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Studies on Koenigs-Knorr Glycosidations

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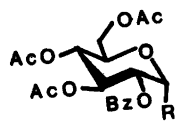
Mercury salt and silver triflate-promoted Koenigs-Knorr reactions of 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl bromide and 2-*O*-benzoyl-3,4,6-tri-*O*-acetyl-α-D-glucopyranosyl bromide with mono, di, and trichloroethanol were studied. The products in each reaction were quantified using chromatographic methods. A reaction scheme based on the intermediacy of orthoesters is proposed to explain the varying amounts of glycosidic products formed.

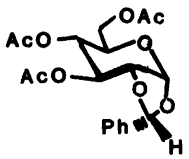
The classical method for the synthesis of 1,2-*trans* glycosides is the Koenigs-Knorr reaction. In this, a glycosyl halide, carrying an acyl substituent at O-2 is treated with an alcohol in the presence of a halide ion acceptor ("promoter"), usually a silver or mercury salt. The subject has been extensively reviewed[1–4]. In previous studies[5,6] of orthoester glycosidation reactions, we showed that variously substituted ethanols are useful models for studying the relation between electron density at the alkoxyl oxygen and product composition in the glycosidation. We have now made similar studies on Koenigs-Knorr glycosidations using the same alcohols (mono, di and trichloroethanol) and acylated glucosyl bromides. Three of the most commonly used promoters were investigated: Mercury(II) cyanide, mercury(II) cyanide/mercury(II) bromide, and silver triflate. The acyl group at O-2 of the bromide was either acetyl of benzoyl. Dichloromethane, acetonitrile, or 1:1 nitromethane–toluene were used as solvents.

RESULTS

Two glycosyl halides were used for glycosidation: 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl bromide[7] and 2-*O*-benzoyl-3,4,6-tri-*O*-acetyl-α-D-glucopyranosyl bromide (*2*). The latter was prepared in 92 % crystalline yield by hydrogen bromide treatment of 2-*O*-benzoyl-



1 R=OAc
2 R=Br



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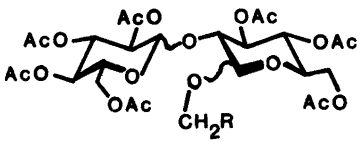


4

R CH_2Cl, $CHCl_2$, or CCl_3

0302-4369/85 $2.50

1,3,4,6-tetra-*O*-acetyl-α-D-glucopyranose (*1*) in acetic acid solution. Our physical constants for compund *1* do not agree with those reported[8]. We therefore proved the structure of the product by NMR spectroscopy, elemental analysis, and by reacting the derived bromide *2* with silver triflate and tetrabutylammonium borohydride to give the known[9] 3,4,6-tri-*O*-acetyl-1,2-*O*-benzylidene-α-D-glucopyranose (*3*). The 2-position of the benzoyl group in *1* and *2* is thus evident.

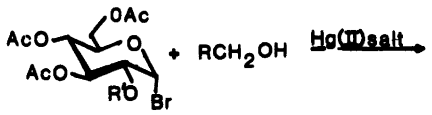
The composition of the glycosidation reaction mixtures was determined by fractionation on a silica gel column and weighing of the fractions. Since complete separation of anomers was not always possible, fractions containing anomeric pairs were pooled, and the α/β ratio was determined by GLC analysis. Peracylated glycosides were the main products in all experiments. Glycosides deacylated in the 2-position ("2-OH glycosides") were found in reactions of 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl bromide when silver triflate was the promoter. Furthermore, silver triflate promotion gave rise to appreciable amounts of compounds which, according to their ^{13}C and ^{1}H NMR spectra, were disaccharide glycoside derivatives. All were not rigorously characterized, but the spectra are best compatible with the general structure *4*. The physical constants for the β,β-trichloroethyl derivative are given in Experimental.

The results from the glycosidation experiments are summarized in Tables 1 (mercury salt promotion) and 2 (silver triflate promotion).

