Reliable method for the synthesis of aryl β-D-glucopyranosides, using boron trifluoride–diethyl ether as catalyst

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Stereospecific formation of aryl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosides was achieved by reaction of penta-*O*-acetyl-β-D-glucose 1 with substituted phenols in the presence of boron trifluoride. Yields of the purified products varied from 52–85%. Benzyl alcohol could also be glucosylated using similar conditions. All products were purified by crystallization from ethanol. The purity and the anomeric configuration of the products were determined by means of ^{1}H and ^{13}C NMR spectroscopy, melting points and optical rotation.

Introduction

Our interest in the preparation of new carbohydrate-derived liquid crystals[1] prompted us to take a closer look at the synthesis of aryl glucopyranosides. The formation of the glycosidic bond is an important step in the synthetic strategy pertinent to our investigations, and also in the synthesis of naturally occurring glycosides. The major leaf metabolites of members of the genus *Protea* (of the family Proteaceae), which are aromatic esters of aryl glucosides,[2] are good examples. Finding an efficient and generally applicable procedure for the preparation of aryl β-D-glucopyranosides was troublesome. Various glucosylation methods have been developed since the classical Koenigs–Knorr synthesis.[3] Usually, these procedures require either an activated glucosyl donor, *e.g.*, a glucosyl halide,[4,5] trimethylsilyl 2,3,4,6-tetra-*O*-acetyl-D-glucopyranoside,[6] or a trichloroacetimidate,[7,8] a glucosyl acceptor with a good leaving group[9–11] or a precious metal catalyst.[12,13] Glucosylation can also be performed enzymically;[14] the unprotected monosaccharide is derivatized in a water-poor system using the glucosyl acceptor (*e.g.*, allyl or benzyl alcohol) as the solvent. However, most of these methods involve purification by means of column chromatography, which is not convenient for the synthesis of multigram quantities of glucosides.

Previously, we have used Lewis-acid catalysis ($BF_3 \cdot Et_2O$) for the synthesis of alkyl 2,3,4,6-tetra-*O*-acetyl-1-thio-α- or -β-D-glucopyranosides.[15] Lepoittevin *et al.*[16] described a convenient direct coupling of penta-*O*-acetyl-β-D-glucose 1 to 3-*n*-alkylcatechols by using $BF_3 \cdot Et_2O$ in dichloromethane at ambient temperature. Isomers substituted on the 1- and 2-OH groups of the 3-alkylcatechol were formed, in favour of the former, but both with exclusively the β-configuration at the anomeric centre of the carbohydrate. Reactions of substituted phenols other than these catechol derivatives were not described.

In this paper, we present the results of a study on the scope and limitations of this procedure[16] for the synthesis of various aryl β-D-glucopyranosides 3. This method is easy to carry out and is applicable for a range of substituted phenols and benzyl alcohols. The starting materials are inexpensive or can be prepared on a large scale without difficulty. The purification of the aryl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosides is achieved conveniently by recrystallization from ethanol.

Results and discussion

The glucosylation which yields compounds 3 requires the reaction of equimolar amounts of pentaacetate 1 and a substituted phenol 2 under the influence of the Lewis acid catalyst $BF_3 \cdot Et_2O$ in dichloromethane at room temperature. The rate of reaction is dependent on the substituent on the phenol ring. An average reaction time of 24 h is sufficient for complete transformation. After aqueous work-up the aryl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosides 3 are obtained in almost quantitative yields. Crystallization from ethanol affords the anomerically pure products 3 in 52–85% yield.

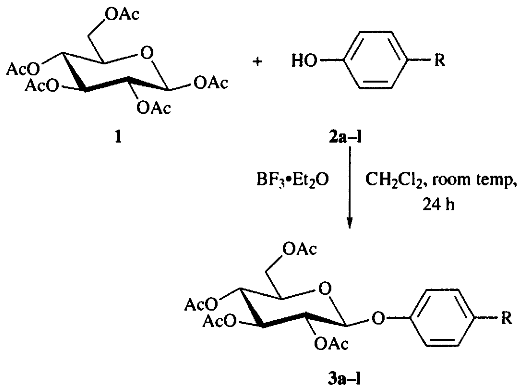
The yields of the individual reactions and the physical constants of purified products 3a–l are reported in Table 1. The crude reaction products from different runs were analysed by means of ^{1}H NMR spectroscopy. The crude aryl β-D-glucopyranosides were contaminated with both starting phenol, in those cases in which the substituted phenols are not soluble in aq. hydrogen carbonate, and traces of unchanged (and anomerized) penta-*O*-acetyl-D-glucose. Aryl α-D-glucopyranosides were not detected. The recrystallized aryl glucosides have the β-configuration as was established with ^{1}H and ^{13}C NMR spectroscopy. The coupling constants between H-1 and H-2 are in the range 7.3–7.7 Hz. The optical rotations were measured and, if reported, are in close agreement with literature data.

There is no need for activation of the glucosyl acceptor, *e.g.*, by converting the phenol into a trialkylstannyl phenoxide as reported by Mottadelli *et al.*,[11] nor for activation of the glucosyl donor.[17,18] Shorter reaction times appear to be the only advantage of the activation of either the donor or the acceptor. Since no side-reactions were observed in the method presented here, the longer reaction time is not a problem.

