Carbohydrate Research
Elsevier Publishing Company, Amsterdam
Printed in Belgium

D-GLUCOPYRANOSYLATION OF CELLULOSE ACETATE*

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(Received May 19th, 1970; accepted for publication, July 23rd, 1970)

ABSTRACT

D-Glucopyranosylation of cellulose acetate (d.s. 2.33) has been effected by treating it with various D-glucosides in the presence of Lewis acids. Glucopyranosylation proceeds rapidly at 25° to derivatize 61% of the free hydroxyl groups, thereby producing up to 0.47 d.s. of D-glucopyranosyl groups. Of various reagents tested, 2,3,4,6-tetra-*O*-acetyl-*N*-*p*-tolyl-*β*-D-glucopyranosylamine with antimony pentachloride catalyst produced most rapid derivatization and yielded the highest d.s. Methyl and isopropyl *β*-D-glucopyranosides and methyl 1-thio-*β*-D-glucopyranoside were also found to be the D-glucosylating agents as was 3,5,6-tri-*O*-acetyl-1,2-*O*-isopropylidene-α-D-glucofuranose. Of the Lewis acids examined, the most active in effecting transfer of D-glucopyranosyl groups to cellulose acetate were antimony pentachloride and boron trifluoride etherate. The major side reaction was the depolymerization of the cellulose chain which occurred to the least extent with antimony pentachloride.

INTRODUCTION

Transfer of a glycosyl group from a glycoside or from another appropriate sugar derivative, such as the 1,2-*O*-isopropylidene derivative, offers a means for either polymerization of a sugar[1] or of joining sugar units on to a polysaccharide chain. Lewis acids are useful reagents in effecting glycosyl transfer since they have the ability to complex with nonbonding electrons on atoms attached to C-1 of sugars, such as the atoms sulfur, oxygen, or nitrogen. This can lead to opening of the bond to C-1, producing a carbonium ion. The latter can react easily with a free hydroxyl group, such as that on another sugar or with a hydroxyl group on a polysaccharide chain.

We have shown[1] earlier that 1,2-*O*-isopropylidene-α-D-glucofuranose undergoes polymerization in the presence of Lewis acids to produce branched polymers having

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*Dedicated to Professor F. Micheel in celebration of his 70th birthday. Presented in part at the 156th National Meeting of the American Chemical Society, Atlantic City, N. J., September, 1968. Supported, in part, by the Corn Industries Research Foundation. Journal Paper No. 4065 of the Purdue University Agricultural Experiment Station.

molecular weights up to 30,000. Later, we have shown[2] that 1,2-*O*-isopropylidene-α-D-xylofuranose can derivatize cellulose acetate of 2.33 d.s. to produce an m.s. up to 0.89.

Bredtschneider and Beran[3] observed that aryl glucosides could be prepared by the reaction of 1,2,3,4,6-penta-*O*-acetyl-β-D-glucopyranose with phenols and boron trifluoride. Similarly, Bonner and co-workers[4] treated a complex of boron trichloride and methyl α-D-glucopyranoside with alcohols to produce D-glucosides.

The present work was undertaken to determine the possibility of transferring the 2,3,4,6-tetra-*O*-acetyl-D-glucopyranosyl group from glycosides, 1-thioglycosides, and glycopyranosylamines to free hydroxyl positions on partially acetylated cellulose.

EXPERIMENTAL

Materials. — Cellulose acetate having an acetyl d.s. of 2.33 and a degree of polymerization (d.p.) of 262 was obtained from the Eastman Kodak Company. Analysis showed it to contain 15 primary hydroxyl groups, and hence 52 secondary hydroxyl groups per 100 D-glucose residues. It was dried at 40° under diminished pressure prior to use. Methyl, isopropyl, and *tert*-butyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosides were prepared by the standard Koenigs–Knorr procedure as described by De Bruyne and Van der Groen[5] for the synthesis of β-D-xylopyranosides. 2,3,4,6-Tetra-*O*-acetyl-α-D-glucopyranosyl bromide[6] (m.p. 88–89°) was purified by crystallization from ether. 1,2-*O*-Isopropylidene-α-D-glucofuranose[7] was acetylated in pyridine and acetic anhydride[8] to form 3,5,6-tri-*O*-acetyl-1,2-*O*-isopropylidene-α-D-glucofuranose, m.p. 74–75°. The method of Helferich and co-workers[9] for the synthesis of methyl 2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-galactopyranoside was adapted to give the corresponding D-glucose derivative, which was purified by two recrystallizations from 95% ethanol; m.p. 93–94°. *N*-*p*-Tolyl-β-D-glucopyranosylamine was prepared[10] and acetylated[11] to give the 2,3,4,6-tetra-*O*-acetyl derivative, m.p. 144–45°.

