molecular sieves (4 Å, 5 g) and mercuric bromide (1.35 g) in dry dichloromethane (30 mL) was stirred and refluxed under dry nitrogen. A solution of 8 (1.32 g) in dry dichloromethane (10 mL) was injected, and stirring and reflux were continued for 2 h. The mixture was worked up as described for 9. The deacetylated mixture was subjected to column chromatography with dichloromethane-methanol (92:8), to give 1.63 g (79%) of 23: mp 150-151 °C (from ethyl acetate-light petroleum); $[\alpha]_D$ -27.5° (c 0.74, chloroform); R_F 0.50 (dichloromethane-methanol, 9:1); ^{1}H NMR ($CDCl_3$) δ 7.4-7.2 (m, 20H, 4Ph), 5.1-4.4 (m, 10H, 4PhCH_2 + H-1,1'), 3.9-2.9 (m, 13H, ring protons + 3OH), 0.94 (d, 3H, H-6').

Anal. Calcd for $C_{40}H_{46}O_{10}$: C, 69.95; H, 6.75. Found: C, 69.81; H, 6.69.

4-O-(α-L-Rhamnopyranosyl)-D-glucose (21). A solution of 23 (1.1 g) in acetic acid (20 mL) was hydrogenolyzed with palladium on charcoal catalyst (10%, 0.9 g) at atmospheric pressure overnight as for 1. Column chromatography (dichloromethane-methanol, 3:2) afforded 21 (0.51 g, 97%) as a white foam: $[\alpha]_D$ -10.5° (c 0.76, water); R_F 0.36, R_{Rha} 0.61 (dichloromethane-methanol, 3:2); lit.[15] $[\alpha]_D$ -6° (c 0.97, water); lit.[37] $[\alpha]_D$ +6.4° (c 1.85, water); lit.[38] $[\alpha]_D$ -6° (c 1, water). ^{1}H NMR (D_2O) δ 5.22 (d, 0.4H, H-1 (α-anomer), $J_{1,2}$= 3.5 Hz), 4.85 (d, 1H, H-1', $J_{1',2'}$= 1.8 Hz), 4.63 (d, 0.6H, H-1 (β-anomer), $J_{1,2}$= 8 Hz), 3.97 (dd, 1H, H-2', $J_{2',3'}$= 3.5 Hz), 3.74 (dd, 1H, H-3', $J_{3',4'}$= 10 Hz), 3.44 (t, 1H, H-4', $J_{3',4'}$= $J_{4',5'}$= 10 Hz), 1.25 (d, 3H, H-6', $J_{5',6'}$= 6.3 Hz).

Methyl (Benzyl 2,3-di-O-Benzyl-β-D-glucopyranosid)uronate (25). A solution of 24[41] (0.46 g) in a mixture of methanol (5 mL) and dichloromethane (5 mL) was treated with ethereal diazomethane. Recrystallization from ethyl acetate-light petroleum gave 25 (0.37 g, 78%): mp 77-78 °C; $[\alpha]_D$ -45.6° (c 0.70, chloroform); R_F 0.43 (dichloromethane-ethyl acetate, 19:1); lit.[41] mp 77.5 °C; $[\alpha]_D$ -47° (c 1.15, chloroform); ^{1}H NMR ($CDCl_3$) δ 7.4-7.2 (m, 15H, 3Ph), 5.02-4.64 (3q, 6H, 3 PhCH_2), 4.57 (d, 1H, H-1, $J_{1,2}$= 8 Hz), 3.84 (s, 3H, OMe), 2.81 (d, 1H, OH).

Benzyl (Benzyl 2,3-di-O-Benzyl-β-D-glucopyranosid)uronate (26). To a mixture of 24 (1 g) and tetrabutylammonium bromide (1.39 g) in 1,2-dichloroethane (15 mL) was added 20% aqueous potassium hydroxide

(5 mL) followed by benzyl bromide (1.5 mL) and the mixture was stirred intensively under reflux for 6 h. The mixture was diluted with dichloromethane, washed with water, dried, and concentrated. The residue was recrystallized from ethyl acetate-light petroleum to afford 26 (0.88 g, 74%): mp 101-102 °C; $[\alpha]_D$ -39.6° (c 0.79, chloroform); R_F 0.42 (light petroleum-ethyl acetate, 4:1); ^{1}H NMR ($CDCl_3$) δ 7.4-7.2 (m, 20H, 4Ph), 5.23 (s, 2H, CO_2CH_2Ph), 4.97-4.61 (3q, 3 X 2H, $3CH_2Ph$), 4.55 (d, 1H, H-1, $J_{1,2}$= 7.5 Hz), 4.0-3.8 and 3.6-3.4 (2m, 2 x 2H, H-2,3,4,5), 2.8 (s, 1H, OH).