Only for the *mono*-glucosylation of dihydroxy aromatic compounds is it necessary to use a more selective system, because hydroquinone 4a, resorcinol 4b and 4,4′-dihydroxybiphenyl 4c are glucosylated on both oxygens in the $BF_3 \cdot Et_2O$-catalysed reaction (Table 2). Due to the poor solubility of compounds 4 in dichloromethane, only a small amount of the starting material is dissolved and this reacts twice with pentaacetate 1. Hence, the synthesis of the *di*-glucosylated derivatives proceeds smoothly. The use of a modified procedure, in which a solution of substrate 1 and catalyst $BF_3 \cdot Et_2O$ was added very slowly to a suspension of hydroquinone, resulted in a mixture of mono- and di-glucosylated products in the ratio 10:7. Other methods[11,17] appear to be better for selective mono-glucosylation.

The rate and the extent of the glucosylation are dependent on

Table 1 Glucosylation of penta-*O*-acetyl-β-D-glucose **1** with phenols **2** under the influence of $BF_3 \cdot Et_2O$. Isolated yields and physical properties of aryl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosides **3**



	R	Yield (%)[a]	Mp (°C) Found	Mp (°C) Reported[18]	Optical rotation $[\alpha]_D^{28}$ (*c* 1)	Optical rotation Reported[18]
3a	H	68	123.5–124.8	125–126	−22.6	−21.0[b]
3b	OCH_3	62	100.6–102.3	98.5	−18.1	−15.5
3c	OC_5H_{11}	85	114.7–115.8		−13.9	
3d	$OC_{10}H_{21}$	75	88.0–89.3		−13.1	
3e	C_8H_{17}	66	113.7–114.7		−14.0	
3f	NO_2	74[c]	175.7–177.2	174.0–174.5	−40.4	−39.3
3g	CN	17[d]	151.3–152.8		−31.0	
3h	CO_2CH_3	72	158.7–160.2	159.5–160.0	−26.0	−25
3i	CO_2Pr	52	120.7–122.6		−19.8	
3j-β	Ph	57	149.9–151.6	152	−14.3	−15.2
3j-α[e]	Ph	18	151.4–157.1	165	+157	+165
3k	$4-C_6H_4CN$	61	175.6–177.8		−14.3	
3l	$4-C_6H_4OC_6H_{13}$	66	134.6–139.3		−8.0	

[a] Isolated yield after recrystallization. [b] The reported values of the optical rotation were measured at 23 °C. [c] The reaction was performed on 50 mmol scale, reaction time 72 h. [d] Special reaction conditions were required to favour the desired glucosylation reaction over the competing Ritter reaction[32] of the nitrile with the glucosyl cation. The Ritter reaction was not observed during the glucosylation of compound **2k**. [e] Product **3j-α** has the α-configuration at the anomeric centre, and was prepared in refluxing chloroform.

the nucleophilicity of the phenols **2**. An electron-donating alkoxy group on the 4-position of the phenol ring enhances the nucleophilicity of compounds **2** and speeds up the reaction. In the reaction of 4-pentyloxyphenol **2c** with compound **1**, NMR analysis of the crude product indicated a conversion of 92% of acetate **1** into the glucopyranoside after 15 h. The degree of conversion of methyl 4-hydroxybenzoate **2h** was 64% after 15 h. 4-Nitrophenol **2f** reacts slowly and is glucosylated to an extent of only 47% in 15 h. However, glucosylation of compound **2f** carried out on a 50 mmol scale with a reaction time of 72 h, gave pure compound **3f** in 74% yield after recrystallization.

The same substrates were used to study the effect of the amount of promotor on the extent of conversion. Reactions were carried out in the presence of increasing amounts of $BF_3 \cdot Et_2O$ (0.2–2.0 mol equiv.) and were quenched after 15 or 48 h. The crude reaction products were analysed by means of ^1H NMR spectroscopy. The best results were obtained when approximately equivalent amounts of promotor and reactants were used.

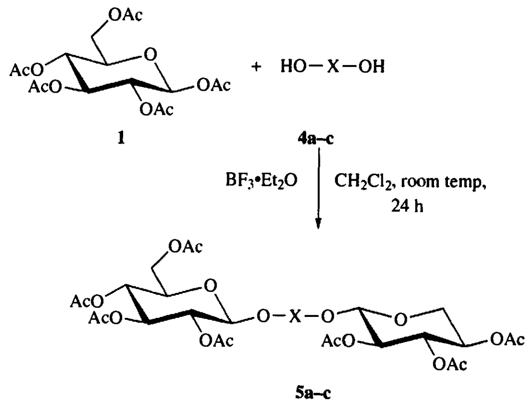
Another Lewis acid, tin(IV) tetrachloride $SnCl_4$, is also frequently used in glucosylation reactions.[19,20] Although this is a stronger acid, it did not give better results than $BF_3 \cdot Et_2O$. Glucosylation of α- and β-naphthol using $SnCl_4$ gave the β-D-glucopyranosides in 20 and 32% yield, respectively, whereas the yields of the $BF_3 \cdot Et_2O$-catalysed reactions were significantly higher (61 and 70%).

Jeffrey *et al.*[21] and others[22] reported that the temperature at which the glucosylation is carried out determines the configuration at the anomeric centre. Using $SnCl_4$ as the promotor, they obtained the aryl β-D-glucopyranosides under conditions of kinetic control at 20 °C and the thermodynamically more stable α-anomer when the reaction temperature was 40 °C. Using $BF_3 \cdot Et_2O$, we found the formation of only β-glucopyranosides. When 4-hydroxybiphenyl **2j** was glucosylated in refluxing chloroform under nitrogen, the α-anomer **3j-α** was isolated in 18% yield. Anomerization of compound **3h** in dichloromethane at 20 °C or at 40 °C did not occur. The β-anomer was recovered almost quantitatively. When glucosylation of compound **2d** was carried out at 40 °C for 19 or 76 h under nitrogen, mixtures of α and β isomers were obtained (α : β = 1 : 5 and 1 : 1.2, respectively).