Methylene chloride was purified by washing with 5% aqueous sodium carbonate and water, dried over calcium chloride, and then fractionally distilled. The fraction boiling at 41° was collected and kept over calcium chloride. Boron trifluoride etherate was purified by vacuum distillation[12].

Methods. — Melting points were determined on a Fisher–Johns apparatus and are corrected. Thin-layer chromatography was conducted on plates (5 × 13 cm) coated with Silica gel G.

Trans-D-glucosylations were conducted in closed containers at 25°, and reagent transfers were made in a dry box. A 4% solution of cellulose acetate in methylene chloride was prepared by stirring the mixture for 1 h. The appropriate amount of Lewis acid catalyst was then added by means of a syringe. Thereafter, a solution of the monomer in 10 ml of methylene chloride was added. After the preferred reaction time, the reaction mixture was concentrated to dryness at 40°. Ether was added to dissolve any unreacted monomer and to complex with the catalyst. After 12 h, the mixture was filtered on a tared glass-filter, dried, and weighed.

Viscosity measurements were made with an Ostwald–Cannon–Fernske viscometer.

Characterization of D-*glucopyranosylated polymers*. — The degree of substitution by 2,3,4,6-tetra-*O*-acetyl-D-glucopyranosyl units was calculated from the increase in weight of the polysaccharide, the increase in acetyl content of the reacted polymer, and formic acid determination following periodate oxidation of the deacetylated polysaccharide. D-Glucopyranosylation values showed good agreement from the three determinations.

Weight determination d.s. is calculated from the equation:

$$\text{d.s.} = \frac{\text{moles of monomer units grafted}}{\text{moles of cellulose acetate units}}$$

$$= \frac{\text{mg of monomer unit grafted}}{\text{mol.wt. of monomer unit grafted}} \times \frac{\text{mol.wt. of cellulose acetate unit}}{\text{mg of starting cellulose acetate}}$$

Acetyl contents of polymers were determined on 100-mg samples dissolved in 20 ml of absolute acetone at 25°. 0.5M Sodium hydroxide (15 ml) was added by a burette, and the suspension was heated for 15 min at 60–70°. The solution was cooled to 25° and held at this temperature for 1 h, and the remaining sodium hydroxide was titrated with 0.4M hydrochloric acid.

From the acetyl content, the d.s. of D-glucosyl units was calculated as follows:

$$\text{d.s.}_{\text{acetyl}} = \frac{3.86\ (\%\ \text{acetyl})}{102.40 - \%\ \text{acetyl}}\ \text{d.s.}_{\text{glucose}}$$

$$= \frac{\text{d.s. acetyl final} - \text{d.s. acetyl initial}}{4 - \text{d.s. acetyl final}}$$

Following deacetylation of the polysaccharide with sodium methoxide, periodate oxidations were conducted by stirring 1.0 g of the polymer at 25° for 72 h in 200 ml of 0.1M sodium metaperiodate. Following the addition of 10 ml of ethylene glycol to consume excess periodate, the formic acid liberated was distilled from the mixture and titrated to a phenolphthalein end-point with 0.1M sodium hydroxide.

As one example of the agreement of the three determinations, the 24-h antimony pentachloride-catalyzed reaction with 2,3,4,6-tetra-*O*-acetyl-*N*-*p*-tolyl-*β*-D-glucopyranosylamine (Table I) gave d.s. values of 0.43 by weight determination, 0.47 by acetyl determination, and 0.49 by formic acid determination. The values given in Table I were calculated from acetyl determinations. Acetyl determinations on the starting cellulose acetate and the product obtained after 24-h treatments with boron trifluoride or antimony pentachloride showed that no loss of acetyl groups had occurred during the reaction period. Although depolymerization of the cellulose acetate occurs, no oligomers are ether extractable, since thin-layer examination of this extract on Silica gel G with benzene–ethyl acetate (6:1 v/v) showed the presence of monomer only.