DISCUSSION

The Koenigs-Knorr reaction is still the most widely used reaction for preparation of di- and oligosaccharides, yet few systematic investigations of the factors influencing yield and product composition have been made. Systematization of the vast amount of results reported in the literature is difficult since too many parameters vary between the experiments. Also, reported yields are not always representative of the relative amounts of products actually present, especially in cases where products have been crystallized from crude reaction mixtures. Gradually, the knowledge has emerged that the yield and product composition of a Koenigs-Knorr reaction is dependant on parameters such as: (a) the structure of the glycosyl halide (b) the structure of the alcohol (c) the promoter used (d) the solvent used. Since it has been shown[10,11] beyond reasonable doubt that orthoesters are intermediates in Koenigs-Knorr reactions of the usual type (employing soluble mercury or silver salts), the same factors likewise affect the outcome of orthoester "rearrangement" reactions. In investigations[5,6] of such mercury(II) bromide catalyzed reactions of orthoesters derived from alcohols with varying electron density at the alkoxyl oxygen, we found that decreased electron density gave rise to a higher proportion of α-glycosides (Table 3). If the steric acessibility of the alcohol hydroxyl was decreased by introducing bulky substituents in adjacent positions, the proportion of α-glycoside likewise increased[6,12], although this effect was less drastic. The results were rationalized by reference to the different possible reaction pathways depicted in Scheme 1. The explanation presented[6] was based on the implicit assumption, that electrophilic attack on the orthoester oxygens is rate-determining. This is probably not so, therefore the observed difference in product composition with different orthoester alkoxyls must have another explanation. We now propose, that the rate-determining step in path A is the rearrangement of the ion pair *7* to the β-glycoside *9* (path B probably is unimportant, as well as path C in cases where no 2−OH glycosides are formed). If the oxygen electron density of EOR^- in *7* is decreased, or if R is made more bulky, the

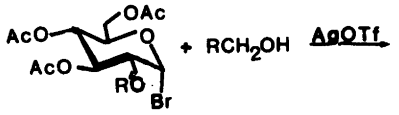
Table 1. Product compositions in glycosidations with mercury salts. Abbreviations: ND=not determined



R	R'	Promoter	Solvent	Peracylated glycosides total yield[a] (%)	Peracylated glycosides $\alpha:\beta$[a]	2-OH glycosides total yield (%)	2-OH glycosides $\alpha:\beta$	Disaccharides total yield (%)
CH_2Cl	Ac	$Hg(CN)_2$	CH_3CN	65	5:95	<5	ND	<5
$CHCl_2$	Ac	$Hg(CN)_2$	CH_3CN	78	25:75	<5	ND	<5
CCl_3	Ac	$Hg(CN)_2$	CH_3CN	72	60:40	<5	ND	<5
$CHCl_2$	Ac	$Hg(CN)_2$	toluene/CH_3NO_2	74	28:72	<5	ND	<5
$CHCl_2$	Ac	$Hg(CN)_2$	CH_2Cl_2	51	11:89	<5	ND	<5
CH_2Cl	Bz	$Hg(CN)_2$	CH_3CN	88	5:95	<5	ND	<5
$CHCl_2$	Bz	$Hg(CN)_2$	CH_3CN	83	17:83	<5	ND	<5
CCl_3	Bz	$Hg(CN)_2$	CH_3CN	74	67:33	<5	ND	<5
CH_2Cl	Ac	$Hg(CN)_2/HgBr_2$	CH_3CN	78	6:94	<5	ND	<5
$CHCl_2$	Ac	$Hg(CN)_2/HgBr_2$	CH_3CN	77	27:73	<5	ND	<5
CCl_3	Ac	$Hg(CN)_2/HgBr_2$	CH_3CN	72	55:45	<5	ND	<5
$CHCl_2$	Ac	$Hg(CN)_2/HgBr_2$	toluene/CH_3NO_2	67	28:72	<5	ND	<5
$CHCl_2$	Ac	$Hg(CN)_2/HgBr_2$	CH_3NO_2	55	37:63	<5	ND	<5
$CHCl_2$	Ac	$Hg(CN)_2/HgBr_2$	CH_2Cl_2	70	14:86	<5	ND	<5

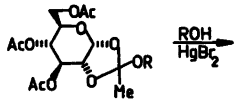
[a] The $\alpha:\beta$ ratio did not change significantly on increasing the amount of alcohol to 10 equivalents but the total yields were then generally higher (data not shown).