The 4-cyanobiphenyl moiety is a well known mesogenic group which we wanted to incorporate in carbohydrate-derived liquid crystals. 4-Cyanobiphenyl β-D-glucopyranoside has been prepared by Baker *et al.*[23] using a $SnCl_4$-catalysed reaction, and by Tschierske *et al.*[24] using the Koenigs–Knorr method as described by Conchie and Levvy.[25] In our hands, this method gave product **3j** in only 14% yield. Using a modified procedure,[4] the reaction of compound **2j** with 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl bromide **1′** in dichloromethane with silver triflate as promotor, compound **3j** was prepared in 43% yield. When this method was used for the glucosylation of 4-cyano-4′-hydroxybiphenyl **2k**, the corresponding glucopyranoside **3k** was obtained in 40% yield. The $BF_3 \cdot Et_2O$-promoted reaction was found to proceed more efficiently, resulting in products **3j** and **3k** in 54 and 61% yield, respectively.

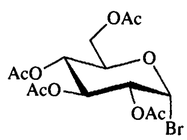
There are some limitations with respect to the choice of substituted phenols that can be used in the $BF_3 \cdot Et_2O$-catalysed reaction. Methyl 4-hydroxybenzoate **2h** is readily glucosylated, but in the reaction with the free acid, 4-hydroxybenzoic acid,

Table 2 Glucosylation of penta-*O*-acetyl-β-D-glucose **1** with dihydroxy aromatic compounds **4** under the influence of $BF_3 \cdot Et_2O$. Isolated yields and physical properties of bis-(2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl)aryls **5**

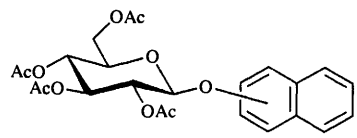


	Glucosyl acceptor **4**	X	Yield (%)[a]	Mp (°C) Found	Mp (°C) Reported	Optical rotation $[\alpha]_D^{28}$ (c 1)	Optical rotation Reported[b]
5a	hydroquinone	p-C_6H_4	81	178–183	195–196[18]	−19.9	−16[18]
5b	resorcinol	m-C_6H_4	42	202–205	193–195[28]	−25.7	−29[28]
5c	4,4′-dihydroxybiphenyl	$(p$-$C_6H_4)_2$	47	199–210		−11.8	

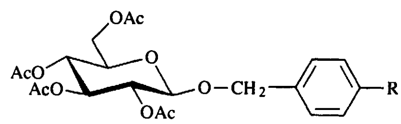
[a] Isolated yield after recrystallization. [b] The reported values of the optical rotation were measured at 23 °C in ref. 18 and at 26 °C in ref. 28.



1′



6a (1-naphthyl)
b (2-naphthyl)



7a R = H
b R = NO_2

the expected glucopyranoside was not formed. Also, glucosylation of 4-hydroxybenzaldehyde failed. A valuable extension to the range of glucosyl acceptors is that benzyl alcohol and 4-nitrobenzyl alcohol can also be glucosylated using the method described above, giving the products **7a** and **7b** in 24 and 70% yield. 4-Hydroxybenzyl alcohol and 4-alkoxybenzyl alcohol failed to react with pentaacetate **1** under the influence of a Lewis acid. Both $BF_3 \cdot Et_2O$ and $SnCl_4$ were used, but in each case only degradation of the starting alcohol was found. 4-Hexyloxybenzyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside has been prepared by Tschierske *et al.*[26] using a silver oxide-promoted glucosylation of bromide **1′** with 4-hexyloxybenzyl alcohol. Unfortunately, no experimental details were given.

All the aryl 2,3,4,6-tetra-*O*-acetylglucopyranosides prepared with the $BF_3 \cdot Et_2O$-catalysed reaction can be deprotected[15] by the action of trimethylamine in aq. methanol to yield the corresponding aryl glucopyranosides quantitatively.

Experimental

General

All reagents and solvents were purchased and were used without further purification. 4-Nitrophenol and 4-cyanophenol were recrystallized from toluene and 4-pentyloxyphenol was recrystallized from light petroleum (distillation range 40–60 °C). Penta-*O*-acetyl-β-D-glucose **1** was prepared by the method described by Vogel.[27] The structures of all products were confirmed by NMR spectroscopy; no impurities were detected in the final products. Where determined, elemental analysis revealed at least 99% purity. ^1H and ^{13}C NMR spectra were recorded on a 300 MHz Varian VTR-300 spectrometer. Chemical shifts are relative to $CHCl_3$ (δ_H 7.24). Mps were measured using a Perkin-Elmer PC Series DSC 7. Optical rotations were measured for solutions in $CHCl_3$ on a Perkin-Elmer 241 polarimeter, and $[\alpha]_D$-values are given in units of 10^{-1} deg cm^2 g^{-1}.