Anal. Calcd for $C_{34}H_{34}O_7$: C, 73.63; H, 6.18. Found: C, 73.71; H, 6.14.

2,3,4-Tri-O-benzyl-L-rhamnopyranose (28). L-rhamnose (12.5 g) was converted into a mixture of methyl glycosides as described.[51] The crude syrup (12.6 g) was stirred in dimethyl sulfoxide (70 mL), and powdered potassium hydroxide (50 g), and benzyl bromide (50 mL) were added in five portions in 1 h. The mixture was stirred for 30 min and methanol (20 mL) was added. The mixture was stirred for 30 more min, dichloromethane and water were added, and the organic layer was washed with water five times and was concentrated. The resulting syrup was dissolved in acetic acid (300 mL), and stirred at 80 °C for 50 min after addition of 3.5 M sulfuric acid (40 mL). Toluene and water were added, the inorganic layer was back-extracted with toluene, and the combined organic layer was washed with aqueous sodium hydrogen carbonate, water, and then dried, and concentrated. Flash chromatography of the residue with gradient elution using dichloromethane-light petroleum (1:1), dichloromethane, dichloromethane-ethyl acetate (19:1) gave 22.8 g of 28, which still contained minor impurities. Recrystallization from ethyl acetate-light petroleum gave 18.28 g (61%) pure 28: mp 91-92 °C; $[\alpha]_D$ -14.8° (c 0.8, chloroform); R_F 0.3 (light petroleum-ethyl acetate, 4:1); lit.[47] mp 90-92 °C; $[\alpha]_D$ -15.4° (c 1.6, chloroform); ^{1}H NMR ($CDCl_3$) δ 7.4-7.1 (m, 15H, 3Ph), 5.00 (s, 1H, H-1), 4.96-4.50 (m, 6H, $3PhCH_2$), 4.05-3.48 (m, 5H, H-2,3,4,5 + OH), 1.26 (d, 3H, H-6).

Methyl 2,3,4-tri-O-Benzyl-α-L-rhamnopyranoside (29). Benzylation of 11 by the method used above followed by chromatographic purification (light petroleum-ethyl acetate, 9:1) gave 29 as a syrup in 79% yield: $[\alpha]_D$ -26.6° (c 1.11, chloroform); R_F 0.21 (light petroleum-ethyl acetate, 9:1); lit.[47] $[\alpha]_D$ -27.8° (c 1.9, chloroform).

2,3,4-Tri-O-benzyl-1-O-trichloroacetimidoyl-α-L-rhamnopyranose (27). To a solution of 28 (4.34 g) in dry dichloromethane (50 mL) sodium hydride (0.24 g) was added, followed by trichloroacetonitrile (3.5 mL). After 30 min at room temperature the mixture was filtered through a short layer of silica gel, the solid was washed with dichloromethane (containing 1% triethylamine) and the filtrate was concentrated to afford 4.91 g (85%) of syrupy 27: $[\alpha]_D$ -33.6° (c 1.06, chloroform); R_F 0.9 (dichloromethane-triethylamine, 99:1); ^{1}H NMR ($CDCl_3$) δ 8.42 (s, 1H, NH), 7.4-7.1 (m, 15H, 3Ph), 6.20 (s, 1H, H-1), 4.74 (q, 2H, $PhC\underline{H}_2$), 4.68 and 4.53 (2s, 2 X 2H, $2PhC\underline{H}_2$), 4.1-3.5 (m, 4H, H-2,3,4,5), 1.31 (d, 3H, H-6).

Benzyl [Benzyl 2,3-di-O-Benzyl-4-O-(2,3,4-tri-O-benzyl-α-L-rhamnopyranosyl)-β-D-glucopyranosid]uronate (30). To a mixture of 26 (0.44 g) and molecular sieves (4 Å, 2 g) in dichloromethane (10 mL) was added a solution of 27 (0.58 g) in dichloromethane (5 mL) and the mixture was treated with a solution of trifluoromethanesulfonic acid (14 μL) in dichloromethane (1 mL) at -20 °C as described for 13. Column chromatography (light petroleum-ethyl acetate, 85:15) gave 26 (0.61 g, 79%): mp 86-88 °C; $[\alpha]_D$ -39.0° (c 0.97, chloroform); R_F 0.71 (light petroleum-ethyl acetate, 4:1); ^{1}H NMR ($CDCl_3$) δ 7.4-7.1 (m, 35H, 7Ph), 5.2-4.5 (m, 16 H, $7PhC\underline{H}_2$ + H-1,1'), 4.15-3.5 (m, 8H, ring protons), 1.08 (d, 3H, H-6').