Table 2. Product composition in glycosidations with silver triflate. Abbreviations and comments, see Table 1.



R	R′	Solvent	Peracylated glycosides		2-OH glycosides		Disaccharides total yield (%)
			total yield[a] (%)	$\alpha:\beta$[a]	total yield (%)	$\alpha:\beta$	
CH_2Cl	Ac	toluene/CH_3NO_2	37	3:97	14	35:65	13
$CHCl_2$	Ac	toluene/CH_3NO_2	40	7:93	8	70:30	10
CCl_3	Ac	toluene/CH_3NO_2	55	18:82	9	70:30	ND
CH_2Cl	Bz	toluene/CH_3NO_2	68	1:99	<5	ND	ND
$CHCl_2$	Bz	toluene/CH_3NO_2	73	2:98	<5	ND	ND
CCl_3	Bz	toluene/CH_3NO_2	64	12:88	<5	ND	ND
CH_2Cl	Ac	CH_2Cl_2	41	2:98	10	40:60	ND
$CHCl_2$	Ac	CH_2Cl_2	53	3:97	5	85:15	17
CCl_3	Ac	CH_2Cl_2	85	5:95	10	70:30	ND
CH_2Cl	Bz	CH_2Cl_2	89	0:100	<5	ND	ND
$CHCl_2$	Bz	CH_2Cl_2	89	1:99	<5	ND	ND
CCl_3	Bz	CH_2Cl_2	81	4:96	<5	ND	ND

Table 3. Product compositions[5,6] when 1,2-*O*-alkoxyethylidene-3,4,6-tri-*O*-acetyl-α-D-glucopyranoses are reacted with $\frac{1}{3}$ equiv. of mercurie bromide and 2 mol. equiv. of the corresponding alcohol in nitromethane at reflux temperature.



R	Peracylated glycosides	
	total yield (%)	α:β
CH_2CH_2Cl	87	16:84
CH_2CHCl_2	83	50:50
CH_2CCl_3	78	67:33

rate of the β-glycoside yielding reaction is lowered. Reaction by way of the more reactive ion pair *8* becomes important, leading to a high proportion of α-glycosides.

The present investigation is a continuation of the above orthoester studies. In fact, the use of Koenigs-Knorr reaction conditions is seen as merely a convenient way of generating an orthoester *in situ*. Although it can not be excluded[10], that a small fraction of products of a Koenigs-Knorr glycosidation are formed along pathways that do not involve orthoester intermediates, this possibility is neglected in the following discussion.