General procedure for the glucosylation of phenols with $BF_3 \cdot Et_2O$

Penta-*O*-acetyl glucose **1** (3.9 g, 10 mmol) and 10 mmol of a 4-substituted phenol **2** were dissolved in 20 ml of anhydrous CH_2Cl_2. Then $BF_3 \cdot Et_2O$ (1.25 ml, 10 mmol) was added. The reaction mixture was stirred at room temperature for 24 h and then poured into 40 ml of 5% aq. $NaHCO_3$. The organic layer was separated, washed successively with aq. $NaHCO_3$ and (once) with water, dried over Na_2SO_4, and concentrated. The crude product was recrystallized from ethanol. The physical data reported below were determined on the first crop of recrystallized product.

Remarks. The glucosylation reactions were also carried out on a scale up to 50 mmol; the products were obtained in similar yields and selectivity. For the glucosylation of dihydroxy aromatic compounds **4** two mol equiv. of pentaacetate **1** were used. The naphthyl and benzyl β-D-glucopyranosides **6** and **7** were synthesized using the same general procedure.

NMR data and elemental analysis of selected compounds

Phenyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside[18] **3a.** δ_H 2.02, 2.03, 2.06 and 2.07 (4 s, 12 H, 4 × acetyl), 3.78 (m, 1 H, H-5), 4.15 (dd, $J_{6a\text{-}6b}$ 12.2, $J_{5\text{-}6a}$ 2.5, 1 H, H^a-6), 4.26 (dd, $J_{5\text{-}6b}$ 5.4, 1 H, H^b-6), 5.08 (d, $J_{1\text{-}2}$ 7.3, 1 H, H-1), 5.14–5.27 (3 dd, 3 H, H-2, -3 and -4) and 6.97–7.32 (m, 5 H); δ_C 20.5 (q, 4 × acetyl), 61.9 (t, C-6), 68.2, 71.1, 71.9 and 72.6 (4 d, C-2/5), 99.0 (d, C-1), 116.9, 123.2 and 129.5 (each d, arom CH), 156.7 (s, arom C-O) and 169.1, 169.2, 170.1 and 170.4 (4 s, CO acetyl).

4-Methoxyphenyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside[18] **3b.** δ_H 2.02, 2.03, 2.06 and 2.07 (4 s, 12 H, 4 × acetyl), 3.76 (s, 3 H, OCH_3), 3.78 (m, 1 H, H-5), 4.15 (dd, $J_{6a\text{-}6b}$ 12.1, $J_{5\text{-}6a}$ 2.2, 1 H, H^a-6), 4.26 (dd, $J_{5\text{-}6b}$ 5.2, 1 H, H^b-6), 4.94 (d, $J_{1\text{-}2}$ 7.7, 1 H, H-1), 5.14–5.27 (3 dd, 3 H, H-2, -3 and -4), 6.86 (d, 2 H) and 6.94 (d, 2 H); δ_C 20.5 (q, 4 × acetyl), 55.5 (q, OCH_3), 61.8 (t, C-6), 68.2, 71.1, 71.9 and 72.6 (4 d, C-2/5), 100.2 (d, C-1), 114.4 and 118.6 (2 d, arom CH), 150.8 and 155.7 (2 s, arom C-O) and 169.1, 169.2, 170.1 and 170.4 (4 s, CO acetyl).

4-Pentyloxyphenyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside 3c. δ_H 0.91 (t, 3 H, H_3-5′), 1.35–1.50 (m, 4 H, H_2-3′ and 4′), 1.74 (m, 2 H, H_2-2′), 2.01, 2.02, 2.05 and 2.06 (4 s, 12 H, 4 × acetyl), 3.78 (m, 1 H, H-5), 3.89 (t, 2 H, H_2-1), 4.15 (dd, $J_{6a\text{-}6b}$ 12.1, $J_{5\text{-}6a}$ 2.2, 1 H, H^a-6), 4.26 (dd, $J_{5\text{-}6b}$ 5.1, 1 H, H^b-6), 4.93 (d, $J_{1\text{-}2}$ 7.3, 1 H, H-1), 5.1–5.26 (3 dd, 3 H, H-2, -3 and -4), 6.79 (d, 2 H) and 6.91 (d, 2 H); δ_C 13.9 (q, C-5′), 20.5 (q, 4 × acetyl), 22.4, 28.1 and 28.9 (each t, C-2′/4′), 61.9 (t, C-6), 68.5 (t, C-1′), 68.3, 71.2, 71.9 and 72.7 (4 d, C-2/5), 100.3 (d, C-1), 115.2 and 118.6 (2 d, arom CH), 150.7 and 155.3 (2 s, arom C–O) and 169.2, 169.3, 170.2 and 170.5 (4 s, CO acetyl) (Found: C, 58.7; H, 6.7. $C_{25}H_{34}O_{11}$ requires C, 58.82; H, 6.71%).