TABLE I

D-GLUCOPYRANOSYLATION OF CELLULOSE ACETATE (d.s. 2.33) AT 25°

D-Glucose derivative	*Degree of substitution*				
	Boron trifluoride[a]		*Antimony pentachloride*[b]		
	12 h	*24 h*	*1 h*	*12 h*	*24 h*
Methyl 2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside	0.10	0.13	0.02	0.12	0.15
Methyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside	0.11	0.21	0.02	0.12	0.13
Isopropyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside	0.17	0.23	0.00	0.08	0.21
2,3,4,6-Tetra-*O*-acetyl-*N*-*p*-tolyl-β-D-glucopyranosylamine	0.23	0.37	0.15	0.33	0.47
3,5,6-Tri-*O*-acetyl-1,2-*O*-isopropylidene-α-D-glucofuranose	0.24	0.39	0.05	0.13	0.20

[a] Molar ratio of monomer–cellulose acetate–boron trifluoride, 1:1:1. [b] Molar ratio of monomer–cellulose acetate–antimony pentachloride, 1:1:0.1.

RESULTS AND DISCUSSION

Initial conditions for D-glucopyranosylation of cellulose acetate (d.s. 2.33) were developed with boron trifluoride etherate and 3,5,6-tri-*O*-acetyl-1,2-*O*-isopropylidene-α-D-glucofuranose. Optimal conditions appeared to exist with a molar ratio of D-glucose derivative–cellulose acetate–catalyst of 1:1:1 and a temperature of 25°. Lower temperature reduced the rate of derivatization, and the higher temperatures up to the boiling point of methylene chloride led to no increase in d.s. Lower catalyst ratios gave lower d.s. values, whereas increased catalyst ratios induced excessive depolymerization of the cellulose chain. Increasing the relative amount of D-glucose derivative did not increase d.s. values.

When various D-glucopyranosides are compared under equivalent conditions of boron trifluoride catalysis, it is evident that only 2,3,4,6-tetra-*O*-acetyl-*N*-*p*-tolyl-β-D-glucopyranosylamine is equal or more effective than the 1,2-*O*-isopropylidene derivative. It is interesting to observe in Table I the trend in d.s. values for the *S*-methyl, *O*-methyl, and *O*-isopropyl groups on C-1. D.s. values obtained increase with increasing electron density on the glycosidic atom. This is consistent with a mechanism involving Lewis acid–base combination as a first step in the formation of a carbonium ion at C-1, which then reacts with a free hydroxyl group of a cellulose acetate molecule.

The effect of boron trifluoride on the intrinsic viscosity of the cellulose acetate is shown in Table II. It is apparent that in a 24-h reaction period at 25° the intrinsic viscosity of the cellulose acetate has decreased to about 10% of its original value. Hence, as observed earlier[2], boron trifluoride readily complexes with the glycosidic bonds of the polysaccharide chain, causing C-1–glycosidic oxygen bond-opening, incident chain cleavage, and formation of a carbonium ion at the C-1 cleavage site.

This, of course, can potentially lead to combination with a free hydroxyl group of a neighboring chain, resulting in chain transfer or a type of grafting reaction producing branched molecules.

TABLE II

EFFECT OF CATALYST ON INTRINSIC VISCOSITY OF CELLULOSE ACETATE AT 25°

Reaction period (h)	*Intrinsic viscosity*	
	Boron trifluoride[a]	*Antimony pentachloride*[b]
0	1.180	1.180
1	0.600	1.050
3	0.300	0.850
12	0.150	0.590
24	0.125	0.125

[a] Molar ratio of cellulose acetate to catalyst, 1:1. [b] Molar ratio of cellulose acetate to catalyst, 1:0.1.

Antimony pentachloride coordinates better with nitrogen than with sulfur and oxygen and hence yields higher d.s. values than the other D-glucose derivatives tested, as seen in Table I. Because of lower association with oxygen, antimony pentachloride causes less depolymerization of the cellulose chain, as evident from the data in Table II.

Other Lewis acids tested were less effective in the D-glucopyranosylation reaction than either boron trifluoride or antimony pentachloride (Table III).

TABLE III

GRAFTING REACTIONS (24 h AT 25°); MOLAR RATIO OF MONOMER–CELLULOSE ACETATE–CATALYST, 1:1:1

Catalyst	*2,3,4,6-Tetra-*O*-acetyl-*N*-*p*-tolyl-β-D-glucopyranosylamine*	*3,5,6-Tri-O-acetyl-1,2-O-isopropylidene-α-D-glucofuranose*
$AlCl_3$	none	0.03
$AlBr_3$	0.32	0.03
$TiCl_4$	none	none
$ZnCl_2$	0.06	none

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