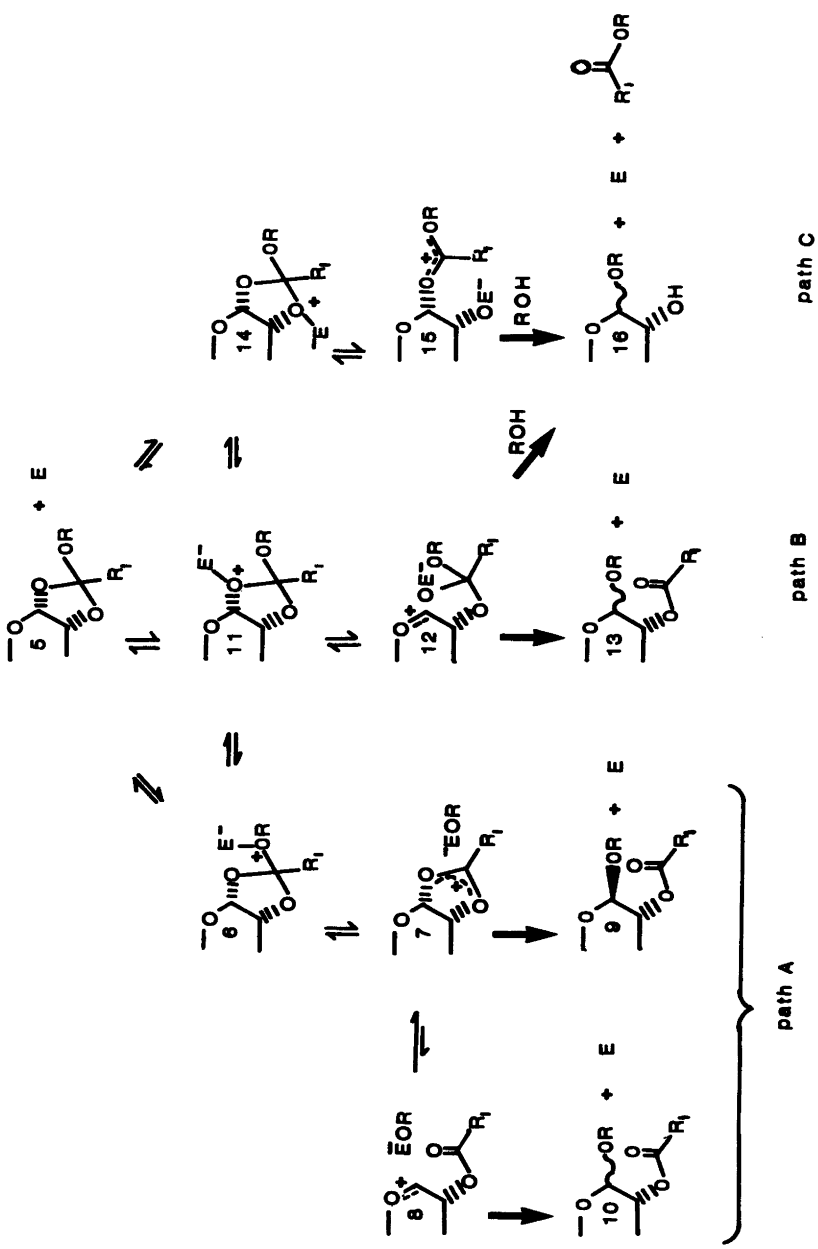
The results in Table 1 (mercury salt promotion) show the same trend towards higher proportion of α-glycosides when going from mono- to trichloroethanol as in the orthoester experiments (Table 3). The α/β glycoside ratio is slightly lower in corresponding mercury-salt promoted Koenigs-Knorr reactions, probably because of difference in reaction temperatures (25 *vs.* 101 °C) and/or different acidic species present ($HgBr_2$/HBr *vs.* $HgBr_2$).

That the type of acid present is indeed an important factor is evident from the experiments presented in Table 2, in which silver triflate was the promotor, and thus the acid formed in the medium was triflic acid. The trend towards higher α/β ratio with increased chloro substitution of the alcohol is considerably weaker. This indicates, that the acidic species (E, Scheme 1) influences the rate, with which the ion pair *7* rearranges to the β-glycoside *9*, probably by its effect on oxygen electron density of the counterion EOR^-.

There is also a higher amount of 2-OH glycosides formed with silver triflate as promoter. According to scheme 1, these glycosides should result from reaction *via* path C. Their formation (together with acylated alcohol) has been observed before[11,12,13]. It was found[13], that proton acids in dichlormethane were efficient catalysts for this type of orthoester opening, and that a high proportion of 2-OH α-glycosides were formed. The reason for the observed differences in yield of 2-OH glycosides is unclear. Principally, however, the relative stabilities of *7*, *12* and *15* with different acids (E) has to be considered.

Formation of 2-OH glycosides is an important cause of low yields in glycosidations especially since, once formed, they can be glycosylated by more bromide to form disaccharide glycosides, *e.g. 4*. Such compounds were indeed observed in the present investigation.