4-Decyloxyphenyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside 3d. δ_H 0.87 (t, 3 H, H_3-10′), 1.2–1.50 (m, 14 H, H-3′/9′), 1.77 (m, 2 H, H_2-2′), 2.01, 2.02, 2.05 and 2.06 (4 s, 12 H, 4 × acetyl), 3.80 (m, 1 H, H-5), 3.90 (t, 2 H, H_2-1′), 4.15 (dd, $J_{6a\text{-}6b}$ 12.1, $J_{5\text{-}6a}$ 2.7, 1 H, H^a-6), 4.28 (dd, $J_{5\text{-}6b}$ 5.5, 1 H, H^b-6), 4.94 (d, $J_{1\text{-}2}$ 7.3, 1 H, H-1), 5.1–5.3 (3 dd, 3 H, H-2, -3 and -4), 6.80 (d, 2 H) and 6.92 (d, 2 H); δ_C 14.0 (q, C-10′), 20.5 (q, 4 × acetyl), 22.5, 25.9, 29.2, 29.3, 29.5 and 31.8 (each t, C-2′/9′), 61.9 (t, C-6), 68.5 (t, C-1′), 68.3, 71.2, 71.9 and 72.7 (4 d, C-2/5), 100.3 (d, C-1), 115.1 and 118.6 (2 d, arom CH), 150.7 and 155.3 (2 s, arom C-O), 169.2, 169.3, 170.1 and 170.4 (4 s, CO acetyl) (Found: C, 62.0; H, 7.5. $C_{30}H_{44}O_{11}$ requires C, 62.05; H, 7.64%).

4-Octylphenyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside 3e. δ_H 0.87 (t, 3 H, H_3-8′), 1.2–1.50 (m, 10 H, H_2-3′/7′), 1.56 (m, 2 H, H_2-2′), 2.01, 2.02, 2.05 and 2.06 (4 s, 12 H, 4 × acetyl), 2.54 (t, 2 H, H_2-1′), 3.83 (m, 1 H, H-5), 4.15 (dd, $J_{6a\text{-}6b}$ 12.2, $J_{5\text{-}6a}$ 2.3, 1 H, H^a-6), 4.28 (dd, $J_{5\text{-}6b}$ 5.4, 1 H, H^b-6), 5.02 (d, $J_{1\text{-}2}$ 7.5, 1 H, H-1), 5.1–5.3 (3 dd, 3 H, H-2, -3 and -4), 6.89 (d, 2 H) and 7.07 (d, 2 H); δ_C 14.0 (q, C-8′), 20.5 (q, 4 × acetyl), 22.5, 29.1, 29.3, 31.5 and 31.7 (each t, C-2′/6′), 35.0 (t, C-1′), 61.9 (t, C-6), 68.3, 71.1, 71.9 and 72.7 (4 d, C-2/5), 99.3 (d, C-1), 116.7 and 129.2 (2 d, arom CH), 137.9 (s, arom C), 154.8 (s, arom C–O) and 169.1, 169.2, 170.1 and 170.4 (4 s, CO acetyl) (Found: C, 62.3; H, 7.6. $C_{28}H_{40}O_{10}$ requires C, 62.7; H, 7.51%).

4-Nitrophenyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside[18] **3f.** δ_H 2.02, 2.03, 2.06 and 2.07 (4 s, 12 H, 4 × acetyl), 3.92 (m, 1 H, H-5), 4.16 (dd, $J_{6a\text{-}6b}$ 12.4, $J_{5\text{-}6a}$ 2.4, 1 H, H^a-6), 4.26 (dd, $J_{5\text{-}6b}$ 5.2, 1 H, H^b-6), 5.1–5.3 (m, 4 H, H-1/4), 7.05 (d, 2 H) and 8.17 (d, 2 H); δ_C 20.5 (q, 4 × acetyl), 61.7 (t, C-6), 67.9, 70.8, 76.5 and 76.9 (4 d, C-2/5), 97.9 (d, C-1), 116.5 and 125.6 (2 d, arom CH), 143.1 (s, arom C-N), 161.0 (s, arom C–O) and 169.1, 169.2, 170.1 and 170.4 (4 s, CO acetyl).

4-Cyanophenyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside 3g. δ_H 2.03, 2,04, 2.04 and 2.05 (4 s, 12 H, 4 × acetyl), 3.90 (m, 1 H, H-5), 4.19 (dd, $J_{6a\text{-}6b}$ 12.5, $J_{5\text{-}6a}$ 2.5, 1 H, H^a-6), 4.26 (dd, $J_{5\text{-}6b}$ 5.2, 1 H, H^b-6), 5.14–5.27 (m, 4 H, H-1/4), 7.04 (d, 2 H) and 7.59 (d, 2 H); δ_C 20.5 (q, 4 × acetyl), 61.8 (t, C-6), 68.1, 71.0, 72.3 and 72.5 (4 d, C-2/5), 98.1 (d, C-1), 106.8 (s, arom *C*-CN), 117.3 (d, arom CH), 118.5 (s, CN), 134.0 (d, arom CH), 159.6 (s, arom C–O) and 169.1, 169.3, 170.0 and 170.3 (4 s, CO acetyl) (Found: C, 56.0; H, 5.15; N, 3.1. $C_{21}H_{23}NO_{10}$ requires C, 56.12; H, 5.16; N, 3.12%).

4-(Methoxycarbonyl)phenyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside[18] **3h.** δ_H 2.02, 2.03, 2.04 and 2.06 (4 s, 12 H, 4 × acetyl), 3.87 (s, 3 H, OCH_3), 3.90 (m, 1 H, H-5), 4.15 (dd, $J_{6a\text{-}6b}$ 12.1, $J_{5\text{-}6a}$ 2.4, 1 H, H^a-6), 4.26 (dd, $J_{5\text{-}6b}$ 5.5, 1 H, H^b-6), 5.1–5.3 (m, 4 H, H-1/4), 6.99 (d, 2 H) and 7.99 (d, 2 H); δ_C 20.5 (q, 4 × acetyl), 51.9 (q, OCH_3), 61.8 (t, C-6), 68.1, 70.1, 72.1 and 72.4 (4 d, C-2/5), 98.1 (d, C-1), 116.0 (d, arom CH), 124.9 (s, arom C–C), 131.4 (d, arom CH), 160.0 (s, arom C–O), 166.2 (s, CO_2CH_3) and 169.0, 169.2, 170.0 and 170.3 (4 s, CO acetyl) (Found: C, 54.85; H, 5.4. $C_{22}H_{26}O_{12}$ requires C, 54.77; H, 5.43%).