Anal. Calcd for $C_{61}H_{62}O_{11}$: C, 75.44; H, 6.44. Found: C, 75.35; H, 6.40.

Methyl [Benzyl 2,3-di-O-Benzyl-4-O-(α-L-rhamnopyranosyl)-β-D-glucopyranoside]uronate (31). A mixture of 26 (0.28 g) and mercuric cyanide (0.19 g) in a mixture of dry nitromethane (10 mL) and toluene (10 mL) was boiled until about 10 mL of the solvent distilled off. The mixture was cooled to 40 °C, and kept at this temperature. Molecular sieves (4 Å, 0.5 g) were added, the mixture was stirred for 30 min, and then a solution of 8 (0.26 g) in toluene (10 mL) was added dropwise. Additional amounts of 8 (0.26 g) and mercuric cyanide (0.19 g) were added after 4 and 8 h, and the mixture was stirred overnight. The reaction mixture was concentrated, the residue was taken up in dichloromethane, filtered through Celite, and the solid washed with dichloromethane. The filtrate was washed with 10% aqueous potassium iodide, then with water, dried, and concentrated. Column chromatography (light

petroleum-acetone, 3:1) gave 0.46 g of impure disaccharide, which was deacetylated in dry methanol (25 mL) with 1 M sodium methoxide (0.2 mL) overnight. After neutralization and concentration the residue was purified by column chromatography (dichloromethane-methanol, 95:5) to give 0.16 g (51%) of 31: mp 172-174 °C; $[\alpha]_D$ -49.8° (c 0.63, chloroform); R_F 0.24 (dichloromethane-methanol, 19:1).

Anal. Calcd for $C_{34}H_{40}O_{11}$: C,65.37; H, 6.45. Found: C, 65.49; H, 6.50.

ACKNOWLEDGEMENTS

The author thanks Professors Pál Nánási and András Lipták for their interest, and Dr. János Harangi and Dr. András Neszmélyi for recording the NMR spectra.