Interestingly, 2-OH glycosides were not observed in glycosidations with the benzoylated bromide *2*. This fact offers an explanation for the higher yields reported[14] for glycosidations with benzoylated bromides. The reason could be the better resonance stabilization[15] of the



Scheme 1. Possible reaction pathways when reacting an orthoester (5) with an acid (E). Proposed rate determining steps are marked with bold arrows. Transition states are assumed to be reactantlike in all such steps.

cyclic *7* as compared to the acyclic *12* and *15*.

The influence of solvent on product composition is noteworthy. The amount of 2-OH glycoside formed in silver triflate-promoted reactions is not seriously affected by solvent change. However, polar solvents tend to give higher proportions of peracylated α-glycosides with both promoters. This is probably so because of the higher ionic character, and thus higher demand for solvation by a polar solvent, of intermediates (*e.g.*, *8*) leading to α-glycosides.

It should be noted, finally, that path A in Scheme 1 involve the intramolecular reaction *6*→*9*, *i.e.* a true rearrangement. This is a suggestion, based on recent indications[16] of an intramolecular mechanism for acid-catalyzed rhamnose orthoester to glycoside conversion.

From a preparative point of view it can be concluded, that silver triflate promotion, 2-*O*-benzoylated glycosyl bromides and non-polar solvents such as dichloromethane (preferably in admixture with toluene, which is a better solvent for silver triflate) are the 1,2-*trans*-glycosidation conditions of choice.

EXPERIMENTAL

General methods. Melting points are corrected. Concentrations were performed at reduced pressure (1–2 kPa) at a bath temperature below 40 °C. Optical rotations were recorded for samples in chloroform solution (c: 0.5–1.0) using a Perkin-Elmer 141 polarimeter, 100 MHz ^{1}H and 25 MHz ^{13}C NMR spectra were recorded for samples in deuterochloroform solution using a JEOL JNM FX-100 instrument. Chemical shifts are given in p.p.m. downfield from internal tetramethylsilane. TLC was performed using silica gel plates (F_{254}, Merck) and the spots were detected with UV light and/or by charring with aqueous sulfuric acid. Column chromatography was performed on silica gel 60 (0.040–0.063 mm, Merck) using suitable toluene/ethyl acetate mixtures for elution. Gas chromatograms were recorded at 190–250 °C with a Hewlett-Packard 5880A gas chromatograph, equipped with a Hewlett-Packard 3390A integrator unit. The stationary phase in the 12 m capillary column used was methylsilicone fluid (19091–60010). Anhydrous magnesium sulfate was used for drying of organic solutions after extraction of washing procedures. Molecular sieves (4 Å, Union Carbide) were desiccated in a vacuum at 300 °C overnight and ground immediately before use. All glassware used in glycosidations were dried at 170 °C before use. Solvents were dried according to standard procedures and were kept over molecular sieves.

Glycosidation procedure. (a) With mercuric salts: Mercury(II) cyanide (253 mg, 1.0 mmol) or a mixture of mercury(II) cyanide (126 mg, 0.5 mmol) and mercury(II) bromide (180 mg, 0.5 mmol) was added to a stirred mixture of alcohol (1.0 mmol) and glycosyl bromide (1.0 mmol) in solvent (5.0 ml, either 1/1 nitromethane/toluene, nitromethane, acetonitrile, or dichloromethane). Stirring at room temperature was continued until TLC indicated no further change. The mixture was then diluted with dichloromethane, washed with aqueous sodium hydrogencarbonate, and water. The residue after drying and concentration was purified by column chromatography. The fractions containing peracylated glycosides and "2-OH glycosides" were pooled separatedly, concentrated (final drying conditions: 40 °C, 100 Pa, 15 min) and weighed. The α/β glycoside ratio was determined by GLC analysis. If other fractions were present containing material in yields exceeding 5 %, these were collected, dried, weighed and analyzed by NMR spectroscopy.

In control experiments dichloroethanol and 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl bromide were reacted as described above. An extra amount of 2′,2′-dichloroethyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside was added, and the α/β glycoside ratio thus obtained was found by GLC analysis to remain unchanged for at least 3 d, thus the acidic glycosidation conditions were not sufficient to cause anomerization.