4-(Propoxycarbonyl)phenyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside 3i. δ_H 1.00 (t, 3 H, H_3-3′), 1.76 (m, 2 H, H_2-2′), 2.02, 2.03, 2.04 and 2.06 (4 s, 12 H, 4 × acetyl), 3.89 (m, 1 H, H-5), 4.15 (dd, $J_{6a\text{-}6b}$ 12.1, $J_{5\text{-}6a}$ 2.4, 1 H, H^a-6), 4.24 (t, 2 H, H_2-1′), 4.28 (dd, $J_{5\text{-}6b}$ 5.5, 1 H, H^b-6), 5.1–5.3 (m, 4 H, H-1/4), 7.00 (d, 2 H) and 8.00 (d, 2 H); δ_C 10.4 (q, C-3′), 20.5 (q, 4 × acetyl), 22.0 (t, C-2′), 61.8 (t, C-6), 68.1 (t, C-1′), 68.1, 70.1, 72.2 and 72.5 (4 d, C-2/5), 98.2 (d, C-1), 116.1 (d, arom CH), 125.4 (s, arom C–C), 131.4 (d, arom CH), 160.0 (s, arom C-O), 165.9 (s, CO_2 propyl) and 169.1, 169.2, 170.0 and 170.3 (4 s, CO acetyl) (Found: C, 56.2; H, 5.9. $C_{24}H_{30}O_{12}$ requires C, 56.47; H, 5.92%).

4-Biphenylyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside[18] **3j-β.** δ_H 2.01, 2.02, 2.04 and 2.05 (4 s, 12 H, acetyl), 3.85 (m, H-5), 4.17 (dd, $J_{6a\text{-}6b}$ 12.2, $J_{5\text{-}6a}$ 2.4, 1 H, H^a-6), 4.28 (dd, $J_{5\text{-}6b}$ 5.4, 1 H, H^b-6), 5.07–5.31 (m, 4 H, H-1/4) and 7.02–7.52 (m, 9 H); δ_C 20.6, 20.4 and 20.5 (each q, 4 × acetyl), 61.8 (t, C-6), 68.1, 71.0, 71.8 and 72.5 (4 d, C-2/5), 98.9 (d, C-1), 117.1, 126.7, 126.9, 128.1 and 128.6 (each d, arom CH), 136.3 and 140.2 (2 s, arom C), 156.1 (s, arom CO) and 169.1, 169.2, 170.0 and 170.3 (4 s, CO acetyl) (Found: C, 62.1; H, 5.8. $C_{26}H_{28}O_{10}$ requires C, 62.39; H, 5.64%).

4-Biphenylyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside[18] **3j-α.** δ_H 2.02, 2.03, 2.04 and 2.06 (4 s, 12 H, acetyl), 4.05 (dd, $J_{6a\text{-}6b}$ 12.2, $J_{5\text{-}6a}$ 2.0, 1 H, H^a-6), 4.13 (m, 1 H, H-5), 4.25 (dd, $J_{5\text{-}6b}$ 4.4, 1 H, H^b-6), 5.05 (dd, 1 H, H-2), 5.16 and 5.71 (2 dd, 2 H, H-3 and -4), 5.77 (d, $J_{1\text{-}2}$ 3.9, 1 H, H-1) and 7.12–7.53 (m, 9 H); δ_C 20.5 (q, 4 × acetyl), 61.4 (t, C-6), 67.9, 68.2, 69.9 and 70.3 (4 d, C-2/5), 94.1 (d, C-1), 116.7, 126.7, 126.9, 128.2 and 128.6 (each d, arom CH), 136.1 and 140.2 (2 s, arom C), 155.4 (s, arom C–O), 155.4, 169.5, 170.0 and 170.4 (4 s, CO acetyl).

4′-Cyanobiphenylyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside[24] **3k.** δ_H 2.01, 2.02, 2.04 and 2.05 (s, 12 H, acetyl), 3.90 (m, H-5), 4.19 (dd, $J_{6a\text{-}6b}$ 12.2, $J_{5\text{-}6a}$ 2.2, 1 H, H^a-6), 4.30 (dd, $J_{5\text{-}6b}$ 5.2, 1 H, H^b-6), 5.15 (d, $J_{1\text{-}2}$ 7.7, 1 H, H-1), 5.15–5.33 (m, 3 H, H-2, -3 and -4), 7.09 (d, 2 H), 7.52 (d, 2 H), 7.62 (d, 2 H) and 7.71 (d, 2H); δ_C 20.5 and 20.5 (each, 4 × acetyl), 61.9 (t, C-6), 68.2, 71.1, 72.1 and 72.6 (4 d, C-2/5), 98.8 (d, C-1), 110.7 (s, arom *C*-CN), 118.8 (s, CN), 117.4, 127.3, 128.4, 132.5 (each d s, arom CH), 134.2 and 144.7 (2 s, arom C), 157.2 (s, arom CO), 169.1, 169.3, 170.1 and 170.4 (4 s, CO acetyl) (Found: C, 61.4; H, 5.1; N, 2.6. $C_{27}H_{27}NO_{10}$ requires C, 61.71; H, 5.18; N, 2.67.