REFERENCES

1. M. Heidelberger and W. Nimmich, Immunochemistry, 13, 67 (1976).

2. L. Kenne, and B. Lindberg in The Polysaccharides, Vol 2.; G. O. Aspinall, Ed.; Academic Press, 1983, p. 287.

3. G. G. S. Dutton, H. Parolis, and L. A. Parolis, Carbohydr. Res., 152, 249 (1986), and references therein.

4. M. Heidelberger, W. Nimmich, J. Eriksen, and S. Stirm, Acta Path. Microbiol. Scand., Sect. B, 86, 313 (1978).

5. H. Björndal, B. Lindberg, J. Lönngren, W. Nimmich, and K.-G. Rosell, Carbohydr. Res., 27, 373 (1973).

6. G. O. Aspinall and K.-G. Rosell, Can. J. Chem., 56, 685 (1978).

7. G. G. S. Dutton and D. N. Karunaratne, Carbohydr. Res., 119, 157 (1983).

8. M. Curvall, B. Lindberg, J. Lönngren, and W. Nimmich, Carbohydr. Res., 42, 73 (1975).

9. G. G. S. Dutton and K. L. Mackie, Carbohydr. Res., 62, 321 (1978).

10. G. G. S. Dutton and T. E. Folkman, Carbohydr. Res., 80, 147 (1980).

11. G. G. S. Dutton and M. Paulin, Carbohydr. Res., 87, 107 (1980).

12. H. Björndal, B. Lindberg, J. Lönngren, M. Mészáros, J. L. Thompson, and W. Nimmich, Carbohydr. Res., 31, 93 (1973).

13. V. L. L'vov, N. V. Tochtamysheva, B. A. Dmitriev, N. K. Kochetkov, and I. L. Hofman, Bioorg. Khim., 6, 1842 (1980).

14. P.-E. Jansson, B. Lindberg, U. Lindquist, and D. J. Carlo, Carbohydr. Res., 118, 157 (1983).

15. G. O. Aspinall, A. J. Charlson, E. L. Hirst, and R. Young, J. Chem. Soc., 1696 (1963).

16. G. O. Aspinall and K.-G. Rosell, Can. J. Chem., 56, 680 (1978).

17. H. Geyer, K. Himmelspach, B. Kwiatkowski, S. Schlecht, and S. Stirm, Pure Appl. Chem., 55, 637 (1983).

18. A. Klemer, Chem. Ber., 92, 218 (1959).

19. A. Lipták, J. Imre, and P. Nánási, Carbohydr. Res., 92, 154 (1981).

20. P. Fügedi and P. Nánási, J. Carbohydr. Nucleosides Nucleotides, 8, 547 (1981).

21. J. G. Buchanan, A. R. Edgar, D. I. Rawson, P. Shahidi, and R. H. Wightman, Carbohydr. Res., 100, 75 (1982).

22. S. L. Patt, J. N. Shoolery, J. Magn. Res., 46, 535 (1982).

23. E. Conway, R. D. Guthrie, S. D. Gero, G. Lukacs, and A.-M. Sepulchre, J. Chem. Soc., Perkin Trans. II, 542 (1974).

24. A. Lipták and P. Fügedi, Angew. Chem., 95, 245 (1983); Angew. Chem. Suppl., 254 (1983).

25. D. G. Gorenstein, J. Am. Chem. Soc., 99, 2254 (1977).

26. H. Paulsen, Angew. Chem., 94, 184 (1982).

27. P. Sinaÿ, Pure Appl. Chem., 50, 1437 (1978).

28. J.-M. Petit, J.-C. Jacquinet, and P. Sinaÿ, Carbohydr. Res., 82, 130 (1980).

29. K. Bock and C. Pedersen, J. Chem. Soc., Perkin Trans. II, 293 (1974).

30. C. Laffite, A. M. Nguyen Phuoc Du, F. Winternitz, R. Wylde, and F. Pratviel-Sosa, Carbohydr. Res., 67, 105 (1978).

31. R. Boss and R. Scheffold, Angew. Chem. Int. Ed. Engl., 15, 558 (1976).

32. T. Ogawa and M. Matsui, Carbohydr. Res., 62, C1 (1978).

33. J. Hoffman and B. Lindberg, Methods Carbohydr. Chem., 8, 117 (1980).

34. B. S. Bal, K. S. Kochhar, and H. W. Pinnick, J. Org. Chem., 46, 1492 (1981).

35. E. Zissis and H. G. Fletcher, Jr., Carbohydr. Res., 12, 360 (1970).

36. P. Fügedi, A. Lipták, P. Nánási, and J. Szejtli, Carbohydr. Res., 104, 55 (1982).

37. L. Birkofer and B. Hammes, Liebigs Ann. Chem., 731 (1973).

38. F. Imperato, Carbohydr. Res., 58, 217 (1977).

39. K. Takeo, K. Okushio, K. Fukuyama, and T. Kuge, Carbohydr. Res., 121, 163 (1983).

40. K. Heyns and H. Paulsen, Adv. Carbohydr. Chem., 17, 169 (1962).

41. A. Wacek, F. Leitinger, and P. Hochbahn, Monatsh. Chem., 90, 562 (1959).

42. P. J. Garegg, T. Iversen, and S. Oscarson, Carbohydr. Res., 50, C12 (1976).

43. P. J. Garegg, T. Iversen, and S. Oscarson, Carbohydr. Res., 53, C5 (1977).

44. P. Fügedi, A. Lipták, P. Nánási, and A. Neszmélyi, Carbohydr. Res., 107, C5 (1982).

45. R. R. Schmidt and J. Michel, Angew. Chem., 92, 763 (1980).

46. R. R. Schmidt, Angew. Chem., 98, 213 (1986).

47. J. M. J. Fréchet and H. H. Baer, Carbohydr. Res., 42, 369 (1975).

48. S. Koto, N. Morishima, Y. Miyata, and S. Zen, Bull. Chem. Soc. Japan, 49, 2639 (1976).

49. P. Fügedi, COMECON Symposium on Chemistry of Carbohydrates and Their Derivatives, Moscow, Nov. 14-17, 1983.

50. K. Bock and C. Pedersen, Adv. Carbohydr. Chem. Biochem., 41, 27 (1983).

51. D. M. Clode, D. Horton, and W. Weckerle, Carbohydr. Res., 49, 305 (1976).