(b) With silver triflate (1/1 nitromethane/toluene as solvent). A mixture of solvent (4.0 ml), alcohol (1.0 mmol) and 4 Å molecular sieve (0.5 g) was stirred for 10 min at room temperature. Then glycosyl bromide (1.0 mmol) was added, and the mixture was cooled to

−25 °C in a dry ice/ethanol bath. A solution of silver triflate (257 mg, 1.0 mmol) in solvent (1.0 ml) was added. After stirring for 15 min at −25 °C, the mixture was diluted with dichloromethane and filtered. Further processing was done as under a).

(c) With silver triflate (dichloromethane as solvent). A mixture of solvent (5.0 ml), alcohol (1.0 mmol) and 4 Å molecular sieve (0.5 g) was stirred for 10 min at room temperature. Then glycosyl bromide (1.0 mmol) was added, and the mixture was cooled to −25 °C in a dry ice/ethanol bath. Solid silver triflate (257 mg, 1.0 mmol) was added in portions. After 2 h, the mixture was processed as under b).

2-O-Benzoyl-1,3,4,6-tetra-O-acetyl-α-D-glucopyranose (*1*) Benzoyl chloride (1.41 g, 10 mmol) was added dropwise to a cooled (ice bath) solution of 1,3,4,6-tetra-*O*-acetyl-α-D-glucopyranose[17] (2.5 g, 7.2 mmol) in pyridine (5 ml). After 2 h at room temperature water (0.2 ml) was added and stirring was continued for 15 min. The mixture was diluted with dichloromethane, washed with water, aqueous sulfuric acid, aqueous sodium hydrogencarbonate, dried, and concentrated. Column chromatography of the residue gave chromatographically homogenous *1* (2.5 g, 83 %). Crystals were obtained from diethyl ether/light petroleum, m.p. 78–79 °C, $[\alpha]_D$+135°. (lit.[8] m.p. 186 °C, $[\alpha]_D$+51.8°). ^{1}H NMR: δ 1.97, 2.07, 2.12, 2.16 (4s, acetyl Me), 4.05–4.38 (m, H-5, 6), 5.23 (t, H-4), 5.28 (dd, H-2), 5.70 (t, H-3), 6.50 (d, H-1), 7.36–8.00 (m, aromatic H). J (Hz): 3.7 (1,2), 9.5 (2,3 3,4 4,5). Anal. $C_{21}H_{24}O_{11}$: C, H.

2-O-Benzoyl-3,4,6-tri-O-acetyl-α-D-glucopyranosyl bromide (*2*) Hydrogen bromide in acetic acid (30 %, 2 ml) was added to a solution of *1* (0.92 g) in dichloromethane (0.5 ml). After 1 h, the solution was diluted with dichloromethane and washed with water (0 °C), aqueous sodium hydrogencarbonate, dried and concentrated. The residue was crystallized from diethyl ether–light petroleum to give *2* (0.89 g, 92 %), m.p. 112–113 °C, $[\alpha]_D$ +192°. ^{1}H NMR: δ 1.98, 2.08, 2.12 (3s, acetyl Me), 4.05–4.46 (m, H-5, 6), 5.08 (dd, H-2), 5.26 (t, H-4), 5.77 (t, H-3), 6.74 (d, H-1), 7.37–8.08 (m, aromatic H). J (Hz): 3.9 (1,2), 9.9 (2,3), 9.7 (3,4 4,5). Anal. $C_{19}H_{21}O_9$: C, H.

1,2-O-benzylidene-3,4,6-tri-O-acetyl-α-D-glucopyranose (*3*) Silver triflate (59 mg, 0.23 mmol) in 1:1 nitromethane–toluene (1ml) was added to a cooled (−25 °C) solution of *2* (108 mg, 0.23 mmol) in the same solvent (1.0 ml). After 5 min, tetrabutylammonium borohydride (59 mg, 0.23 mmol) was added and stirring was continued at −25 °C for 10 min. Diluting with diethyl ether, washing with aqueous sodium thiosulfate, drying, and concentrating gave a residue, which was purified by chromatography. The ^{1}H NMR spectrum of the main component agreed with that reported[9] for the *endo* phenyl derivative.