4′-Hexyloxybiphenylyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside 31. δ_H 0.92 (t, 3 H, H_3-6′), 1.3–1.50 (m, 6 H, H_2-3′/5′), 1.81 (m, 2 H, H_2-2′), 2.01, 2.02, 2.04 and 2.05 (4 s, 12 H, acetyl), 3.89 (m, H-5), 4.00 (t, 2 H, H_2-1′), 4.20 (dd, $J_{6a\text{-}6b}$ 12.2, $J_{5\text{-}6a}$ 2.5, 1 H, H^b-6), 4.29 (dd, $J_{5\text{-}6b}$ 5.1, 1 H, H^b-6), 5.1–5.3 (m, 4 H, H-1/4) and 7.04 (d, 2 H), 7.45 (d, 2 H), 7.47 (d, 2 H), 7.49 (d, 2 H); δ_H 13.9 (q, C-6), 20.6, 20.4 and 20.5 (each q, 4 × acetyl), 22.5, 25.6, 29.1 and 31.5 (4, C-2′/5′), 61.8 (t, C-6), 68.0 (t, C-1′), 68.2, 71.1, 71.9 and 72.6 (4 d, C-2/5), 99.1 (d, C-1), 114.7, 117.1, 127.6 and 127.7 (4 d, arom CH), 132.6 and 136.2 (2 s, arom C–C), 155.7 and 158.5 (2 s, arom CO) and 169.2, 169.3, 170.1 and 170.4 (4 s, CO acetyl) (Found: C, 63.9; H, 6.8. $C_{32}H_{40}O_{11}$ requires C, 63.99; H, 6.71%).

1,4-Bis(2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl)benzene[18] **5a.** δ_H 2.00, 2.01, 2.03 and 2.04 (4 s, 24 H, 8 × acetyl), 3.79 (m, 2

H, H-5 and -5′), 4.12 and 4.25 (2 dd, 4 H, H_2-6 and -6′), 4.96 (d, $J_{1,2}$ 6.8, 2 H, H-1 and -1′), 5.1–5.3 (m, 6 H, H-2, -2′/4′) and 6.90 (s, 4 H); δ_C 20.4 and 20.5 (each q, 8 × acetyl), 61.7 (t, C-6 and -6′), 68.1, 71.0, 71.9 and 72.5 (4 d, C-2/5, 2′/5′), 99.6 (d, C-1 and -1′), 118.3 (d, arom CH), 152.7 (s, arom C–O) and 169.1, 169.2, 170.0 and 170.3 (4 s, 8 × CO acetyl).

1,3-Bis-(2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl)benzene[28] **5b.** δ_H 2.02, 2.03, 2.07 and 2.09 (4 s, 24 H, 8 × acetyl), 3.85 (m, 2 H, H-5 and -5′), 4.15 (dd, 2 H, H^a-6 and -6′), 4.24 (dd, $J_{5\text{-}6a}$ 5.5, $J_{6a\text{-}6b}$ 12.4, 2 H, H^b-6 and -6′), 5.09 (d, $J_{1,2}$ 7.0, 2 H, H-1 and -1′), 5.1–5.3 (m, 6 H, H-2/4, -2′/4′), 6.6–6.7 (m, 3 H) and 7.1–7.3 (m, 1 H); δ_C 20.4 and 20.5 (each q, 8 × acetyl), 61.8 (t, C-6 and -6′), 68.2, 71.0, 72.0 and 72.6 (4 d, C-2/5, -2′/5′), 98.5 (d, C-1 and -1′), 106.3, 111.1 and 130.0 (each d, arom CH), 157.6 (s, arom C–O) and 169.1, 169.2, 170.0 and 170.4 (4 s, 8 × CO acetyl) (Found: C, 52.4; H, 5.5. $C_{34}H_{42}O_{20}$ requires C, 52.99; H, 5.49%).

4,4′-Bis-(2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl)biphenyl 5c. δ_H 2.03 (4 s, 24 H, 8 × acetyl), 3.85 (m, 2 H, H-5 and -5′), 4.14 and 4.28 (2 dd, 4 H, H_2-6 and -6′), 5.09–5.29 (m, 8 H, H-1/4, -1′/4′), 7.02 (d, 4 H) and 7.42 (d, 4 H); δ_C 20.3, 20.4 and 20.4 (each q, 8 × acetyl), 61.7 (t, C-6 and -6′), 68.1, 71.0, 71.8 and 72.5 (4 d, C-2/5, -2′/5′), 98.9 (d, C-1 and -1′), 117.1 and 127.8 (each d, arom CH), 135.5 (s, arom C), 156.0 (s, arom C–O) and 169.0, 169.1, 169.9 and 170.3 (4 s, 8 × CO acetyl) (Found: C, 54.85; H, 5.4. $C_{40}H_{46}O_{20}\cdot H_2O$ requires C, 54.77; H, 5.43%).