Characterization of glycosides. Appropriate fractions from several different glycosidation experiments were pooled and rechromatographed to give pure glycosides. The physical constants of new compounds are reported below.

2'-chloroethyl 2-O-benzoyl-3,4,6-tri-O-acetyl-α-D-glucopyranoside $[\alpha]_D$+154°. ^{1}H NMR: δ 1.96, 2.07, 2.12 (3s, acetyl Me), 3.58–4.30 (m, H-5, 6, H-1', 2'), 5.06 (dd, H-2), 5.16 (t, H-4), 5.30 (d, H-1), 5.71 (t, H-3). *J* (Hz): 3.8 (1,2), 10.1 (2,3), 9.4 (3,4), 9.8 (4,5).

2'-chloroethyl 2-O-benzoyl-3,4,6-tri-O-acetyl-β-D-glucopyranoside M.p. 121–122 °C, $[\alpha]_D$+26°. ^{1}H NMR: δ 1.93, 2.05, 2.12 (3s, acetyl Me), 3.48–4.29 (m, H-5, 6, H-1', 2'), 4.74 (d, H-1), 5.15–5.43 (m, H-3, 4). *J* (Hz): 7.6 (1,2). Anal. $C_{21}H_{25}ClO_{10}$: C, H.

2',2'-dichloroethyl 2-O-benzoyl-3,4,6-tri-O-acetyl-α-D-glucopyranoside $[\alpha]_D$+144°. ^{1}H NMR: δ 1.97, 2.07, 2.13 (3s, acetyl Me), 3.93–4.28 (m, H-5, 6, H-1'), 5.06 (dd, H-2), 5.15 (t, H-4), 5.37 (d, H-1), 5.70 (t, 9.6 Hz, H-3), 5.79 (dd, H-2'). *J* (Hz): 3.8 (1,2), 10.2 (2,3), 9.4 (3,4), 9.8 (4,5), 5.4 and 6.6 (1',2').

2',2'-dichloroethyl 2-O-benzoyl-3,4,6-tri-O-acetyl-β-D-glucopyranoside M.p. 133–134 °C, $[\alpha]_D$+28°. ^{1}H NMR: δ 1.93, 2.05, 2.12 (3s, acetyl Me), 3.72–4.79 (m, H-5,6, H-1'), 4.81 (d, H-1), 5.07–5.44 (m, H-2,3,4), 5.67 (dd, H-2'). *J* (Hz): 7.6 (1,2), 4.6 and 7.6 (1',2'). Anal. $C_{21}H_{24}Cl_2O_{10}$: C,H.

2',2',2'-trichloroethyl 2-O-benzoyl-3,4,6-tri-O--acetyl-α-D-glucopyranoside $[\alpha]_D$+147°. ^{1}H NMR: δ 1.97, 2.07, 2.12 (3s, acetyl Me), 4.04–4.38 (m, H-5,6), 4.10 (d, H-1'), 4.29 (d, H-1'), 5.15 (dd, H-2), 5.19 (t, H-4), 5.53 (d, H-1), 5.76 (t, H-3). *J* (Hz): 3.8 (1,2), 10.2 (2,3), 9.4 (3,4), 11.6 (1',1').

2',2',2'-trichloroethyl 2-O-benzoyl-3,4,6-tri-O-acetyl-β-D-glucopyranoside M.p. 176 °C, $[\alpha]_D$+6°. ^{1}H NMR: δ 1.95, 2.05, 2.13 (s, acetyl Me), 3.73–3.93 (m, H-5), 4.09–4.40 (m, H-6), 4.15 (d, H-1'), 4.42 (d, H-1'), 5.00 (d, H-1), 5.02–5.58 (H-2,3,4). *J* (Hz): 7.9 (1,2),

12.0 (1',1'). Anal. $C_{21}H_{23}Cl_3O_{10}$: C,H.