1-Naphthyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside[18] **6a.** δ_H 2.02 (4 s, 12 H, 4 × acetyl), 3.91 (m, 1 H, H-5), 4.18 (dd, $J_{5\text{-}6a}$ 2.5, $J_{6a\text{-}6b}$ 12.2, 1 H, H^a-6), 4.30 (dd, $J_{5\text{-}6b}$ 5.4, 1 H, H^b-6), 5.21 (d, $J_{1,2}$ 7.8, 1 H, H-1), 5.24, 5.34 and 5.49 (3 dd, 3 H, H-2/4) and 7.01–8.08 (m, 7 H, naphthyl); δ_H 20.4 and 20.5 (each q 4 × acetyl), 6.18 (t, C-6), 68.2, 70.9, 71.9 and 72.4 (4 d, C-2/5), 99.3 (d, C-1), 108.8, 121.4, 122.8, 125.3, 125.8, 126.4 and 127.3 (7 d, arom CH), 125.5 and 134.3 (2 s, C-9 and -10′), 152.6 (s, C-2′) and 169.2, 169.3, 169.9 and 170.3 (4 s, CO acetyl); mp 174.4–176.5 °C (lit.,[18] 177–178 °C); $[\alpha]_D^{28}$ −71.5 (*c* 1) (lit.,[18] $[\alpha]_D^{23}$ −71) (Found: C, 60.8; H, 5.5. $C_{24}H_{26}O_{10}$ requires C, 60.76; H, 5.52%).

2-Naphthyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside[11,29] **6b.** δ_H 2.02 (4 s, 12 H, 4 × acetyl), 3.86 (m, 1 H, H-5), 4.16 (dd, $J_{5\text{-}6a}$ 2.2, $J_{6a\text{-}6b}$ 12.2, 1 H, H^a-6), 4.27 (dd, $J_{5\text{-}6b}$ 5.9, 1 H, H^b-6), 5.17 (m, 2 H), 5.29 (m, 2 H), 7.13, 7.31–7.45 and 7.69–7.77 (m, 7 H, naphthyl); δ_C 20.3, 20.4, 20.4 and 20.5 (4 q, 4 × acetyl), 61.9 (t, C-6), 68.2, 71.1, 71.9 and 72.6 (4 d, C-2/5), 98.9 (d, C-1), 111.3, 118.6, 124.5, 126.4, 126.8, 127.5 and 129.5 (7 d, arom CH), 130.0 and 133.9 (2 s, C-9′ and 10′), 154.4 (s, C-2′) and 169.0, 169.2, 169.9 and 170.3 (4 s, CO acetyl); mp 129.2–130.6 °C (lit.,[11] 124–125 °C; lit.,[29] 135–136 °C; $[\alpha]_D^{28}$ −12.3 (*c* 1) (lit.,[11] $[\alpha]_D^{21}$ −18; lit.,[29] $[\alpha]_D^{21}$ −19).

Benzyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside[30,31] **7a.** δ_H 2.01, 2.03, 2.06 and 2.07 (4 s, 12 H, 4 × acetyl), 3.68 (m, H-5), 4.17 (dd, $J_{6a\text{-}6b}$ 12.4, $J_{5\text{-}6a}$ 2.6, 1 H, H^a-6), 4.29 (dd, $J_{5\text{-}6b}$ 4.7, 1 H, H^b-6), 4.55 (d, $J_{1\text{-}2}$ 7.4, 1 H, H-1), 4.63 (d, $J_{1'a,b}$ 12.4, 1 H, H^a-1′), 4.91 (d, 1 H, H^b-1′), 5.03–5.24 (m, 3 H, H-2/4) and 7.27–7.36 (m, 5 H); δ_C 20.4, 20.5 and 20.6 (each q, 4 × acetyl), 61.9 (t, C-6), 70.6 (t, C-1′), 68.3, 71.2, 71.7 and 72.7 (4 d, C-2/5), 99.2 (d, C-1), 127.6, 127.9 and 128.3 (3 d, arom CH), 136.5 (s, arom C), 169.1, 169.2, 170.1 and 170.5 (4 s, CO acetyl); mp 95.9–98.2 °C (lit.,[31] 101–104 °C); $[\alpha]_D^{28}$ −51.5 (*c* 1) (lit.,[30] $[\alpha]_D$ −52.3) (Found: C, 57.55; H, 6.0. $C_{21}H_{26}O_{10}$ requires C, 57.53; H, 5.98%).

***p*-Nitrobenzyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside 7b.** δ_H 2.01, 2.03, 2.06 and 2.07 (4 s, 12 H, 4 × acetyl), 3.72 (m, H-5), 4.15 (dd, $J_{6a\text{-}6b}$ 12.4, $J_{5\text{-}6a}$ 2.2, 1 H, H^a-6), 4.26 (dd, $J_{5\text{-}6b}$ 4.7, 1 H, H^b-6), 4.62 (d, $J_{1,2}$ 7.7, 1 H, H-1), 4.70 (d, $J_{1'a,b}$ 13.6, 1 H, H^a-1′), 5.09 (d, 1 H, H^b-1′), 5.01–5.24 (m, 3 H), 7.44 (d, 2 H) and 8.18 (d, 2 H); δ_C 20.4, 20.5 and 20.6 (each q, 4 × acetyl), 61.7 (t, C-6), 69.3 (t, C-1′), 68.2, 71.1, 71.9 and 72.5 (4 d, C-2/5), 99.9 (d, C-1), 123.5 and 127.4 (2 d, arom CH), 144.2 and 147.4 (2 s, arom) and 169.1, 169.2, 170.0 and 170.4 (4 s, CO acetyl); mp 126.4–129.7 °C; $[\alpha]_D^{28}$ −40.9 (*c* 1) (Found: C, 52.1; H, 5.3; N, 2.9. $C_{21}H_{24}NO_{12}$ requires C, 52.18; H, 5.21; N, 2.90%).

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