*2'-chloroethyl 3,4,6-tri-*O*--acetyl-α-D-glucopyranoside* ^{1}H NMR: δ 2.04, 2.09, 2.10 (s, acetyl Me), 3.62–4.33 (m, H-2,5,6, H-1',2', OH), 4.98 (d, H-1), 5.01 (t, H-4), 5.26 (t, H-3). *J* (Hz): 3.9 (1,2), 9.5 (2,3=3,4=4,5).

*2'-chloroethyl 3,4,6-tri-*O*-acetyl-β-D-glucopyranoside* ^{1}H NMR: δ 2.03, 2.08, 2.09 (3s, acetyl Me), 2.81 (s, OH), 3.51–4.30 (m, H-2,5,6, H-1',2'), 4.44 (d, H-1), 4.92–5.24 (m, H-3,4). *J* (Hz): 7.8 (1,2).

*2',2'-dichloroethyl 3,4,6-tri-*O*-acetyl-α-D-glucopyranoside* ^{1}H NMR: δ 2.05, 2.09, 2.10 (3s, acetyl Me), 2.43 (s, OH), 3.72 (dd, H-2), 3.95–4.30 (m, H-5,6, H-1'), 5.01 (t, H-4), 5.03 (d, H-1), 5.25 (t, H-3), 5.89 (dd, H-2'). *J* (Hz): 3.7 (1,2), 9.5 (2,3=3,4=4,5), 5.7 and 6.2 (1',2').

*2',2'-dichloroethyl 3,4,6-tri-*O*-acetyl-β-D-glucopyranoside* ^{1}H NMR: δ 2.03, 2.08, 2.10 (3s, acetyl Me), 2.75 (s, OH), 3.63 (dd, H-2), 3.55–3.80 (m, H-5), 3.88–4.37 (m, H-6, H-1'), 4.50 (d, H-1), 4.91–5.24 (m, H-3,4), 5.84 (dd, H-2'). *J* (Hz): 7.8 (1.2), 9.3 (2,3), 4.9 and 7.3 (1',2'), 11.7 (2',2').

*2',2',2'-trichloroethyl 3,4,6-tri-*O*-acetyl-α-D-glucopyranoside* ^{1}H NMR: δ 2.05, 2.10, 2.11 (3s, acetyl Me), 2.20 (s, OH), 3.78 (m, H-2), 3.98–4.45 (m, H-5,6), 4.17 (d, H-1'), 4.33 (d, H-1'), 5.05 (t, H-4), 5.20 (d, H-1), 5.30 (t, H-3). *J* (Hz): 3.8 (1,2), 9.3 (2,3), 9.5 (3,4=4,5), 11.2 (1',1').

*2',2',2'-trichloroethyl 3,4,6-tri-*O*-acetyl-β-D-glucopyranoside* ^{1}H NMR: δ 2.04, 2.08, 2.10 (s, acetyl Me), 2.65 (s, OH), 3.64–3.80 (m, H–5), 3.72 (dd, H-2), 4.01–4.29 (m, H-6), 4.18 (d, H-1'), 4.48 (d, H-1'), 4.69 (d, H-1), 4.95–5.28 (m, H-3,4). *J* (Hz): 7.8 (1,2), 9.3 (2,3), 9.5 (3,4), 11.7 (1',1').

*2',2',2'-trichloroethyl 2-*O*-(2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyl)-3,4,6-tri-*O*-acetyl-β-D-glucopyranoside* ^{13}C NMR: δ 20.5, 20.7, (acetyl Me), 61.6, 61.7 (C–6, 6'), 67.9, 68.1, 71.5, 71.7, 71.8, 72.8, 73.8 (C–3, 4, 5, C–2', 3', 4', 5'), 77.2 (C–2), 80.3 (CH_2CCl_3), 95.6 (CCl_3), 100.81, 101.2 (C–1, 1'), 168.9, 169.1, 169.2, 169.6, 169.7, 169.9, 170.2 (C=O).

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